AJO-DO

Effects of mechanical stress and growth on the velocity of tooth movement

Jeffrey C. Nickel,[a] Honzeng Liu,[b] David B. Marx,[c] and Laura R. Iwasaki[d]
Kansas City, Mo, and Lincoln, Neb

Introduction: In this study, we investigated the effects of the magnitudes of applied stress and growth status on the speed of tooth movement. **Methods:** Eighty-two maxillary canines in 41 subjects were retracted for 84 days by estimated stresses of 4, 13, 26, 52, or 78 kPa applied continuously via segmental mechanics. Dental impressions made at intervals of 1 to 14 days resulted in 9 or 10 dental casts per subject. Three-dimensional tooth movements were quantified using these casts, custom reference templates, and a measuring microscope. Serial height and cephalometric measurements determined growth status. **Results:** Distal tooth movement was linear with no lag phase in 96% of the teeth. Speeds averaged 0.028, 0.040, 0.050, 0.054, and 0.061 mm per day (standard errors, ± 0.004) for 4, 13, 26, 52, and 78 kPa, respectively. The maximum difference in speed between teeth was 9:1. Teeth moved significantly faster (P <0.0001) in growing compared with nongrowing subjects, on average by 1.6-fold. Stress and speed of tooth movement were logarithmically related in growing ($R^2 = 0.47$) and nongrowing ($R^2 = 0.34$) subjects. Other tooth movements were relatively small, except for the distopalatal rotation of teeth moved by 78 kPa that averaged more than 19°. **Conclusions:** The speed of retraction was logarithmically related to the applied stress and was significantly faster in actively growing subjects compared with those who were not growing. (Am J Orthod Dentofacial Orthop 2014;145:S74-81)

The variables that affect the speed of tooth movement, such as applied stress magnitude and growth status, remain poorly understood. Previous reviews of the literature on optimal mechanics for maximizing the speed of tooth movement have demonstrated the paucity of data on this topic. Quinn and Yoshikawa[1] proposed 4 hypotheses of the relationship between applied stress and velocity of tooth movement, with insufficient but tentative support for a linearly increasing speed of tooth movement up to a maximum at 7 to 14 kPa (100-200 cN for an average canine).[1]

[a]Associate professor, Departments of Orthodontics & Dentofacial Orthopedics and Oral & Craniofacial Sciences, School of Dentistry, University of Missouri, Kansas City.
[b]Postdoctoral fellow, Departments of Orthodontics & Dentofacial Orthopedics and Oral & Craniofacial Sciences, School of Dentistry, University of Missouri, Kansas City.
[c]Professor, Department of Statistics, University of Nebraska, Lincoln.
[d]Associate professor, Leo Rogers Chair of the Department of Orthodontics & Dentofacial Orthopedics; joint appointment, Department of Oral & Craniofacial Sciences, School of Dentistry, University of Missouri, Kansas City.
All authors have completed and submitted the ICMJE Form for Disclosure of Potential Conflicts of Interest, and none were reported.
Funded in part by the American Association of Orthodontists Foundation.
Address correspondence to: Jeffrey C. Nickel, UMKC School of Dentistry, 650 E 25th St, Kansas City, MO 64108; e-mail, nickeljc@umkc.edu.
Submitted, April 2013; revised and accepted, June 2013.
0889-5406/$36.00

http://dx.doi.org/10.1016/j.ajodo.2013.06.022

The relatively limited quantitative data available were further illustrated by a comprehensive review through 2001; only 17 animal studies and 4 human studies met reasonable inclusion criteria, and only 1 human study attempted to quantify applied stress.[2] Consequently, the limited information on the rate of tooth movement and stress has challenged previous attempts to model these relations. Ren et al[3] used published results from dogs and humans to develop a mathematical model for the relationship between speed and applied force. Their results showed widely scattered velocities of different-sized teeth moved by various protocols and in different species. They concluded that there is a dose-response relationship only for lower forces with a maximum predicted speed of 0.041 mm per day for 272 cN in humans. More recently, Van Leeuwen et al[4] reported on tooth translation of first molars and second premolars relative to implant anchorage in dogs using a relatively disparate range of forces and where forces were systematically increased. Variability in the speed of tooth movement for an equivalent force (scaled to account for differences in root surface areas between molars and premolars) was high and estimated at more than 15:1. Despite the high variability, the authors suggested a logarithmic model, where only forces in the low range can affect the speed of tooth movement. Theoretical models involving finite element approaches and up-to-date methods for characterizing the anatomy of the teeth and surrounding structures might in the future be used to study this clinically important relationship.[5-8] However, these theoretical approaches currently lack physiological and clinical data for patient-specific predictions and validations, respectively.

More recently, controlled tooth translational movements in humans were reported.[9-12] Among individual teeth, the speeds of maxillary canine retraction differed by as much as 9:1.[9] The combined results of these human studies suggested that 26 kPa was an optimal applied stress, and 0.063 mm per day was the average maximum mean speed of tooth movement. These data also demonstrated that mean speeds of tooth movement were about 2 times faster in growing subjects compared with subjects who showed no growth during orthodontic treatment.

To date, no statistically significant mathematical model has been proposed that relates the speed of tooth movement and applied mechanics in humans. Here, we report a model based on data collected from 41 subjects in whom determinant mechanics were used to translate the maxillary canines over 84 days.

MATERIAL AND METHODS

The methods for recruitment and data collection were reported previously and are briefly described in the following paragraphs.[9-13] Patients with good oral hygiene and at least 6 permanent teeth in each maxillary quadrant and who required bilateral maxillary canine retraction into the extracted maxillary first premolar sites were recruited for the study from the University of Missouri Kansas City Graduate Orthodontic Clinic. Forty-one subjects gave informed consent to participate according to the ethical standards of the appropriate institutional review boards. During the study, the subjects were instructed to rinse orally with chlorhexidine gluconate (Sunstar Americas, Inc, Chicago, Ill) twice daily and to avoid taking any other medications.

In each subject, the maxillary teeth were set up for segmental mechanics to translate the bilateral maxillary canines distally, whereas the mandibular teeth had no appliances. The anchorage included a Nance appliance and linking of the posterior teeth on each side with passive buccal stainless steel segment archwires of rectangular cross-section (≥0.016 × 0.018 in) plus figure-eight ligation (Fig 1). Approximately 2 weeks after anchorage placement, the maxillary first premolars were removed; approximately 2 weeks later, at a time point defined as day 0, active retraction of the maxillary canines began. In brief, a 0.016 × 0.022-in diameter stainless steel auxiliary wire with a vertical loop just distal to the maxillary canine was constructed to extend passively from the maxillary first molar band's auxiliary tube to the canine bracket. The height of this loop matched the canine's center of resistance, relative to its root length, which was measured from a periapical radiograph of this tooth corrected for magnification, according to the relationship: center of resistance = 0.24 root length. The vertical-loop auxiliary wire was made passive initially, ligated to the canine bracket with a stainless steel tie and an elastomeric tie overlay, and then activated by a nickel-titanium coil spring, calibrated at mouth temperature (see the study of Iwasaki et al[12] for details of the methods), stretched between hooks on the molar band and on the auxiliary wire just distal to the loop (Fig 1). This caused separation of the vertical legs of the loop, creating both a retraction force and apicodistal counter-moment at the canine bracket that was designed to result in translation of the canine with respect to the posterior anchorage. The force required for a given stress level (4, 13, 26, 52, or 78 kPa) was determined by dividing the stress by the maxillary canine's estimated distal root surface area (A) involved in periodontal ligament compression during canine retraction. This estimate took into account root

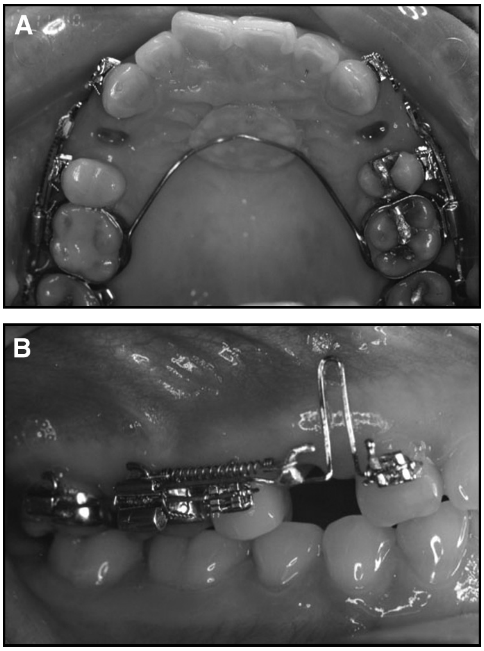

Fig 1. A, Maxillary occlusal view showing anchorage appliances and vertical loops activated by calibrated nickel-titanium coil springs selected to deliver a prescribed continuous force (F) for a specified stress (σ) to each maxillary canine, according to $\sigma = F/A_a$, where A_a is the distal root surface area of the maxillary canine adjusted for root curvature; **B**, right buccal view showing the height of the vertical loop approximating the estimated center of resistance of the maxillary canine.