Biomechanical behavior of the periodontium before and after orthodontic tooth movement

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The periodontium is a supporting structure of the tooth. It consists of gingiva, alveolar bone, cementum and periodontal ligament (PDL). Several parameters have been used to objectively assess periodontal status, i.e., depth of periodontal pocket, alveolar bone height, blood flow, inflammatory mediator levels and tooth mobility.[1-3] Due to the simplicity in measurement,[4-10] tooth mobility – the biomechanical reaction of the periodontium to external forces – has been used as a periodontometric indicator to determine the periodontal status. In general dentistry, tooth mobility has thus been investigated in relation to the degree of periodontal support in patients with certain periodontal diseases. The degree of tooth mobility is influenced by such variables as mechanical properties of the PDL and alveolar bone, thickness of the PDL space and anatomy of the periodontium. Therefore, tooth mobility may be used as an important key in the evaluation of biomechanical characteristics of the periodotium.

In orthodontic tooth movement, the remodeling process in periodontal tissues is repeated,[11-15] and biomechanical properties may be affected substantially by remodeling as well as by anatomical alterations in the PDL space and alveolar bone height. Thus, tooth mobility or instantaneous tooth displacement may be used as a target to predict the biomechanical responses of the periodontium to therapeu-

Abstract

This study was designed to investigate the biomechanical behavior of the periodontium including the periodontal ligament (PDL) in terms of tooth mobility. Tooth mobility was measured in the canines of 10 adolescent patients before and after distal movement. Distal movement of the canines was carried out by use of a calibrated sectional archwire exerting an initial retraction force of 200 g. Tooth mobility was measured immediately before and after canine retraction by use of a noncontact displacement sensor when varying distal forces of 0 to 500 g were applied to the mesial of the canine. Before tooth movement, tooth mobility exhibited a substantial increase in loading with forces ranging from 50 to 150 g. The rate of increase gradually decreased up to 500 g. A nonlinear change in tooth mobility was similarly observed at the end of tooth movement or 24 days after the initiation of movement. Tooth mobility, however, was significantly greater when forces above 200 g were loaded. The periodontal tissues—the PDL and alveolar bone in particular—become more flexible at the end of tooth movement, indicating reduced support by the periodontal tissues. These findings suggest that the elastic nature of the PDL and alveolar bone may decrease substantially at the end of tooth movement.

Key words

Tooth mobility • Orthodontic tooth movement • Biomechanical property • Periodontium • Noncontact sensor

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Figure 1
Canine retraction by use of a calibrated sectional archwire and measurement of tooth mobility by use of a noncontact displacement sensor.
A: Calibrated sectional archwire for canine retraction
B: Acrylic block with guide plane for force transducer (a) and U-shaped metal plate (b) for sensor. A broken line denotes the direction of canine retraction.
C: Force transducer (c) to apply load and noncontact sensor (d) close to conducting metal plate (e)
D: Enlargement of C

Figure 1A

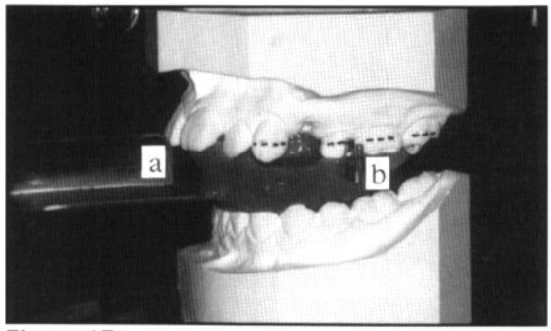

Figure 1B

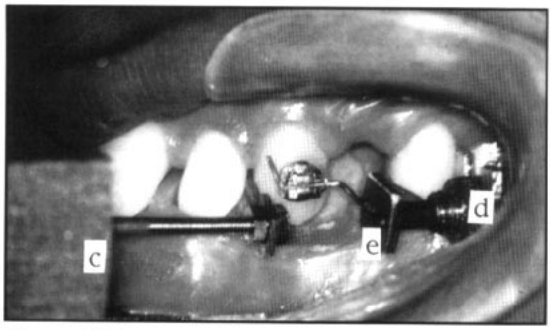

Figure 1C

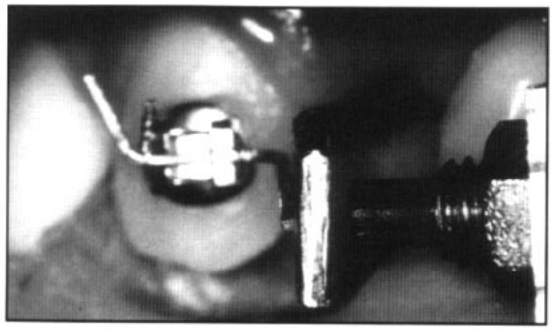

Figure 1D

tic forces. However, while studied of histologic alterations are replete in the literature,[11-15] the degree to which biomechanical properties are affected by artificial tooth movement has not been adequately explored.

The purpose of this study was to investigate the biomechanical behavior of the periodontal tissues, in particular the change in tooth mobility from immediately before to immediately after orthodontic tooth movement.

Materials and methods

Ten adolescent patients (four boys and six girls ranging in age from 13 to 16 years) were selected as subjects. The treatment plan for each subject included the extraction of four premolars and the use of edgewise appliances. Canine retraction into the extraction site was initiated by use of calibrated sectional archwires with four closing loops (Rocky Mountain Co., Denver, Colo). The first molars were firmly held as the anchorage unit reinforced by lingual holding arches (Figure 1A). An initial force of 200 g was applied with appropriate antitipping moment for 24 days. The amount of tooth movement was measured by use of digimatic calipers every 3 or 4 days.

Mobility of the maxillary canine was measured immediately before and after canine retraction when varying loads were applied to the mesial of the crown. The measuring system consisted of a noncontact displacement sensor (Figure 1C, Japan Vibration Co., Tokyo) and force transducer (Figure 1C, Toyo Boldwin Co., Tokyo), both of which were connected to a personal computer system (PC-9801 UX-41, NEC Corp., Tokyo), as shown in Figure 2.

For the measurement, an acrylic block with guide plane and U-shaped metal plate for the force transducer and sensor was fabricated to define the force direction parallel to that of canine distal movement, as denoted by a broken line in Figure 1B. The device was held firmly in position by the subject and the transducer and sensor were aligned so they were parallel and opposite to each other with the tooth between them (Figure 1C). The force transducer, which created distal forces of 0 to 500 g applied to the canine, was used to quantify the magnitude of load and to input the data. When the tooth was displaced distally, a conducting metal plate attached to the bracket on the tooth approached the sensor, producing changes in eddy current (Figure 1D). Finally, the electric change was converted to instantaneous displacement of the tooth or tooth mobility (Figure 2).

The measurement was repeated six times for each subject and the values were averaged to obtain tooth mobility. The measured values after the completion of distal movement were compared statistically with those from immediately before the movement. For statistical comparison, Student's and Welch's t-tests were alternately employed when the variances in the two groups were equal or not as a result of the

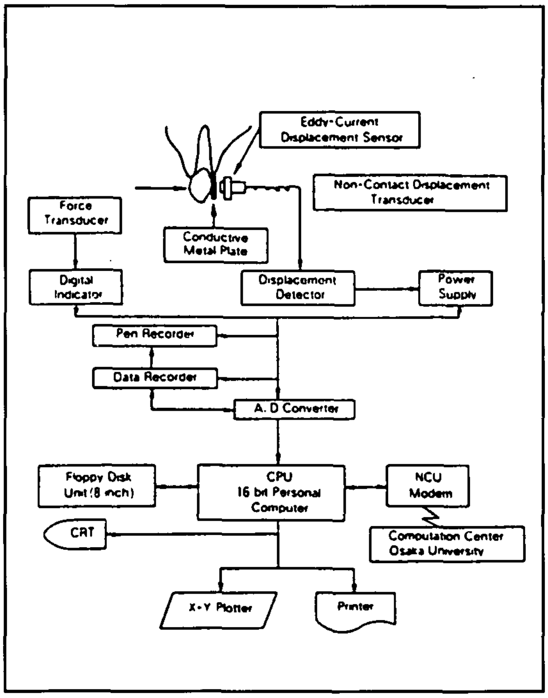

Figure 2

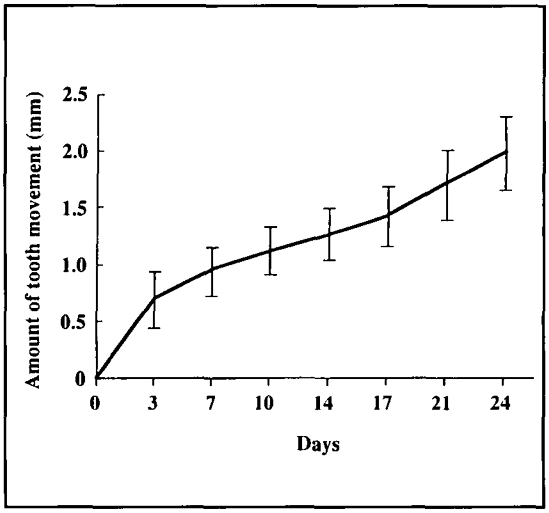

Figure 3

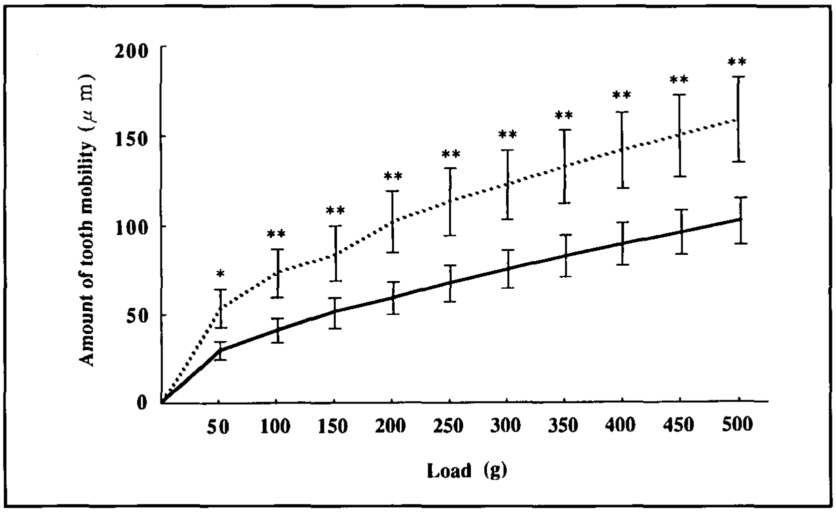

Figure 4

F-test. The nature of the tooth mobility curve was evaluated by means of nonlinear regression analysis.

Results

Figure 3 shows a mean curve of the canine movement. The curve was roughly divided into three phases—initial (0 to 3 days), lag (3 to 17 days), and postlag (17 to 24 days). The amount of tooth movement exhibited a substantial increase during the initial phase and the rate of increase became smaller in the lag phase. During the postlag phase, the amount of tooth movement increased again, although the rate of increase was slightly less than during the initial phase.

Figure 4 shows the load-tooth mobility curves before and after canine retraction. Before movement, mobility was 41.3 and 101.5 μm on average when 100- and 500-g forces were applied, respectively. Tooth mobility exhibited a substantial increase in loading, with forces ranging from 50 to 150 g, then the rate of increase gradually decreased as the load rose to 500 g.

As a result of the F-test, variances in the measured values before and after movement were not equal, although the coefficients of variation were almost invariable between the data in the two groups. Thus, Welch's t-test was used for statistical comparison of the measured tooth mobilities. Tooth mobility significantly increased after the completion of canine retraction for 24 days for all the loads up to 500 grams. The mean tooth mobility was 73.1 μm for 100 g load and 157.6 μm for 500 g load. In particular, tooth mobility produced by the loads greater than 100 g was significantly larger ($P<0.01$) than that before tooth movement. Thus, the amount of tooth mobility was significantly greater after tooth movement in response to both light and heavy forces.

Table 1 shows the increment of tooth mobility for every 50-g load. Ratios of the increment before and after tooth movement are also presented. Immediately before tooth movement, the increment exhibited the maximum values of 0.62 μm/g when a 50-gload was applied, and then gradually decreased to 0.16 μm/g for a 200-g load. The values were almost invariable in the range of force from 200 to 500 g. Meanwhile, the ratios at the end of tooth movement were larger than those before the movement. In particular, the ratios were 1.07, 0.39

Figure 2
Schematic representation of the present measuring system for tooth mobility.

Figure 3
Curve of tooth movement for the period of 24 days.

Figure 4
Curve of tooth mobility in response to varying forces ranging from 0 to 500 g.
*** : significantly different at 5 % level of confidence from those before tooth movement**
****: significantly different at 1 % level of confidence from those before tooth movement**

Table 1
Changes in tooth mobility for every 50 g-load

Load (g)	50	100	150	200	250	300	350	400	450	500
Before movement (a)	0.62	0.21	0.20	0.16	0.16	0.15	0.15	0.13	0.13	0.12
After movement (b)	1.07	0.39	0.21	0.35	0.23	0.19	0.20	0.18	0.17	0.17
c (b/a)	1.73	1.86	1.05	2.19	1.44	1.27	1.33	1.38	1.31	1.42
d (1/c)	0.58	0.54	0.95	0.46	0.69	0.79	0.75	0.72	0.76	0.70

(unit of (a) and (b): μm/g)

and 0.35 for 50-, 100- and 200-g loads, and were substantially greater than those before movement. The ratios were almost constant within the range of load from 250 to 500 g. Since this ratio is approximately the inverse of elasticity, the elastic nature of the PDL and alveolar bone are speculated to decrease at the end of orthodontic tooth movement, as denoted by the values in Table 1.

As a result of regression analysis, both load-tooth mobility curves were approximated as $y = a x^b$ (y=mobility; x=load; a and b are constants), as shown in Table 2. The coefficients of determination were approximately 0.988 and 0.985 for the curves before and after tooth movement. If "a" increases, tooth mobility increases irrespective of the changes in external loads, and thus the coefficient "a" is pertinent to an overall change in tooth mobility. On the other hand, increases in tooth mobility produced by the changes in "b" are highly dependent upon the magnitude of loads. From this viewpoint, the following interpretation of the regression analyses is available. The value "a" increased substantially at the end of tooth movement, demonstrating that load-independent increase in tooth mobility was produced by tooth movement. Meanwhile, the coefficient "b" was almost constant, indicating that the load-dependent increase was almost invariable irrespective of tooth movement.

Discussion

Periodontal tissues exhibit nonlinear behavior in response to external forces.[16] However, the nature of biomechanical behavior of the periodontium before and after orthodontic tooth movement has not been elucidated because of difficulties in measurement. It is thus important to investigate the biomechanical reactions of the periodontium to external forces to determine an optimal force application for orthodontic tooth movement.

To investigate biomechanical reactions of connective tissues, specimens must be subjected to various loading tests.[17,18] However, it is very difficult to make specimens of the periodontium without surgical invasion of the tissues. Therefore, measurement of tooth mobility may be the only way to explore reactions to external forces. With respect to tooth mobility, most of the previous studies employed direct measuring techniques with dialmeters and strain gauges.[6-9,16,19] In these measuring systems, external pressure on transducers or gauges essentially exerted by tooth displacement is speculated to affect the degree of tooth displacement. In order to eliminate such a shortcoming, a technique with laser holography was developed by Burstone and associates.[20] However, the system is expensive and involves a huge apparatus; therefore, it is not suitable for clinical use. On the other hand, the present system with a noncontact displacement sensor is compact and it is easy for most clinicians to handle .[5]

For these reasons, the noncontact measuring system was used in this study. The point of application and the direction of force (variables which may influence the degree of tooth mobility[19]) were held constant before and after movement by use of the acrylic block with guide plane and U-shaped metal plate. Further, the archwire used for canine retraction produced a momemt-to-force (M/F) value of 13.0 mm, which is optimal for translation of the canine.[21] The magnitude of the distal force and antitipping moment decreased in an almost proportional manner to the amount of archwire deactivation resulting from tooth movement; however, the M/F value was nearly constant. Canine movement was actually translatory without rotation or distal tipping, as observed in the plaster models and standardized dental X-ray films. Thus, the present measuring system can precisely measure tooth mobility under the same conditions before and after tooth movement.

Load-tooth mobility curves reported in pre-

Table 2
Result of nonlinear regression analysis for load-tooth mobility curve

	Coefficient a	Coefficient b
Before movement	3.3	0.55
After movement	8.6	0.48

vious studies[7-9,22] were divided into initial and secondary phases according to the magnitude of load. Initial mobility was within the range of load of 100 g or less, and secondary mobility was within the range of load more than 100 g. Further, these studies indicated that the initial and secondary tooth mobilities were due to deflections of the PDL and alveolar bone, respectively.[4,7-10,22,23]

In this study, load-tooth mobility curves exhibited two phases, which were almost coincident to those in previous studies.[4,7-10,22,23] However, the limit of load to distinguish the two phases was slightly larger in this study than the 100 g previously reported.[7-9] For this reason, differences among the teeth subjected to measurement were first recognized. The canines used in this study were larger than the central incisors frequently employed.[7-9] In addition, changes in the PDL width and biomechanical properties of the periodontium[24] may explain the higher limit of load observed after tooth movement.

Since the load-tooth mobility curve is almost equivalent to the stress-strain curve of living or nonliving materials, valuable information on the biomechanical properties may be derived from the tooth mobility curve. Increments of tooth mobility, evaluated for 50-g light and heavy forces, approximated inverse relationships of elasticity for the PDL and alveolar bone and were substantially different before and after tooth movement. In particular, substantial reduction in the elastic property of the PDL was indicated from the data on increments of tooth mobility for every 50-g load, provided the initial and secondary phases resulted completely from changes in the PDL and alveolar bone.[4,7-10,22,23] The present results also provide new information on the nature of tooth mobility before and after orthodontic tooth movement. These findings may be interpreted by evaluating the equations of the curves as well as the actual values. The equation of the curve obtained by regression analysis can be converted to $Y = A + BX$ ($Y=\log y$, $X=\log x$, $A=\log a$, $B=\log b$, y=tooth mobility, x=load) by logarithmic transformation. In this new form, the coefficients "a" and "b" represented by A and B are pertinent to overall load-independent increase and load-dependent increases of tooth mobility, respectively.

Different patterns of tooth mobility before and after tooth movement may be caused by changes in the biomechanical properties of the PDL and alveolar bone which undergo various remodeling activities. In a histologic aspect, the PDL is stretched or compressed; subsequently the alveolar bone is restructured by young bony tissues.[11-15] In this study, bone resorption was induced in the periodontal space during tooth movement; however, new bone deposition did not occur, hence the bony support was not yet tight. Therefore, a decrease in the elasticity of the periodontal tissue may be confirmed by such histologic findings.

Various models have been proposed to simulate the behavior of the periodontium.[10,23,25] The optimal model consists of a spring, two viscous dampers, and two masses.[10,25] The spring and dampers relate to the stiffness or elasticity of the PDL and the flow of periodontal fluid. According to this theory, a decrease in the elasticity of the PDL may also be approved.

Periodontal space becomes wider during orthodontic tooth movement and is not occupied by newly deposited bone; hence, the elasticity of the PDL and alveolar bone decreases during and immediately after tooth movement. To elucidate the biomechanical reactions of the teeth, mobilities at all timepoints during tooth movement and the return of tooth mobility may be more useful. In the future, an advanced study is anticipated to clarify such points by use of a larger sample.

Conclusions

The biomechanical behavior of the periodontium, including the PDL, was investigated to determine tooth mobility. The amount of tooth mobility was measured immediately before and after canine retraction by use of a noncontact displacement sensor. Retraction was accomplished with varying distal forces of 0 to 500 g applied to the mesialof the canine.

The following results were obtained:

1. Tooth mobility curves before and after canine retraction were nonlinear and exhibited two phase changes according to varying force

levels. However, the limit of force to distinguish the two phases was greater after tooth movement than before.

2. Before tooth movement, tooth mobility exhibited a substantial increase when forces ranging from 50 to 150 g were applied; the rate of increase gradually decreased as the force rose to 500 g.

3. At the end of tooth movement, or 24 days after the initiation of movement, the amount of tooth mobility was significantly greater than it was before tooth movement in response to both the light and heavy forces.

Periodontal tissues, the PDL and alveolar bone in particular, become more flexible, indicating that the elastic nature of the PDL and alveolar bone may decrease substantially at the end of tooth movement.

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