

## Quantification of Tooth-Tapping Forces

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### Abstract

**Objective:** Percussion of teeth with a handle of a mouth mirror is a common method of diagnosis in dentistry. Pain or discomfort in response to the percussive force can indicate a variety of problems including diseased periodontium or pulp via eliciting pain. The main objective was to instrument a mouth mirror to assess the forces that dentists routinely use in such percussion, as compared to maximum bite forces.

**Methods:** The instrumented handle of a mouth mirror was used by one clinician to tap healthy teeth in 15 subjects. These percussive forces were compared to maximum voluntary forces produced by the subjects. A pilot study of 15 dentists was then run, who percussed the teeth of two healthy subjects.

**Results:** In the preliminary study, biting forces were variably two orders of magnitude higher than for tapping, being higher on posterior teeth ( $p < 0.001$ ). In the multi-dentist dataset, tapping forces remained consistently in the low-Newton range, being significantly higher on posterior than anterior teeth and when male dentists were performing the percussion ( $p < 0.001$ ).

**Conclusions:** Knowledge of the physiological sensitivity is important in formulating guidelines for training dentists in these techniques such that forces are kept appropriate for diagnosis.

**Keywords:** Clinical dentistry; Percussion test; Tooth-tapping forces

### Introduction

The percussion test is among the common diagnostic methods used for evaluating pulpal and periapical disease in clinical dentistry [1,2]. The accepted manner of accomplishing this is to tap the suspected tooth and adjacent healthy teeth with the handle of a mouth mirror or other instrument. The operator cannot always judge the amount of force required to elicit a response, and large variations are possible. The literature reports no method for recording any quantitative measure of force of percussion. A clinical study by Weisman in 1985 [3] tested an instrument developed to record various degrees of tenderness to percussion on a standardized basis. The teeth were tested using a spring-loaded instrument able to deliver loads at six different settings (actual loads were not measured). No further reports of the clinical use or its commercial development have been documented. Thus, it is clearly unclear what vertical forces dentists should employ [3]. Large variations of force are possible in the procedure without clear guidelines on what would be required to obtain evidence with some disease specificity. The technique is also used to examine cracked teeth [4], in which context it has been automated [4,5].

Another method for ascertaining pain thresholds is to ask patients to bite with maximum force using teeth suspected of infection [6,7]. The force magnitude can be compared to that generated on the contralateral side of the mouth using homologous healthy teeth. A reduction in force on one side, due to pain, is called 'allodynia' [6,7]. While percussion is specific to a single tooth, bite force registration depends on the presence of at least a pair of occluding teeth. In an actual bite, in addition to the teeth being loaded directly, there is an anterior component to the force, which is as high as 30% of the vertical load according to some estimates, varying with degree of jaw opening [8,9]. This thus adds involvement of receptors in and around adjacent teeth to that infected. Variability in maximum bite forces has been related to both dental state and muscular problems [10,11]. With the latter, maximal biting is painful. However, it seems unclear what factor limits voluntary maximal biting in healthy subjects.

The aim of this study was to create a pair of low-cost, low-weight devices for research in this area. A variety of designs have been patented for use in percussion studies [12-15]. However, the emphasis here was not on automating the process, but on providing a means for establishing the force-time characteristics of tapping by dentists. Two small-scale trials were carried out, one where one dentists tapped the anterior and posterior teeth of 15 healthy subjects, and the other where 15 dentists tapped the teeth of two healthy subjects.

### Materials and Methods

Ethical approval for these experiments was obtained from Kuwait University Ethics Committee on April 2, 2014 (as research grant no. DR 02/14). Written informed consent for all subjects who participated in the experiment was obtained after explaining the nature of the procedure, possible discomforts and risks. All data were collected during one session.

The tapping device consisted of the handle of a mouth mirror mounted under a 50 N load cell (Transducer Techniques MLP-10, Temecula CA) using a tensile grip (Figure 1a). The handle projected 20 cm beyond the grip to enable easy tapping of either upper or lower teeth. The whole device weighed 59.6 g. Its output was sampled at 4 kHz by a 14-bit analog-to-digital converter (National Instruments USB6009, Austin, TX) producing real-time records (Figure 2a). Calibrated using dead weights, it was accurate to  $\pm 0.01$  N. The bite force gauge was made from a hollowed work-hardened aluminum cube, somewhat like a published design [16]. However, our device possessed only one

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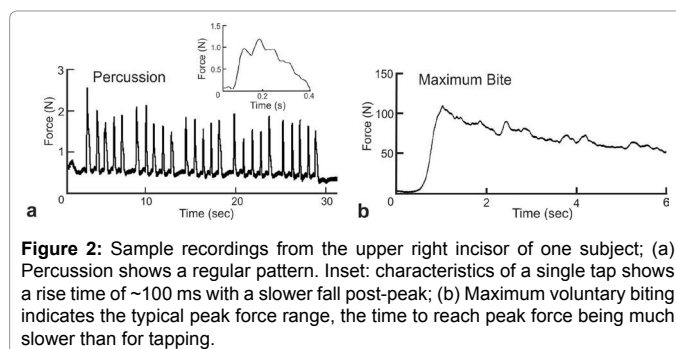
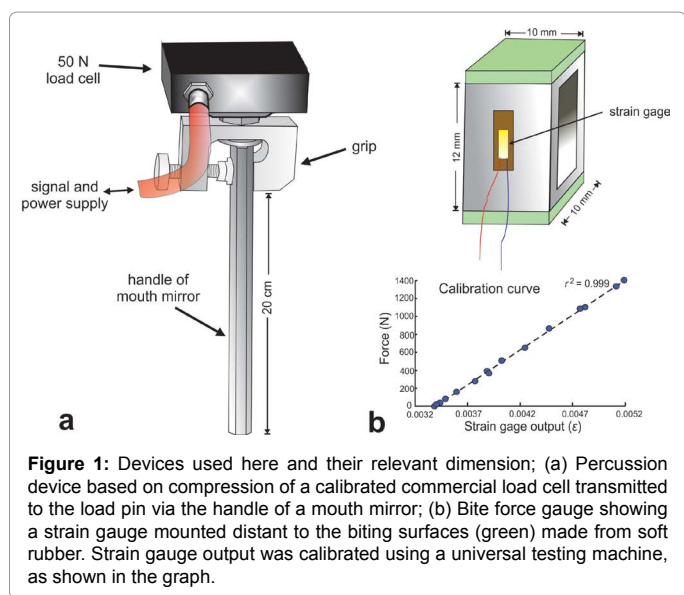
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strain gauge to detect vertical forces, mounted away from the biting surfaces (Figure 1b). These surfaces were faced with 2-mm thick soft rubber, since compliant platforms are known to encourage significantly greater maximum voluntary bite forces [17]. The device weight was 3.1 g. The signal passed to a 24-bit analog-to digital converter (National Instruments cDAQ 9171), sampled at 500 Hz, and viewed in real-time. The gauge was calibrated in a universal testing machine in compression up to 1500 N vertical force using a 4000 N load cell (calibration curve in Figure 1b). During experiments, both mirror handle and bite force gauge were covered with sterile plastic radiology bags (Figures 1a and 1b).

Experiments were performed in a clinical setting. For percussion, the clinician held the cell firmly, orienting the mirror handle along the long axis of the tooth. Prior to contact, the load cell output was zeroed and tapping/biting commenced. The computer was operated by a technician, the clinician being shielded from recorded force levels. In the first study, all subjects were examined by one clinician, an endodontist with 15 years of experience. Fifteen subjects, 8 male and 7 female, aged 22-72 years (median 28), were chosen at random from staff and students at Kuwait University Dental Clinic. During the procedure, each subject was asked to open his/her mouth. After a full oral examination, teeth to be tested were chosen at random with the proviso that these had minimal or no restorations. First, the tapping test was performed on both healthy anterior (incisor and canine) and posterior (premolar and molar) teeth. The full sequences of taps on each tooth were recorded as force-time graphs. Next, the bite gauge was placed between these upper and lower teeth. The subject was asked to bite with as much force as possible till he/she felt discomfort or could not produce a higher force. Each bite included a tooth percussed previously. This voluntary maximum biting force was recorded again in terms of force-time information (Figures 2a and 2b).

In the second pilot study using the tapping device, 15 dentists, 6 male and 9 female, aged 26-65 years (median 33) with between 2-30 years of experience, were recruited at the same clinic to tap the teeth of two subjects (a male of 32 years and a female of 41 years). Each clinician was asked to tap the upper first right incisor and then the upper first right molar of the subjects as per their usual practice. Force-time graphs were recorded as before.



Peak forces for both tapping and maximum bites were extracted from the force-time records and then imported into SPSS version 19 (IBM, Endicott, NY) together with subject information. For analysis, force data were separated into anterior (incisor and canine) versus posterior (premolar and molar) teeth. Forces were log-transformed to normalize their distribution. A general linear model was used in SPSS to analyze these data, plus an ANOVA for comparing the difference between loads applied by the operators and between the loads applied to maxillary vs. mandibular teeth.

## Results

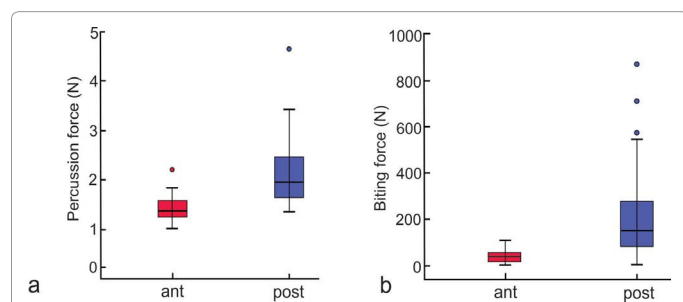
The duration of the load applied to the tooth and the intervals between taps were calculated from the recordings. Both tapping forces and their rate of application seemed consistent for individual dentists (Figure 2a). In the first study, where 60 teeth (23 anterior and 37 posterior) were tapped by one operator on 15 subjects, the minimum tapping force was 0.8 N and the maximum, 5.67 N. The rise time to peak force was between 100-200 ms (Figure 2a) with a ~400 ms 'recovery period' between taps. Tapping forces on posterior teeth were significantly greater than on anterior teeth (Figure 3a) with a mean force of 1.44 (std. dev. 0.28) N for anterior teeth versus 2.14 (std. dev. 0.7) N for posteriors ( $F_{1,60}=22.0; p<0.001$ ). The number of "taps" also varied among operators, and among teeth percussed by the same operator, with a range of 3 - 10 taps for each tooth; anterior teeth were tapped more frequently than posterior teeth (Figures 3a and 3b).

Biting forces on posterior teeth were also significantly greater than those on anterior teeth (Figure 3b) with a mean force of 44.5 (std. dev. 32.6) N for anterior teeth versus 226.2 (std. dev. 207.0) N for posteriors ( $F_{1,57}=18.08; p<0.001$ ). However, forces were very variable. A typical biting record is shown in Figure 2b with the maximum force reached in ~0.5 s for a total biting time of 6 s.

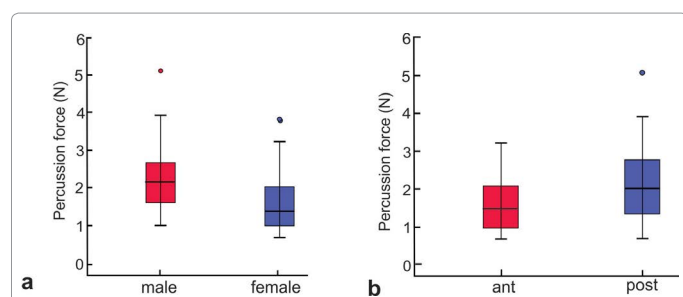
In the second study, a corrected statistical model, taking account both of clinician age and years of experience, and also the gender of both clinician and subject, was significant ( $F_{1,30}=5.164; p<0.001$ ). The most notable findings were again that posterior teeth were tapped with significantly higher force ( $p<0.001$ ) than anterior teeth (Figure 4a), but also that male dentists used greater forces ( $p<0.001$ ) than females (Figure 4b). A more marginal factor was the number of years of clinical experience ( $p<0.02$ ). The gender of the subject had no effect ( $p>0.1$ ) (Figures 4a and 4b).

## Discussion and Conclusion

Tenderness to percussion is considered a diagnostic feature in the classification of periapical conditions. A positive response indicates inflammation of the periradicular tissues. However, a negative response does not rule out the presence of such inflammation.



**Figure 3:** (a) Significantly less force was used to percuss anterior versus posterior teeth ( $F_{1,60}=22.0$ ;  $p<0.001$ ); (b) Bite forces were higher on posterior than anterior teeth ( $F_{1,57}=18.08$ ;  $p<0.001$ ). The plots show the minimum, first quartile, median, third quartile, and maximum values. Outliers are shown as circles.



**Figure 4:** (a) Significantly less force was used to percuss anterior versus posterior teeth ( $F_{1,60}=22.0$ ;  $p<0.001$ ); (b) Bite forces were higher on posterior than anterior teeth ( $F_{1,57}=18.08$ ;  $p<0.001$ ). The plots are as in Figure 3.

The devices used in this study were found light and easy to use. That for percussion resembles the clinical situation. A comparison between Figures 3a and 3b shows an obvious difference between tapping and maximum biting forces. This raises the question in clinical situations, when periapical tissues are inflamed, why such small tapping forces elicit pain when a patient would present with pain on biting, which inevitably involves much higher forces? The rate of loading is important: percussion delivers a maximum load much more rapidly than biting and sustained for far less time (Figure 2). Albeit that percussion forces were highly consistent on given teeth in this preliminary study. The finding from the second study that different forces are used on different teeth, possibly being higher with male dentists suggest further research: do clinicians differ in the forces they apply and does this influence clinical diagnosis?

The physiological literature on neural receptors that either sense forces on a healthy tooth, or produce pain subsequent to a bite, is fairly extensive, but not without controversy. Both the pulp and periodontal ligament have nociceptors, but only the latter has well-defined mechanoreceptors. Interestingly, periodontal mechanoreceptors respond to maximal forces in the low Newton range [18-20]. These receptors saturate at  $\leq 1$  N for anterior teeth versus  $\leq 4$  N for posterior teeth [19]. Such forces are far below those operating during mastication, let alone during maximal biting. However, they are clearly in the range of percussion forces found here. We conclude that tapping forces were definitely being detected by mechanoreceptors in the ligament of healthy teeth. Interestingly, inhibition of the masseter muscles in response to tooth-tapping with 2-4 N is also thought to involve periodontal mechanoreceptors [21].

Although there is debate as to whether the pulp has specialized

mechanoreceptors, the tissue is definitely sensitive to low forces if these are sustained. Recent orthodontic literature suggests that forces as low as 0.5 N, continuous for a week, can disrupt pulpal tissue greatly [22]. Although the pulp was still vital after this period, it proves effective pulpal transfer of sub-Newton forces. Fluid movement through dentinal tubules is slow, but proven for forces  $>20$  N [23]. Experiments on maximum voluntary bite forces on anterior teeth suggest that pulpal receptors can respond rapidly [24,25].

It is not known exactly which nerves are stimulated when tapping a tooth. It is thought that this will activate mechanoreceptors in the periodontal ligament only. Some workers have suggested that the presence of mechanoreceptors in the dental pulp might play a role in detecting the forces during function. The actual load that will elicit a painful response is not known, nor is there knowledge how this changes under inflammatory conditions e.g. pulpitis, or apical periodontitis. In this study, we tried to find out some answers for some of these issues.

We conclude that instrumenting a mouth mirror is a useful research tool for percussing teeth with potential periapical inflammation, with further studies needed to confirm its capacity for clinical diagnosis.

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