Relationship between articulation paper mark size and percentage of force measured with computerized occlusal analysis

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PURPOSE. Articulation paper mark size is widely accepted as an indicator of forceful tooth contacts. However, mark size is indicative of contact location and surface area only, and does not quantify occlusal force. The purpose of this study is to determine if a relationship exists between the size of paper marks and the percentage of force applied to the same tooth. **MATERIALS AND METHODS.** Thirty dentate female subjects intercuspated into articulation paper strips to mark occlusal contacts on their maxillary posterior teeth, followed by taking photographs. Then each subject made a multi-bite digital occlusal force percentage recording. The surface area of the largest and darkest articulation paper mark (n = 240 marks) in each quadrant (n = 60 quadrants) was calculated in photographic pixels, and compared with the force percentage present on the same tooth. **RESULTS.** Regression analysis shows a bi-variant fit of force % on tooth (*P*<.05). The correlation coefficient between the mark area and the percentage of force indicated a low positive correlation. The coefficient of determination showed a low causative relationship between mark area and force (r^2 = 0.067). The largest paper mark in each quadrant was matched with the most forceful tooth in that same quadrant only 38.3% of time. Only 6 2/3% of mark surface area could be explained by applied occlusal force, while most of the mark area results from other factors unrelated to the applied occlusal force. **CONCLUSION.** The findings of this study indicate that size of articulation paper mark is an unreliable indicator of applied occlusal force, to guide treatment occlusal adjustments. **[J Adv Prosthodont 2012;4:7-12]**

KEY WORDS: Articulation paper; Force percentage; Computerized occlusal analysis system

INTRODUCTION

The conventional methods used in clinical practice for guiding contact selection during occlusal adjustment are using articulation paper, impression waxes and shim-stock foil, which are all often combined with the patient's occlusal "feel" feedback. None of these listed static dental materials' methods has demonstrated the capability to quantify occlusal forces. The use of articulation paper is the most commonly used method to determine excessive force in differing occlusal contacts. Patients occlude upon strips of articulation paper that leave behind various ink markings on the tooth surface.

Published studies about articulation paper are analyses of physical properties themselves (thickness, composition, ink substrate and plastic deformation).[1-3] But, no scientific evidence that shows articulation paper mark size, or mark appearance characteristics, can accurately describe varying occlusal loads exists.[4,5] Additionally, "subjective interpretation" is required by the operator, to determine which contacts are forceful and which are not.[6,7] Studies conducted on mounted epoxy casts that were subjected to varying applied occlusal loads, suggested that there is no direct relationship between paper mark area (size) and applied occlusal load.[4,5] Additionally, when articulating paper is employed intraorally, it is subject to fragmentation and perforation during patient intercuspations, showing that its' marking repeatability is poor.[8] Despite this lack of scientific

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evidence, it has been repeatedly advocated in textbooks on occlusion that mark area is representative of the load contained within the mark.[9-14]

Alternatively, digital occlusal analysis has been shown to consistently measure relative occlusal forces in highly repeatable fashion.[15] The T-Scan III computerized occlusal analysis system (Software Version 7.0, Tekscan Inc. South Boston, MA, USA) uses an electronically-charged, mylar-encased recording sensor (High-definition Generation IV sensor, Tekscan Inc. S. Boston, MA, USA) that is scanned in 0.003 second time-increments, to acquire occlusal contact relative force variances, excessively forceful tooth contacts, and occlusal contact timing sequences.[16,17] The recording sensor is placed intraorally between the dental arches, to capture real-time occlusal force and time-sequence data, when a subject intercuspates, or makes excursive movements, across its' recording surface. The software processes the occlusal data of any recorded occlusal event for graphical display in 2 and 3 dimensions (Fig. 1). The recorded occlusal force data offers the operator improved information about occlusal contact locations that demonstrate excessive occlusal force, when compared to the highly subjective method of "judging" paper mark size appearance characteristics.

The purpose of this *in-vivo* study was to determine whether a direct relationship exists between the size of articulation paper marks and the degree of applied occlusal force percentage observed on the same tooth. The study examined how frequently the largest, the most prominent paper mark observed in a quadrant of paper markings, described the most forceful tooth.

MATERIALS AND METHODS

Sixty intra oral photographs of dental articulating paper marks made in the maxillary posterior quadrants of 30 female dental hygienists, age 20 - 25 years old, were compared to corresponding patient T-Scan III multi-bite occlusal contact force data recordings. The study volunteers worked at the Guro Hospital Dental Center in South Korea. The Institutional Review Board at Korea University Guro Hospital approved this study protocol. Prior to an individual subject's participation, each subject was given instructions that explained the study protocol, and had the opportunity to ask questions about the protocol, so as to accept or reject their participation in the study.

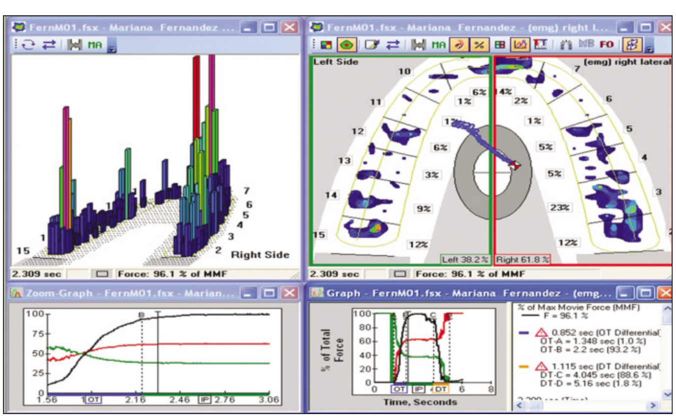

Fig. 1. Digital occlusal analysis presented in 2 and 3 dimensions.

The inclusion criteria for the subjects were:

(1) Class I Angles' classification with normal occlusal relations
(2) Presence of existing anterior tooth contact
(3) Presence of healthy non-crowned premolars in the maxillary arch with contacting lower counterparts
(4) Presence of healthy first and second non-crowned molars in the maxillary arch with contacting lower counterparts

Exclusion criteria were:

(1) Presence of an anterior open occlusion
(2) Presence of a Class II and III malocclusion
(3) Presence of a deep overbite
(4) Presence of chronic bruxism
(5) Presence of TMD symptomotology
(6) Presence of healthy non-crowned premolars present in the maxillary arch
(7) Absence of healthy first and second non-crowned molar present in the maxillary arch
(8) Absence of contacting lower molar and premolar counterparts
(9) Presence of orthodontic appliances

The presence or absence of third molar was not a criteria considered in the study.

Articulation paper marking and photographic capture procedure

The subjects sat upright in the dental chair. Double sided mylar-based articulation paper strips (Accufilm, Parkell, Inc. Edgewood, NY, USA) was smeared with a thin layer of petroleum jelly (Vaseline Petroleum Jelly, Johnson and Johnson, Langhorne, PA, USA) prior to its' use so as to improve the visualization of the markings of the contact points that existed in a subject' s intercuspal position. The articulating paper was held intraorally with Miller forceps while the subject tapped their teeth together firmly through the articulation paper 5 times in succession. Each subject was instructed to attempt to generate their perceived maximum occlusal force while tapping through the articulation strips. Standardized photographs were taken of the markings for later comparison to the occlusal force data obtained from the same subject's T-Scan III multi-bite recordings.

Intraoral photographic procedure

All photographs were taken with a digital SLR camera (Nikon D700, Nikon Inc., Melville, NY, USA) in manual mode, with a fixed focal length of 105 mm, an aperture of F14, and a shutter speed of 1/125 second. A ring flash provided a consistent light source. The camera sat on a tripod placed 210 cm away from an intraoral mirror that was positioned parallel to the maxillary teeth, with dental chair consistently set maximum vertically down, and fully reclined to the near horizontal. This procedure repeatedly aligned the photographic mirror with camera, such that the photographic technique used between all subjects was standardized. One clean photograph of the markings made per quadrant was selected for study analysis. Any over or underexposed images were discarded. Acceptable photographs displayed clear and easily discernable paper markings.

Calculation of the size of the largest paper mark per photograph

A freehand sketcher (Adobe Photoshop CS4, San Jose, CA, USA) was used 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. The software was used to magnify the markings so that the freehand sketcher could be used to trace the boundry of the paper mark. The largest mark was outlined using the software outline sketcher command, which accessed the number of pixel count within the enclosed boundry (the freehand sketcher automatically calculates the number of pixels enclosed within the outlined area). The tooth and the contact location of the largest paper mark in a quadrant were recorded in a spreadsheet for future data analysis (Microsoft Office Excel 2003, Microsoft Corp. Seattle, WA, USA).

T-Scan III multi-bite recording procedure

The central incisor width of each subject was measured utilizing a digital caliper, so as to customize the graphical dental arch to properly mimic the subject's dental arch dimensions. Other relevant tooth details (the presence of crowns, bridges and presence or absence of 3rd molar) were included within each subject's custom arch, as well.

As per the manufacturer's recommendation, prior to any occlusal force data being acquired from each subject, the recording sensitivity level was adjusted to fit the bite force of the patient. This was accomplished by increasing or decreasing the amount of the electric charge supplied to the sensor. Proper sensitivity is selected by limiting the number of red/pink high-force columns/contacts observed in the graphical display, to a maximum of 3 during pre-recording test conditions.

Each subject was then asked to occlude into and through the recording sensor once again, to hold their teeth firmly intercuspated together for 1 - 2 seconds, before twice more repeating that same firm intercuspation twice more followed by a 1 - 2 second intercuspated hold. These "Multi-bite recordings" contained 3 intercuspations, made in succession. This 3-closure recording technique insures that at least one maximum force closure was obtained from each subject.

Within the force versus time graph (Fig. 2), the most forceful closure was chosen from where in the recording, the total force curve (the rising black line visualized over the red and green lines) reached near-maximum occlusal force percentage. In Fig. 3, the first closure of the 3 "bites" contained the

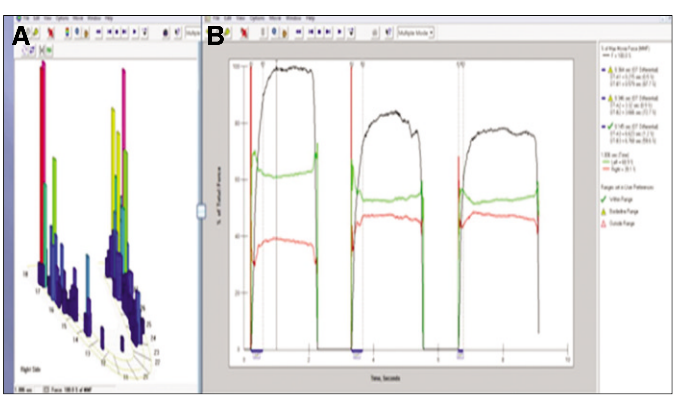

Fig. 2. Force vs time graph of multi bite recording. A: 3-Dimensional view of T-Scan recording indicating amount of force on each tooth represented by colored columns, B: Three tap multi-bite recording showing total force reached during the 3 individual closures.

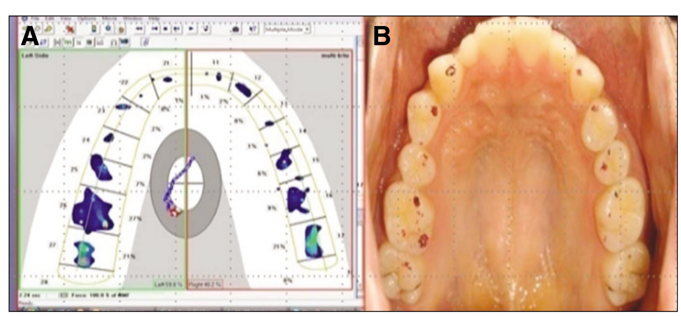

Fig. 3. Side by side orientation of force % and articulating paper marks. A: 2-Dimesional view of T-Scan recording frame, B: Intraoral photo showing articulation paper marks.

most total force. The total force curve of the second and third closures reached only 60% of the total force that closure #1 generated. The vertical "Time Cursor" was then placed at the 100% point of the Total Force curve. This determined the corresponding force distribution present within the 2-Dimensional force playback window representing the intercuspated, 100% point. The posterior tooth force percentage distribution was then compared to the paper mark photograph of the same subjects' corresponding articulating paper marks (Fig. 3).

Data analysis was accomplished by placing the relative occlusal force distribution data side-by-side with the counterpart photograph of the articulating paper marks (Fig. 3). When the largest paper mark (measured in surface area of pixels) demonstrated the highest relative force on the same tooth in that quadrant, it was considered to be a "match". When the tooth with the largest paper mark did not demonstrate the largest force on that same tooth, it was considered to be a "no match".

An example of how this matching procedure was performed, can be seen in Fig. 4. The largest paper mark in right posterior quadrant is on ISO tooth #15 (Universal tooth #4) with the force percentage totaling 6%. Here, the largest mark and highest force percentage did not match, because ISO tooth #17 (Universal tooth #2) demonstrates 21% of the force. Alternatively, the largest mark in second quadrant is on ISO tooth #26 (Universal tooth #14), while the highest force in the quadrant can be observed on the same tooth (27%). In this case, the largest mark did match the tooth with highest force.

Statistical analysis

The "matches" and "no matches" were then tabulated for statistical analysis assessing the frequency of the matches to the no matches. A regression analysis was performed, using the JMP 5.0.1 software (SAS Institute, USA) which revealed a bivariant fit of force percentage per tooth. Statistical significance was established at the 95% confidence level ($P<.05$).

RESULTS

The Results showed that largest paper mark in each quadrant was matched with the highest force tooth in the quadrant only 38.3% of time. Regression analysis showed a bivariate fit of force % on tooth by pixels, with P value of 0.0063 ($P<.05$) (Fig. 5). When relating the largest paper mark per quadrant (T = 240), the correlation coefficient between the mark area and the percentage of force was calculated as 0.259, which indicates a low positive correlation between the occlusal force percentage and the mark's surface area. Squaring the correlation coefficient produces the coefficient of determination ($r^2 = 0.067$) between the surface area and force. The amount of the applied force that actually contributed to the observed mark area in this study was only 6 2/3%, which means only about 7% of the paper mark area can be explained by force.

DISCUSSION

The findings of this study are in accordance with the findings of other studies that previously attempted to correlate occlusal force to paper mark size.[4,5] It has been repeatedly shown that the characteristics of paper mark appearance do not describe the amount of occlusal force present on a given tooth. Fig. 5 graphs the "Mark Area versus Relative Force," which includes the regression line. The wide dispersion of the data illustrates the low value of the coefficient of determination. Very few points are on top of, or near the regression line, with most points being far away from it. This data dispersion depicts the low correlation. If a high correlation between mark area and relative force had been observed, the data points would all have

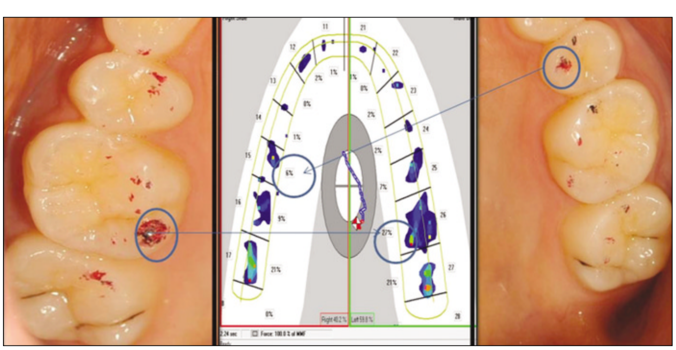

Fig. 4. Matching force % and articulating paper marks: the largest mark (calculated in photographic pixels) in the quadrant is matched with the percentage of force present on the same tooth.

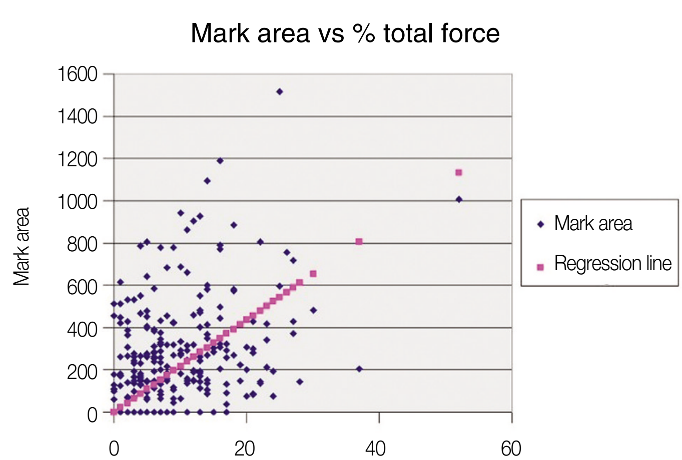

Fig. 5. Bivariate fit of force % on tooth by pixels.

been be clustered around the regression line. Additionally, with most of the points being randomly distributed above and below the regression line, this graph suggests that a higher order correlation is unlikely. Out of a possible 240 posterior teeth analyzed, the largest paper mark and occlusal force corresponded 23 times, with the highest relative force on that same tooth. These findings illustrate a low correlation of 38.3% between the mark surface area and force percentage, and a causative relationship of 6 2/3 % when using the coefficient of determination (r^2 = 0.067). The remaining 93% of the paper mark surface area that is made when articulating paper labels tooth contacts most likely results from occlusal surface morphology.

When large flat surfaces oppose each other (like in areas of wear faceting) large marks are likely to appear because of the broad surface contact the opposing occlusal surfaces share. Conversely, when a sharp pointy surface opposes a flat surface, or another sharp pointy surface, a small mark is likely to result. Tooth morphology then, is likely the overriding factor in what forms the actual paper mark surface area; not the applied occlusal force. This can explain why a large mark can have a low force associated with it, and a small mark can have a much higher force associated with it.

These findings have significant clinical implications because, if an operator assumes that the largest paper mark is representing the most occlusal force during an occlusal adjustment procedure, the operator will likely choose the wrong tooth to treat for most of the time. Under the study conditions where 4 teeth were marked and measured per quadrant, a random relationship should produce a value of 25%, where the largest mark and the most force percentage should occur on the same tooth 25% of the time, purely by chance. The finding of 38.3% agreement is not much better than what would occur by chance alone. This low agreement suggests that operators require a high force contact selection method that is more reliable than is the observing the size of paper markings.

With the overwhelming evidence present in the dental literature that the characteristics of paper mark appearance do not reliably indicate occlusal force,[1-8] for dental medicine educators and authors to continue to teach and/or publish that mark appearance does indicate occlusal force, is clearly problematic for patient care. Evidence-based practice requires that operators use sound, scientifically-based procedures to properly implement patient care. Choosing forceful tooth contacts utilizing paper mark appearance as a guide is, at best not evidence-based, and at worst, highly error-prone.

Operators routinely "judge" articulating paper mark appearance characteristics to select forceful contacts for corrective treatment. With the largest mark indicating the most forceful tooth only 38% of the time, a dentist would be choosing the wrong tooth at least 62% of the time. Clearly, a better method of clinical occlusal force measurement is warranted for the quality of patient care for the human condition because the findings of this study suggest that if the operator uses the largest articulation paper mark as a guide to select the most forceful tooth, it will be an inaccurate method of making occlusal adjustments. It is the opinion of this author, that enough studies exist which contradict the longstanding paper mark force "myths" related to paper mark size, that educators and authors should cease to perpetuate these myths.

Although the subjects were instructed to intercuspate vertically during both the paper marking, and the occlusal force recording procedures, angular occlusal forces may also have been present, that would elevate the force level above what the measured largest mark alone, contributed. Additionally, the tooth with highest relative force percentage often had multiple contacts, elevating its force percentage above the level of the tooth which may have had the largest single paper mark. These differing conditions could conceivably partially cancel each other out during measurement, despite both being present within the same quadrant.

CONCLUSION

The findings of this study indicate that size of articulation paper mark is not an accurate indicator to employ in the selection of tooth contacts for occlusal adjustment treatment. If an operator assumes that the largest paper mark represents the most forceful contact, he/she may likely choose the wrong teeth to adjust, a significant majority of the time. However, employing a non-subjective, quantifying occlusal indicator like computerized occlusal analysis, to guide the selection of tooth contacts for occlusal adjustment treatment, may produce more comprehensive and evidence-based results.

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