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Forces Exerted by a Conventional Dental Explorer during Clinical Examination

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Key Words
Caries diagnosis · Clinical · Force · Measurement · Transducer

Abstract
Purpose: To measure the range of forces exerted clinically in order to determine whether research in this area uses forces that are similar to those generally seen in a clinical setting. ***Methods:*** A transducer was manufactured consisting of a force measurement sleeve positioned over the handle of a conventional explorer. The sleeve housed 4 strain gauges oriented to detect forces in a vertical and lateral direction. Five experienced dentists performed a full-mouth caries exam on three fully dentate caries-free subjects with the force-detecting probe. ***Results:*** The overall average force was 340 ± 6 (SEM) *g* with a standard deviation of 218 *g* and a range of 14–1,006 *g*. The average number of contacts per tooth was 6.2 ± 0.2 (SEM) with a standard deviation of 2.7. ***Conclusions:*** The data from this study show that the forces used in previous studies were sometimes greater than the average force, but were still within the observed range of forces.

Probing with an explorer is one of the oldest methods used in caries detection. Probing is primarily a screening tool and its usefulness has been well studied [Ekstrand et al., 1987; Hintze, 1993; Lussi, 1993; Penning et al., 1992; van Dorp et al., 1988; Weerheijm et al., 1989]. The critical component of caries detection is the catch felt when the explorer penetrates a soft area and resists withdrawal. The advantages of probing include ease of performance, low cost, high specificity [Lussi, 1993; Penning et al., 1992], and use in areas where other methods become limited (e.g. radiography of the occlusal surface). Its disadvantages include low sensitivity [Hintze, 1993; Penning et al., 1992], the possibility of enamel destruction with future caries development [Ekstrand et al., 1987; van Dorp et al., 1988; Weerheijm et al., 1989], the transfer of microorganisms from one fissure to another [Loesche et al., 1979], and technique sensitivity. The possible destruction caused by probing has led to some regional controversy, with dentists reducing or eliminating its use. However, other dentists still frequently use probing for caries detection as well as evaluation of current restorations.

The technique of caries detection with an explorer varies among dentists and past studies had to choose greater consistency and control by using laboratory models or the complexity of a clinical assessment on live patients. Laboratory researchers studying the effects of probing on enamel destruction or the sensitivity of probing define a

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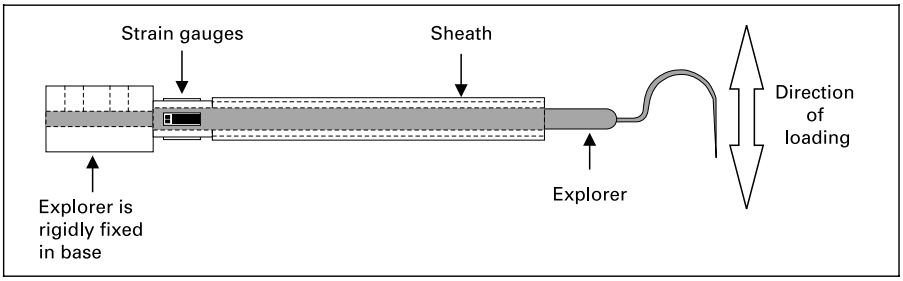

Fig. 1. The probe is shaded to show how it fits into the sheath.

standard downward force applied to the tooth. The force standards range from a simple description of how the subject should perform the exam [Lussi, 1991, 1993, 1996; Merrett and Elderton, 1984; Weerheijm et al., 1989, 1992] to a measured force [Bergman and Linden, 1969; Ekstrand et al., 1987; Penning et al., 1992; Yassin, 1995]. Laboratory studies have used forces of 100–500 *g* [Yassin, 1995], 500–900 *g* [Bergman and Linden, 1969], and 500 *g* [Ekstrand et al., 1987; Penning et al., 1992]. The relationship between these forces and those typically used in clinics has not been reported. If the laboratory studies used forces higher than typical clinical forces, the damage to enamel, sensitivity, and specificity may have been underestimated or overestimated.

The objective of this study was to gather force measurements from a clinical setting and compare them to forces used in previous laboratory research. Taking the measurements in an atmosphere that mimics the typical clinical situation removes many abstractions that occur in a laboratory. The force measurements were related to the explorer's tip. This allowed a more usable measurement of the forces exerted on the irregular occlusal surface. Continuously collecting data at a high sampling rate provided better estimates of the peak forces.

Materials and Methods

A novel force-detecting transducer (fig. 1) developed for this study consisted of a metal sheath that slid over a modified dental explorer [Wagner et al., 2000]. The sheath was 4 mm larger in diameter then a standard explorer. Having the base of the modified explorer rigidly fixed to the base of the sheath caused the shank of the explorer to behave as a cantilever beam. Forces applied by the dentist bend the sheath and cause a measurable strain. By thinning an area at the base of the sheath, the strain was magnified and localized. Four strain gauges (EA-06-125BZ-350 strain gauges, Micro-Measurements, Raleigh, N.C., USA) placed in the thinned area measured the strain. Analog circuitry amplified and conditioned the measurements. The output voltage from the transducer was linearly related to the applied force. The output voltage was low-pass filtered at 15 Hz, sampled at 50 Hz, and digitally processed (HP VEE, Hewlett-Packard, Palo Alto, Calif., USA) to produce a force versus time graph, the desired output for this analysis.

The transducer measured forces exerted along the axis of the explorer's tip. The transducer measured forces with a resolution of ± 0.75 *g*, a repeatability of ± 2 *g*, and a range of –1,400–1,400 *g*. These parameters covered the range of forces found in previous studies and provided a resolution and repeatability of < 1% of the average forces. The ability to measure both positive and negative forces allowed this study to measure and locate any 'catch' forces, such as those observed when the tip of the explorer penetrates into an occlusal cavitation. Previous studies using bench-top linear scales could not accurately perform this measure.

The experiment took place in a fully functional dental unit identical to the units the participants used daily. The patient was seated in a dental chair with a lamp providing good lighting. Each dentist used a planar mouth mirror, a magnifying lens (optional), and the transducer fitted with a Shepherd's hook explorer for each examination.

The arrangement of the examination area was modified to accommodate the wires from the transducer and the computer used for data collection. The dental chair was positioned near the computer, the wires draped across the patient's body. The small diameter of the probe and the length of the wires allowed all the dentists to use the transducer in a manner similar to regular use of the explorer. However, the dentists needed to frequently adjust the probe to keep the wires from tangling.

Five dentists examined three patients who had good oral hygiene and no visible cavities. The dentists (3 males and 2 females) were faculty members at the University of Iowa from the Departments of Prosthodontics and Periodontics with clinical experience ranging from 6 to 40 years. All five dentists examined two of the three patients, but only three of the five dentists examined the third patient due to scheduling conflicts. The dentists completed a pre- and a post-testing questionnaire to provide additional information.

Each dentist examined all four quadrants starting with teeth 14–17, continuing across the upper arch to teeth 24–27, followed by teeth 34–37, and finishing with teeth 44–47. The dentists examined all occlusal surfaces without a time limit. Patient and dentist availability determined the experimental order. While the experimental order was not randomized, it was assumed that the order of the dentists or patients would not affect probing behavior.

After the experimental protocol was read, the dentist inspected the teeth with the instrumented Shepherd's hook. During the exam, the experimenter recorded which tooth was being examined along with the force data in the output files. Once the dentist completed the exam, data collection ceased.

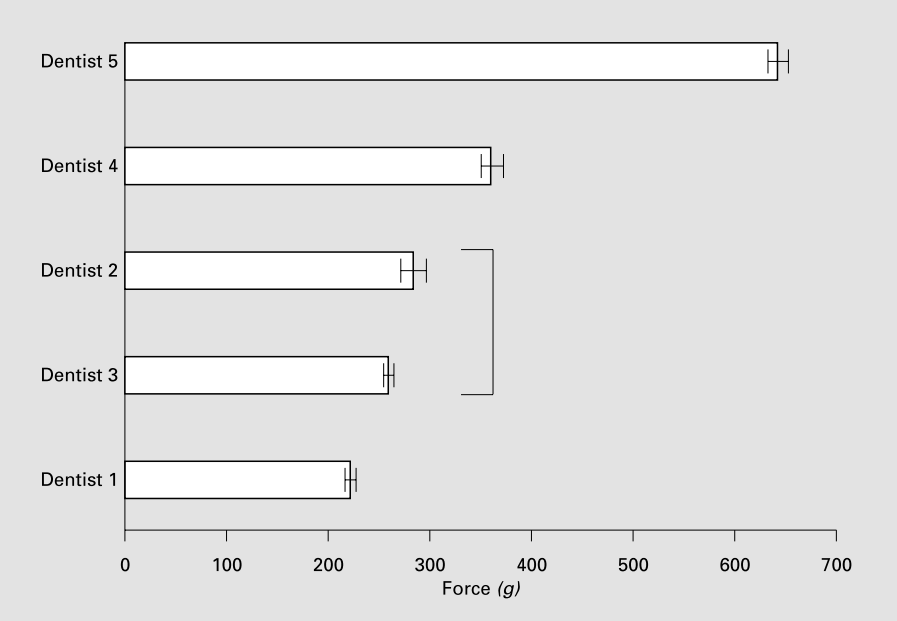

Fig. 2. Plot of mean force versus dentist. The brace indicates means, which are not significantly different; error bars indicate standard errors.

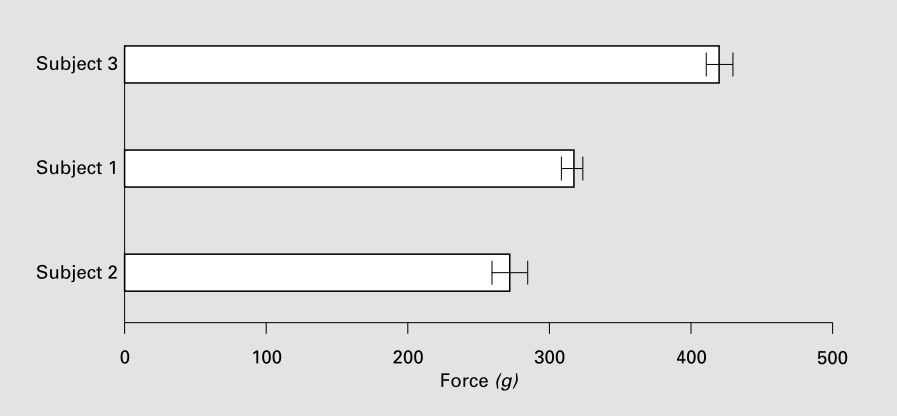

Fig. 3. Plot of mean force versus patient. Error bars indicate standard errors.

Results

The data were graphed based on dentist, patient, and tooth number, yielding 208 individual force versus time plots. Each plot contained a varying number of peaks that corresponded with each instance where the dentist touched the explorer to the tooth surface. The force plots were segmented into individual peaks by marking where the force data returned to or crossed zero. This produced 1,293 peaks. The maximum value was recorded for each peak along with the number of peaks per tooth.

Statistical analysis was completed using StatView (SAS Institute Inc., Cary, N.C., USA). The variation in force was determined using a repeated-measures ANOVA. Because the teeth could not be separated from the subjects, the tooth location variable was nested within the subject variable. Before proceeding to the ANOVA, a normal probability plot of the residuals was constructed for each treatment group, which demonstrated the residuals were normally distributed.

The overall average force was 340 ± 6 (SEM) *g* with a standard deviation (SD) of 218 *g*, a median force of 286 *g* and a range of 14–1,006 *g*. An ANOVA measured the significance of peak force variation as a function of dentist, patient, and tooth location. The force significantly varied with respect to dentist and patient ($p < 0.0001$). There were no significant interactions among the independent variables. A post hoc analysis with Tukey's test on peak force variation versus dentist (fig. 2) indicated that all of the dentists, except dentists 2 and 3, applied significantly

different peak forces. With the exception of dentist 5, most of the dentists probed with a force less then 500 *g* (median force between 200 and 400 *g*). A post hoc analysis with Tukey's test on peak force variation versus patient (fig. 3) indicated that the applied peak forces varied significantly between all patients.

The average number of contacts per tooth was 6.2 ± 0.2 (SEM) with an SD of 2.7 and a median of 6.0. An ANOVA indicated the count measure varied by dentist ($p < 0.0001$), patient ($p = 0.0001$) and tooth location ($p < 0.0001$). There were no significant interactions among the independent variables. Tukey's post hoc analysis indicated that only 4 out of 10 dentist-dentist comparisons significantly differed in their number of peaks per tooth. The maximum difference was 2.5 peaks per tooth. Only subjects 2 and 3 significantly differed in the number of peaks per tooth, with a difference of 1.0. Tukey's test indicating that the dentists probed molars significantly more often than the premolars: 7.5 times versus 4.9 times.

Discussion

The amount of variation in the peak force between clinicians was the most surprising result of this study. Some dentists habitually used lower forces than other dentists. This may be related to hand position, training, experience, age, fatigue, muscle strength, body weight, or other factors. While it appears that some of the force values from previous studies were at the maximum end of the force range of this study, this may not be true for probing in general since this study used a small number of participants who were all trained and practicing in the United States. Dentists who were trained in different areas may probe differently. The earlier studies, which demonstrated the destructive effects of probing, might have caused dentists to reduce their probing forces, which is another explanation of the smaller forces measured in this study.

The data on the number of times a particular tooth was contacted provide information on how a dentist examines teeth for caries. The average number of contacts was less than 8 for any tooth location. It appears that the dentists only checked areas likely to contain caries and not the entire tooth. That a tooth is contacted only a few times during an exam reduces the probability that new caries will appear as a result. All of the subjects in this study had healthy teeth, so the number of times an unhealthy tooth would be inspected cannot be assessed. The number could be significantly greater because a dentist may thoroughly inspect a tooth that appears carious.

In conclusion, the average forces exerted during a typical dental examination in this study, 340 *g,* is less then the forces used in some of the previous studies [Bergman and Linden, 1969; Ekstrand et al., 1987; Penning et al., 1992]. The forces vary widely and future studies need to consider this when they select standardized forces. The number of contacts per tooth was less than 10. This statistic is not reported in other studies and it could have an impact on sensitivity, specificity, and damage. The data from this study show that the forces used in previous studies were sometimes greater than the average force, but were still within the observed range of forces.

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