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Dependence of psychophysical threshold on rate of applied force to the upper first molar in humans

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ABSTRACT

Objective: The study aims to investigate the dynamic perception of a force applied to the upper first molar for different rates of force increase.

Design: Six volunteers (four male and two female; mean age, 27.2 ± 2.4 years) with full natural dentition (except for the third molars) participated in this study. The psychophysical threshold for a force applied to the right maxillary first molar and the reaction time corresponding to each threshold were measured for rate of force increase of 103.74, 236.23, 354.58, 478.22 and 584.63 mN s^{-1}. The physical impulse, which is the integral of force over time, was calculated for each threshold.

Results: Psychophysical thresholds in the upper first molar increased with the rate of force increase. The reaction time corresponding to each threshold decreased with increasing force rate. Impulses corresponding to each threshold were independent of force rate.

Conclusions: In the present study, the psychophysical threshold for a force applied to a molar tooth was shown to change depending on the rate of increase of the exerted force. From the viewpoint of the impulse, the dissipated energy necessary to reach the psychophysical sensation threshold was almost constant, regardless of the rate of force increase.

Mastication, swallowing and speech are very precisely regulated by voluntary and/or involuntary movement of organs related to stomatognathic system performance. Focussing on the fact that the teeth are subjected to various forces accompanied by functional activities in the orofacial region, information concerning the amplitude, direction and rate of force application (henceforth referred to as the 'force rate') to the teeth is processed as a sensation evoked by external forces applied to the teeth. Important sources of this sensation are the periodontal ligament mechanoreceptors (PDLMs).[1] When a tooth is subjected to forces during mastication and biting, it will move slightly in its socket, resulting in displacement of the periodontal ligaments (PDLs), in which sensory nerve fibres terminate. This displacement is detected by the PDLM as information concerning the force applied to the tooth, and the PDLs behave as external force detectors.

Histological research regarding the PDLMs of animals and humans has revealed that Ruffini-like endings primarily terminate close to the collagen fibres in the PDL,[2–5] and are classified as low-threshold, slowly adapting and type-II mechanoreceptors.[6] These features are consistent with the neurophysiological findings of the periodontal mechanoreceptive afferents. Trulsson et al. demonstrated neurophysiologically that the human periodontal mechanoreceptive afferents are 'slowly adapting' and have directional sensitivity to forces applied to the teeth, because these afferents discharge continuously in response to static forces in at least

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one direction of stimulation.[7] The encoding characteristics, amplitude and rate of force applied to both the lower anterior and the lower posterior teeth by periodontal mechanoreceptive afferents were also investigated in the human inferior alveolar nerve. It was suggested that, in the vertical plane, a preference for sensing downward-directed forces gradually decreases in sensitivity distally along the dental arch.[8,9] The lower dynamic and static sensitivity of the periodontal afferents of the posterior teeth compared to the anterior teeth may reflect a functional adaptation to the faster and stronger forces that develop during motor activities involving the posterior teeth.[10] Dorow et al. investigated the stress–strain behaviour of the PDL and found hysteresis curves at different loading velocities. Their results suggest that higher loading velocities have greater stress at corresponding strain values.[11] Ligament stiffness has been shown to be dependent on loading velocity: the higher the loading rate, the stiffer the ligament appears.[12,13] This finding is also consistent with the characteristics of the Kelvin–Voigt rheological model, which is used to describe the creep behaviour of the PDL.[14] Considering the viscoelastic properties of the PDL, this tissue may be difficult to deform by a force with a high increase rate applied to the teeth, and the force needed to evoke a sensation may be higher for larger increase rates.

While the characteristics of the PDLM have been clarified by histological and neurophysiological methods, the sensation evoked by a force applied to teeth (how the mechanical stimulation of the teeth is actually felt) has also been investigated by psychophysics. Psychophysics is a non-invasive branch of psychology that deals with the relationship between a physical stimulus and the resulting sensation.[15] In psychophysics, the absolute threshold is defined as the smallest amount of stimulus energy necessary to produce a sensation, and the differential threshold is defined as the amount of change in a stimulus required to produce the least noticeable difference in the sensation.[15] The relationship between the rate of force applied to the upper incisor and the absolute threshold for the force by the ascending series of the method of limits was examined by van Steenberghe et al.,[16,17] who observed a semi-logarithmic negative relationship between them. Regarding the psychophysical thresholds for forces applied to molar teeth, it has been reported that the thresholds increase distally along the dental arch.[18]

The posterior teeth are usually exposed to fast and strong occlusal forces. The dependence of the psychophysical threshold for forces applied to the posterior teeth on the force rate has not yet been clarified. Considering the influence of the force rate on the stiffness of the PDL and the psychophysical threshold in the anterior teeth, the psychophysical threshold for the force applied to the molar teeth could depend on the force rate. Therefore, the present study investigated the dynamics of force perception for the upper first molar as the force rate was changed.

1. Materials and methods

Six volunteers (four male and two female; mean age, 27.2 ± 2.4 years) with full natural dentition (except for the third molars) participated in this study. Their molar relationship was Angle Class I. The depth of the periodontal pocket in each target tooth was within 2 mm, and no signs of marginal periodontitis were observed. The target tooth in the present study was the right maxillary first molar. All of the subjects' teeth in this study were vital teeth. The protocol used in this study was approved by the ethics committee of Okayama University. Informed consent was obtained from all participating volunteers.

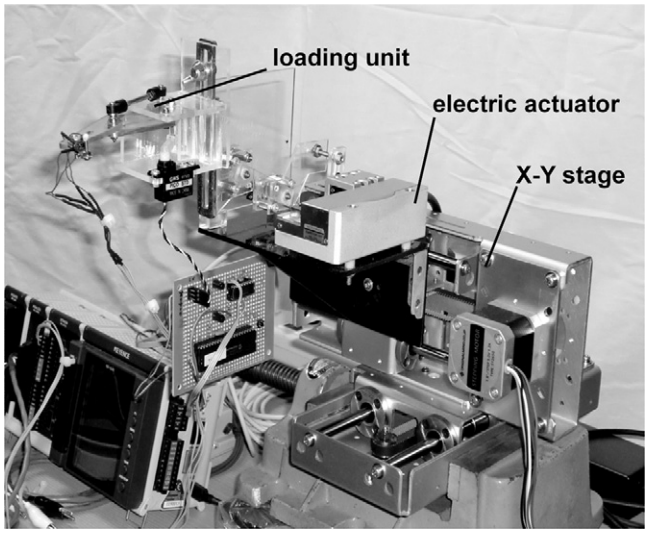

Fig. 1 – General view of the loading device mounted on the X–Y stage.

1.1. *Loading device for examination of the psychophysical threshold for a force applied to a tooth*

The loading device used in this study is shown in Figs. 1 and 2. It was installed on an X–Y stage, which consisted of two uniaxial stages linked in mutually perpendicular directions.

Fig. 2 – Measurement of psychophysical thresholds.