Blood flow changes in gingival tissues due to the displacement of teeth

KazunoriYamaguchi, DDS, PhD; Ram S. Nanda, DDS, PhD

In orthodontic tooth movement, vascular reaction is one of the important processes of bone remodeling and rearrangement of connective tissue in the periodontium. It has been studied from both morphological[1-4] and functional[5-7] aspects. Iida[6] reported increased capillary permeability in rats, induced by orthodontic tooth movement. Yamaguchi et al.[7] studied vascular leakage in palatal soft tissue following lateral expansion of the maxillary arch, and they showed that the first vascular leakage was dependent on tension in the palatal soft tissue.

A change in blood flow is one of the vascular reactions caused by orthodontic stimuli.[8-11] In the periodontal ligament, capillary pressure is regarded as an optimal force per square centimeter for orthodontic tooth movement.[13-15] Kondo[9] studied blood circulation in the periodontal ligament of cats using electrical impedance plethysmography, and he indicated that blood flow decreased according to the tooth displacement relative to periodontal width. Yamaguchi and Nanda[12] studied human gingival blood flow using a laser doppler flowmeter. They reported that decreased blood flow was correlated (r = -0.625) to the degree of force applied, although individual responses to the same degree of force varied.

Based on these findings, it was suggested that stretching or compression stress of the connective tissue fibers, rather than the degree of force applied, might have a close relationship with blood flow changes in the gingival tissue, and could be the determining factor for the vascular reaction. The degree of stretching or compression stress in the

Abstract

Changes in human gingival blood flow were measured using a Laser doppler flowmeter. The change of blood flow was correlated to the degree of force applied and there were variations in measurement of decreased blood flow among the subjects. The variation was attributed to the degree of tooth displacement and the size of the interdental space. This study examined the effect of tooth displacement on the gingival blood flow, as well as age and sex differences.

Blood flow in gingival tissue was measured using a laser doppler flowmeter, and displacement of the maxillary incisors was measured using an eddy current sensor. The correlation coefficient of the decreased blood flow to the tooth displacement was 0.809, and it was higher than that to the degree of applied force (r = -0.625). The regression coefficient of decreased blood flow to the displacement of teeth was significantly correlated to the interdental space. The regression coefficient of decreased blood flow to the percentage of tooth displacement was independent of the interdental space. However, the regression coefficient of decreased blood flow to the percentage of tooth displacement was significantly higher in young subjects than in adults.

This manuscript was submitted July 1991. It was revised and accepted for publication March 1992.

Key words

Gingival blood flow • Laser flowmeter • Interdental space • Displacement of teeth • Eddy current

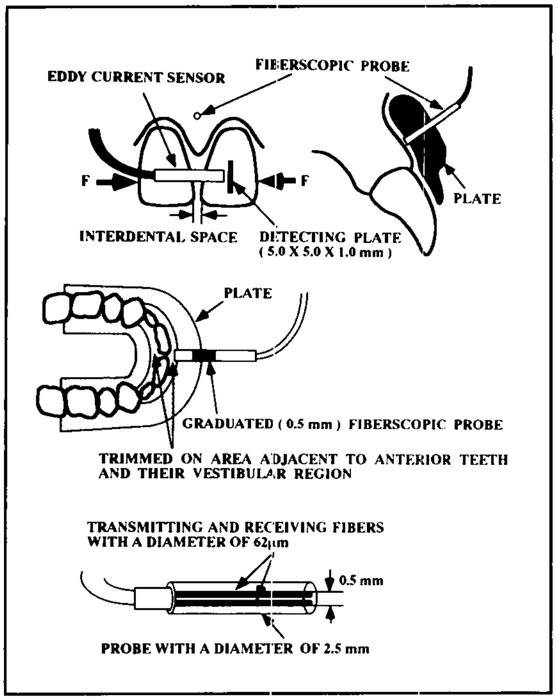

Figure 1

Figure 1
Fiberscoptic probe for Laser flowmetry and position of eddy current sensor. A plate covering the premolars, the anterior teeth and the vestibular region was made with heavy body impression material for each subject. The plate was trimmed in area adjacent to the anterior teeth and their vestibular region. To hold the fibroscopic probe securely, a hole with a diameter of 2.5 mm was opened through the plate, at a right angle to the mucogingival junction, to the center of the interdental space. The probe was graduated in 0.5 mm increments and the tip of the probe was positioned 0.5 mm from the mucosal surface. The probe with a diameter of 2.5 mm had two optical fibers, one for transmitting, the other for receiving. The distance between the fiber with a core diameter of 62 μm was 0.5mm.

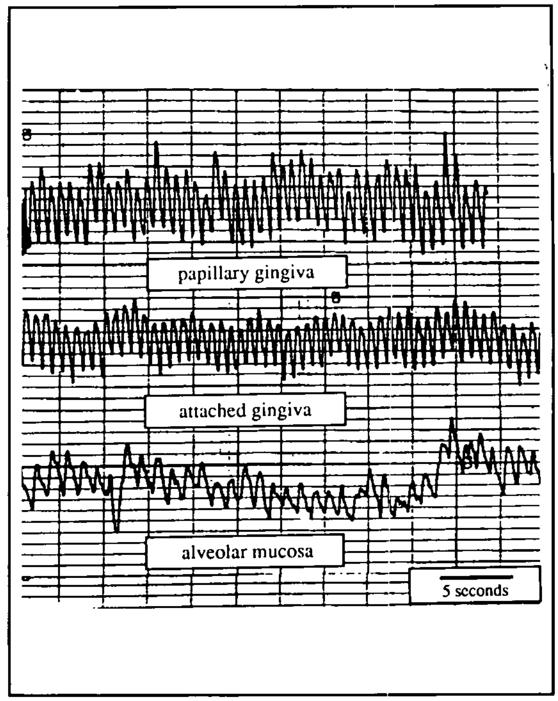

Figure 2

Figure 2
Recording of the wave patterns of the blood flow in the papillary, attached gingiva and the alveolar mucosa. Time constant was 0.1 second. The wave pattern was well synchronized with the heart beat in the papillary and attached gingiva, however, alveolar mucosa was not synchronized.

gingival tissue may vary with the direction of the applied force and tooth displacement. The purpose of this study was to determine the effect of tooth displacement on blood flow in the gingival tissue.

Principle of Laser doppler flowmetry

A helium-neon laser has a constant, stable wave of 632 nm. When the focused beam is scattered in static tissue, it shows no changes in frequency. However, it shows changes in frequency due to the Doppler shift when scattered by moving red cells. Changes in frequency reflect the velocity of the moving red cells.[16-17] Blood flow is represented as the blood flow velocity, multiplying the volume of the red cells in a hemisphere of 1.0 mm radius by their velocity.[18-19]

Material and methods

Ten healthy adult (mean age 24.3 years) and nine young subjects (mean age 10.5 years) with interdental space between their maxillary central incisors were selected. The sample consisted of 8 females and 11 males. Each patient's interdental space (L) was measured as the distance between the incisal edges using a calipers (1/100 mm). Interdental space ranged from 0.9 to 5.5 mm with a mean of 2.078 ± 1.407 mm in the young subjects, and from 0.4 to 4.5 mm with a mean of 1.900 ± 1.262 mm in the adult subjects (Table I). There was no significant difference ($p < 0.2803$) in the interdental space (variable 1) between the young and adult subjects (Table II). All of the subjects were free of clinical signs of gingival inflammation.

Measurement of gingival blood flow

All blood flow measurements were made on a laser doppler flowmeter (ALF 2100, Advance Co., Tokyo, Japan). The instrument and procedure are described in Figure 1. Based on the wave patterns (Figure 2), the muco-gingival junction was identified and the probe was located at 1.0 mm below the junction over the attached gingiva. During the experiment, each subject was placed in a supine position, with the head and the heart on the same plane.

After monitoring for 10 minutes, measurements were started in a quiet room held at 20° C to 25° C room temperature. The flowmeter's time constant was set at 1.0 second, and the signals of blood flow were continuously recorded by pen recorder (302121, Yokogawa Co. of America, Ga.).

Measurements of the displacement of the maxillary central incisors

Displacement of the maxillary central incisors caused by the applied force was measured using an eddy current sensor (AS-421A, Keyence Co., Osaka, Japan) and Controller (AH-303, Keyence Co., Osaka, Japan). Eddy electric current flows in a metal body moving close to a coil (in a sensor), and the current conversely affects the inductance in the sensor.[20,21] Changes in inductance in the sensor were detected as changes of voltage output. The sensor (3.8 mm in diameter) was fixed with Concise orthodontic adhesive on the labial surface of one central incisor perpendicular to its long axis at the incisal one-third of the crown (Figure 1). Two stainless steel plates (5.0 mm x 5.0 mm x 0.5 mm and 5.0 mm x 5.0 mm x 1.0 mm) were fixed next to each other with Concise

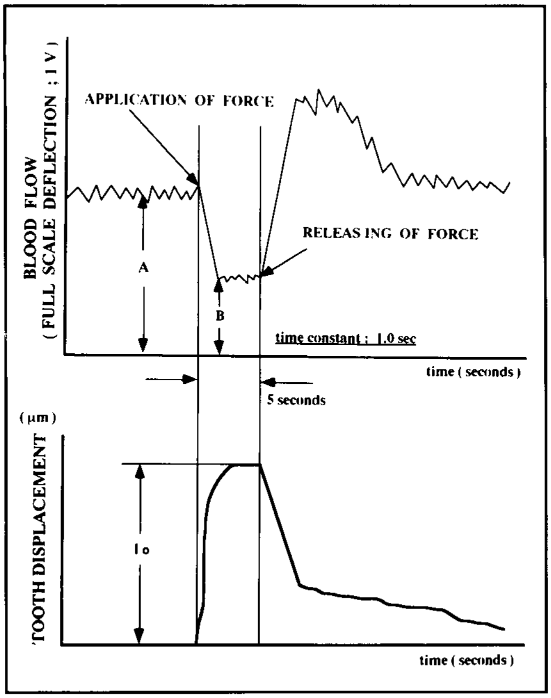

Figure 3

Figure 3
Schematic showing of the recordings for blood flow in the gingiva and tooth displacement (time constant: 1.0 sec.).
A: blood flow during the resting period;
B: decreased blood flow caused by force application;
Io: displacement of the maxillary incisors.
Decreased blood flow (B/A X 100) as the percentage over the resting period, and the percentage of displacement (Io/L X 100) to interdental space (L) were evaluated.

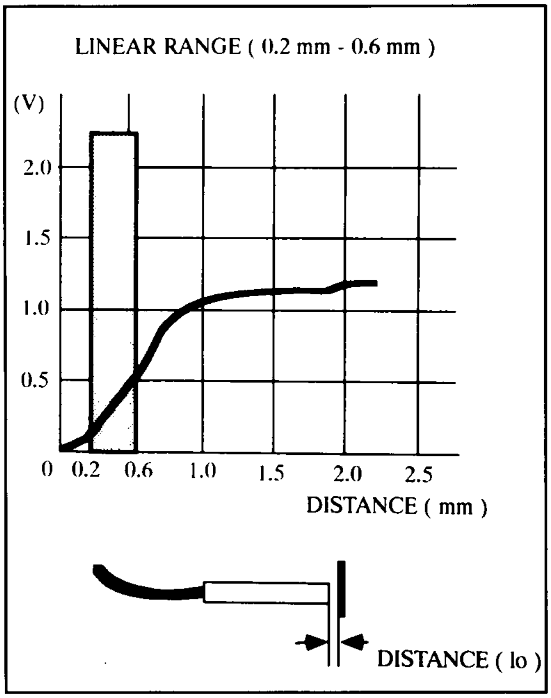

Figure 4

Figure 4
Linear range of the eddy current sensor. ❐: Effective linear range. Eddy current sensor (AS-421A) with detecting plate (5.0 mm X 5.0 mm x 1.0 mm) was calibrated with a caliper (1/100 mm). Distance and output voltage had an effective linear range from 0.2 mm to 0.6mm.

bonding system (the plate with a thickness of 0.5 mm being mesial) on the labial surface of the other central incisor so that output from the sensor indicated zero volts. Finally, one stainless steel plate (5.0 mm x 5.0 mm x 0.5 mm) was pulled out, and a detecting plate (5.0 mm x 5.0 mm x 1.0 mm) had 0.5 mm of space from the surface of the sensor (Figure 1). The controller had an effective range (linear relationship between measured distance and output voltage) from 0.2 mm to 0.6 mm of measurement (Figure 4). The contractive force was applied for 5 seconds to the maxillary central incisors in the mesial direction to close the interdental space (L) using orthodontic pliers (Figure 1). The degree of force was not standardized in this study. The signals of blood flow and displacement of teeth (Io) were recorded simultaneously by pen recorder (Figure 3).

The following seven variables were examined: 1) interdental space; 2) correlation coefficient (R) of the decreased blood flow to the displacement of teeth; 3) correlation coefficient of variable 2 to the interdental space (variable 1); 4) regression coefficient (slope A) of decreased blood flow to the displacement of teeth; 5) correlation of variable 4 to the interdental space (variable 1); 6) regression coefficient (Slope B) of the decreased blood flow to the percentage of the displacement; and 7) correlation coefficient of variable 6 to the interdental space (variable 1). The variables of blood flow measurements for each subject are given in Table I.

Variables 1, 2, 4, and 6 were compared with age and sex using Mann-Whitney U.

Results

Displacement of teeth and decreased blood flow

The mean correlation coefficients (variable 2) of the decreased blood flow to displacement of teeth and percentage of displacement were 0.858 ± 0.092 in young subjects, 0.765 ± 0.218 in adult subjects and 0.809 ± 0.172 for the total sample (Table II). Figure 5 shows the relationship between displacement of teeth (Io) and decreased blood flow (B/A x 100) in subjects with interdental space of 0.4 mm and 4.5 mm. One subject with a large interdental space had a smaller correlation coefficient (Figure 5). The correlation coefficient (variable 2) of the decreased blood flow in all subjects had a negative correlation ($r = -0.543$: $p < 0.05$) with interdental space (variable 3 in Table II). The regression coefficient (variable 4) of the decreased blood flow to the displacement of teeth (Lo) was -0.416 ± 0.237 and -0.331 ± 0.220 respectively in the young and adult subjects. Variable 4 also had a negative correlation ($r = -0.560$; $p < 0.05$) with the interdental space (variable 5 in Table II and Figure 6). There were no significant differences ($p <$ 0.3272 and 0.4624) in the correlation coefficient (variable 2) and regression coefficient (variable 4) between the young and adult subjects (Table II, Figure 7).

Percentage of tooth displacement to interdental space (Io/L x 100) and decreased blood flow (B/A X 100).

The correlation coefficients of decreased blood flow to the percentage of displacement were equal to those obtained for the displacement of teeth. The regression coefficient (variable 6) of the decreased

Table I

Variables of blood flow measurements and their means and standard deviations

	YOUNG SUBJECTS				ADULT SUBJECTS			
	space (mm) (variable 1)	R (variable 2)	SLOPE A (variable 4)	SLOPE B (variable 6)	space (mm) (variable 1)	R (variable 2)	SLOPE A (variable 4)	SLOPE B (variable 6)
No.1	1.5	0.907***	-0.186***	-3.791***	2.0	0.877***	-0.478***	-6.556***
No.2	2.3	0.939***	-0.775***	-17.827***	1.2	0.888***	-0.155***	-1.863***
No.3	2.5	0.899***	-0.416***	-10.402***	0.8	0.868***	-0.692***	-5.537***
No.4	1.6	0.738***	-0.182***	-3.910***	4.5	0.204	-0.016	-0.711
No.5	2.2	0.883***	-0.434***	-9.546***	0.4	0.773**	-0.554**	-2.218**
No.6	1.1	0.948***	-0.632***	-6.324***	1.5	0.640**	-0.217**	-3.257**
No.7	1.2	0.853***	-0.534***	-6.407***	2.2	0.929***	-0.335***	-7.372***
No.8	0.9	0.878***	-0.541***	-4.867***	3.1	0.852***	-0.087***	-2.708***
No.9	5.5	0.676**	-0.047**	-3.592**	0.7	0.772**	-0.278**	-1.946**
No.10					2.6	0.935***	-0.494***	-5.844***
Mean ± S.D.	2.078 ± 1.407	0.858±0.092	-0.416±0.237	-7.407±4.618	1.900±1.262	0.765±0.218	-0.331±0.22	-3.801±2.316

significance ** p < 0.001, *** p < 0.0001

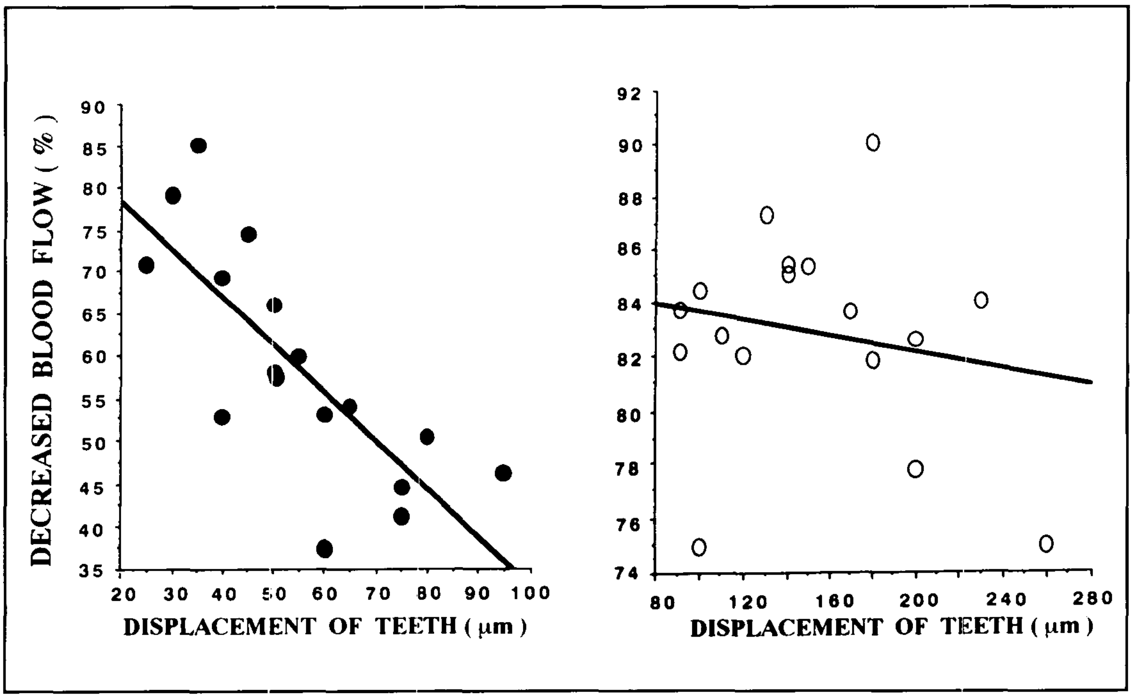

Figure 5
Relationship of decreased blood flow to tooth displacement in subjects with interdental space of 0.4mm and 4.5mm. Regression coefficient (slope) was steeper in the subject with interdental space of 0.4 mm (R = -0.554) than in the subject with interdental space of 4.5 mm (R = -0.016).

Figure 5

blood flow to the percentage of displacement was -7.407 ± 4.618 and -3.801 ± 2.316, respectively in the young and adult subjects (Table II), and there was no significant correlation to interdental space (variable 7 in Table II). The regression coefficient (variable 6) for the percentage of displacement was significantly ($p < 0.0412$) higher in the young subjects than in the adults (Table II and Figure 7). There were no significant differences in any of the variables between the female and male groups (Table II).

Discussion

Blood flow in the gingival tissue and periodontal ligament

Tooth displacement is induced by the application of orthodontic force[9,20,21] as well as by biting force during chewing and bruxism. The periodontal ligament has a visco-elastic property to the

Table II
Comparison of variables with age and sex

	YOUNG SUBJECTS	ADULT SUBJECTS	Mann - Whitney U		TOTAL
			age	sex	
INTERDENTAL SPACE (mm) (variable 1)	2.078 ± 1.407	1.900 ± 1.262	p < 0.7133	p < 0.7412	1.984 ± 1.298
CORRELATION COEFFICIENT (R) OF BLOOD FLOW TO TOOTH DISPLACEMENT (variable 2)	0.858 ± 0.092	0.765 ± 0.218	p < 0.3272	p < 0.4574	0.809 ± 0.172
CORRELATION COEFFICIENT OF R TO INTERDENTAL SPACE (variable 3)	-0.650	-0.591			-0.543*
REGRESSION COEFFICIENT (slope A) OF BLOOD FLOW TO TOOTH DISPLACEMENT (variable 4)	-0.416 ± 0.237	-0.331 ± 0.220	p < 0.4624	p < 0.6979	-0.371 ± 0.226
CORRELATION OF slope A TO INTERDENTAL SPACE (variable 5)	-0.532	-0.594			-0.560*
REGRESSION COEFFICIENT (slope B) OF BLOOD FLOW TO PERCENTAGE OF TOOTH DISPLACEMENT (variable 6)	-7.407 ± 4.618	-3.801 ± 2.316	p < 0.0412	p < 0.4574	-5.509 ± 3.947
CORRELATION OF slope B TO INTERDENTAL SPACE (variable 7)	-0.008	-0.079			-0.004

significance : * $p < 0.05$

applied force,[22] and blood flow in the periodontal ligament drops within a second of the application of force. This is an indication of a semi-open system of microcirculation in the periodontal ligament. On the other hand, Yamaguchi and Nanda[12] used laser flowmetry to study gingival blood flow in humans and reported that while blood flow does decrease in a few seconds when a force is applied, it gradually recovers during the application of force to at-rest levels. The decreased blood flow caused by heavier forces (150 gm and 250 gm) does not recover even after 10 minutes. This may be attributed to capillary loops and networks of vessels present in the gingival tissue's semi-open microcirculatory system.[23,24]

Methodology

Based on previous research,[12] the following points were considered to eliminate variability and increase reproducibility. First, the fiberscopic probe was placed so as to avoid areas over large vessels, because the number of red cells per cubic millimeter varies with the type of tissue. Small vessels and pre- and post-capillaries are widely distributed in the attached gingiva.[25,26] In the present study, blood flow was recorded in full-scale deflection, and its change in the gingival tissue was represented relative to its value in the resting period. Second, care was taken during blood flow measurements to hold the tip of the probe away from the gingival tissue. Holloway[27] and Gush et al.[28] reported that the Doppler shift increased with probe separation distance, however, probe separation of less than 2.0 mm did not significantly affect blood flow parameters. Therefore, the tip of the probe was positioned 0.5 mm from the mucosal surface. All measurements were carried out in a quiet room held at 20° C to 25° C room temperature, after monitoring the subject for 10 minutes to prevent undesired blood flow changes.[29,30] As a result, there was no significance of inter-trial effect on the measurements of blood flow changes and their duration. Gingival blood flow decreased as the degree of force increased, and was negatively correlated ($r = -0.625$) to the degree of applied force.[11]

Displacement of teeth and gingival blood flow

In a previous study,[12] the authors have shown that the same degree of forces results in varying changes in blood flow among subjects. Tooth displacement creates stress in the periodontium, including the periodontal ligament, gingival tissue and palatal soft tissue. This stress is distributed in the oral tissues and alters blood circulation.

Arteriovenous anastomoses regulate blood pressure in the vascular bed.[24,26] In the periodontal ligament, the degree of force per square unit is considered orthodontic stress. Kondo[9] indicated that blood flow decreased when tooth displacement was about one-third of the periodontal space. Yamaguchi et al.[7] stated that vascular leakage in the palatal soft tissue was induced during lateral expansion of the maxillary arch. These findings indicate that the change of blood flow may be subject to deformation of the tissue but not to the degree of force.

In this study of gingival tissue, decreased blood flow had a high positive correlation ($r = 0.809$) to

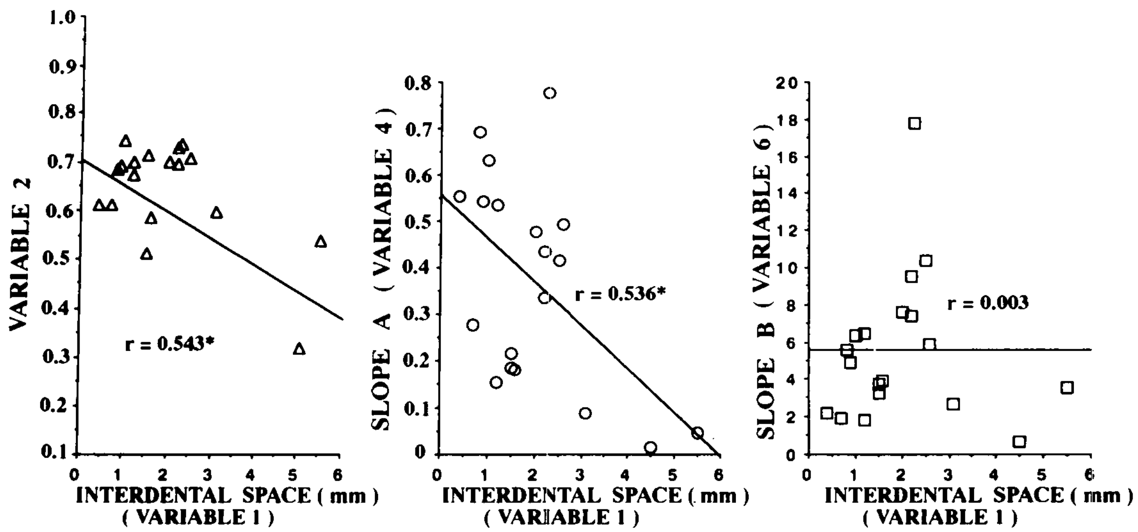

Figure 6

Figure 6
Relationship of variables 2, 4, and 6 to interdental space. Slope A: regression coefficient of decreased blood flow to displacement of teeth. Slope B: regression coefficient of decreased blood flow to percentage of displacement. Correlation coefficient (variable 2) and regression coefficient (variable 4) of decreased blood flow to tooth displacement decreased when interdental space increased. However, there was no significant correlation between interdental space and variable 6.
X axis: interdental space (mm), Y axis: correlation coefficient (variable 2) and regression coefficients (variables 4 and 6).(*p<0.05)

Figure 7
Relationships of the decreased blood flow to displacement of teeth (lo) and percentage of displacement (lo/L x 100) in young and adult subjects. Upper figure shows the relationship between the decreased blood flow and tooth displacement.
X axis: tooth displacement (μm); Y axis: decreased blood flow (B/A x 100;%)
○ adult subjects; ● young subjects
There was no significant difference in the regression coefficient (variable 4) between young and adult subjects. Lower figure shows the relationship between decreased blood flow and percentage of displacement.
X axis: percentage of the tooth displacement to the interdental space (lo/L x 100%) ; Y axis: decreased blood flow (%)
□ adult subjects; ■ young subjects
Regression coefficient (variable 6) of the percentage of tooth displacement to interdental space was significantly higher (p < 0.05) in young subjects than in adults.

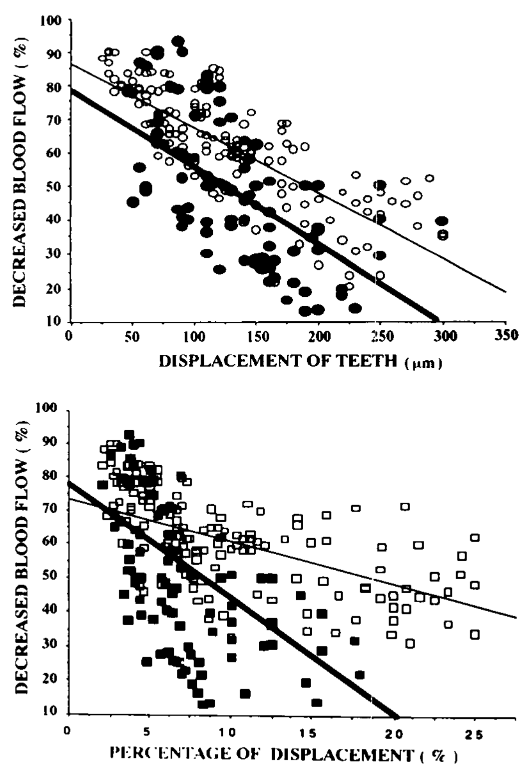

Figure 7

tooth displacement and was much higher than that of the degree of force.[12] The correlation coefficient (variable 2) and its regression coefficient (variable 4) of decreased blood flow to displacement of teeth were correlated to the size of the interdental space (variable 1). However, the regression coefficient of the decreased blood flow (variable 6) had no significant relationship to the percentage of displacement.

These findings mean that tooth displacement as orthodontic stress has a closer relationship to decreased blood flow than to the degree of force. In addition, stress in the gingival tissue as determined by the percentage of displacement, is more important than the size of the interdental space.

Gingival blood flow in young and adult subjects

Biochemical methods[4,31,32] have been used to evaluate activity in the periodontal ligament after the application of orthodontic force. High activity in the turnover rate of periodontal and supra-alveolar fibers and in the cell proliferation rate of the alveolar bone have been observed in young subjects.[33,34] In this study, when variables for blood flow in young and adult subjects were compared, there were no significant differences in the correlation coefficient (variable 2) of decreased blood flow to the displacement of teeth (Io) and its regression coefficient (variable 4). However, the regression coefficient (variable 6) of decreased blood flow to the percentage of tooth displacement to interdental space was significantly higher in young subjects than in adults. This indicates that blood flow changes in the gingiva of young patients are more responsive to the application of orthodontic stimuli than are blood flow changes in adults.

Measurement of blood flow with laser flowmetry

Finally, the plethysmographic recording,[9,10] the electrolytic hydrogen clearance method[19] and the thermal diffusion method[35] have been introduced to the oral tissue as instruments for blood flow measurement. Technical and mechanical complications preclude using any of these systems for continuous, non-invasive measurements in human gingiva. Measurements by the laser flowmetry were verified by other methods, such as plethysmography,[36] microspheres estimation,[19] and other methods[37] and high correlations were found.

Laser flowmetry is a useful method for measuring gingival blood flow in humans. Further investigation of blood flow in orthodontic patients before, during, and after treatment, and in patients with periodontitis should provide valuable clinical information about the biological activity of oral tissue in response to orthodontic stimuli.

Author Address

Ram S. Nanda
College of Dentistry
Department of Orthodontics
University of Oklahoma
P.O. Box 26901
Oklahoma City, OK 73190

K. Yamaguchi was visitng Professor in the Department of Orthodontics, College of Dentistry, University of Oklahoma (1990-1991). He is Professor in the Department of Orthodontics at the University of Hiroshima, Japan.

R.S. Nanda is Professor and Chairman, Department of Orthodontics, College of Dentistry, University of Oklahoma.

References

1. Macapanpan LC, Weinman JP, Brondie AG. Early tissue change following tooth movement in rats. Angle Orthod 1954;24:79-95.
2. Vandersall DC, Zander HA. Experimental obstruction of the periodontal blood circulation. Helv Odont Acta 1967;11:74-79.
3. Baumrind S, Buck DS. Rate change in cell replication and protein synthesis in the periodontal ligament incident to tooth movement. Am J Orthod 1970;57:109-131.
4. Tonna EA. A study of the reformation of severed gingival fibers in aging mice using H3-proline autoradiography. J Period Res 1980;15:43-52.
5. Castelli WA, Dempster WT. The Periodontal vasculature and its responses to experimental pressure. J Am Dent Assoc 1965;70:890-905.
6. Iida J. A study on the time course of the periodontal vascular permeability during experimental tooth movement. J Stomatol Soc 1982;49:141-154.
7. Yamaguchi K, Sawada Y, Tenshin S, Takahashi Y, Kawata T. Experimental study on the changes of palatal soft tissue following lateral expansion of upper dental arch. I. Study on the stressed palatal soft tissue by heavy force and changes of vascular permeability. J Jap Orthod Soc 1987;46:93-106.
8. Filk LEA, Stallard RE. Periodontal microcirculation as revealed by plastic microspheres. J Period Res 1967;2:53-63.
9. Kondo K. A study of blood circulation in the periodontal membrane by electrical impedance plethysmography. J Stomatol Soc 1969;36:20-42.
10. Packmann H, Shoher I, Stein RS. Vascular responses in the human periodontal ligament and alveolar bone detected by photoelectric plethysmography. The effect of force application to the tooth. J Period 1977;48:194-2001.
11. Babb DA, Oberg PA, Holloway GA. Gingival blood flow measured with a Laser doppler flowmeter. J Period Res 1986;21:73-85.

12. Yamaguchi K, Nanda R.S. Effect of orthodontic forces on blood flow in human gingiva. Angle Orthod 1991;61:192-204.
13. Schwarz AM. Tissue changes incident to orthodontic tooth movement. Int J Orthod Oral & Radiol 1932;18:331-352.
14. Oppenheim A. A possibility for physiologic orthodontic tooth movement. Am J Orthod 30:277-328.
15. Storey E. The Nature of tooth movement. Am J Orthod 1973;63:292-305.
16. Stern MD, Jape DL, Bowen LD, Chimosky JE, Holloway GA, Keiser HR, Bowman RL, Continuous measurement of tissue flow by Laser-Doppler Spectroscopy. Am J Physiol 1977;232:H441-H448.
17. Bonner RF, Clem TR. Laser doppler continuous real time monitor of pulsatile and mean blood flow in tissue microcirculation. In: Scattering Techniques Applied to Supramolecular and Nonequilibrium System. SH Chen, B Chu, R Nossal, Ed., New York: Plenum Press, 685-701, 1981.
18. Bonner RF, Nossal R. Model for Laser doppler measurements of blood flow in tissue. Appl. Optics 1981;20:2097-2107.
19. Kvietys PR, Shepherd AP, Granger D.N.: Laser doppler H2 Clearance, and Microsphere estimates of mucosal blood flow. Am J Physiol 1986;249:G221-G227.
20. Igarashi Y, Al M, Saito R. Observation of the tooth support dynamics. Part 1. Non-Contact Sensor System. J Jap Prosth Soc 1989;24:69-81.
21. Igarashi Y, Al M, Saito, R. Observation of tooth support dynamics. Part 2. Measurements of tooth mobility and motility. J Jap Prosth Soc 1981;24:37-45.
22. Kurashima K. The viscoelastic properties of the periodontal membrane and alveolar bone. J Stomatol Soc 1963:30:361-385.
23. Soderholm G, Egelberg J. Morphological changes in gingival blood flow vessels during developing gingivitis in dogs. J Period Res 1973;8:16-20.
24. Gaengler P, Merte K. Effects of force application on periodontal blood circulation. A vital microscopic study in rats. J Period Res 1983;18:86-92.
25. Forsslund G. The Structure and function of the capillary system in the gingiva in man. Parodont 1960;4:137-147.
26. Nuki K, Hock J. The organization of the gingival vasculature. J Period Res 1974;9:305-313.
27. Holloway GA Jr. Laser doppler measurement of cutaneous blood flow, In Non-invasive physiological measurement, Vol. 2, Rolf P, Ed., London, New York, Paris, San Diego, San Francisco, San Paulo, Sydney, Tokyo, Toronto: Academic Press, 219-246, 1983.
28. Gush GJ, King TA, Jaysom MIV. Aspects of laser light scattering from skin tissue with application to laser doppler blood flow measurement. Phys Med Biol 1984;29:1463-1476.
29. Salerud G, Tenland T, Nilsson GE, Ake P. Rhythmical variation in human skin blood flow. Int J Microcirc Clin Exp 1983;2:91-102.
30. Low PA, Neumann C, Dyck PJ, Fealey RD, Tuck RR. Evaluation of skin vascular reflexes by using laser doppler velocimetry. Mayo Clin Proc 1983:58:583-592.
31. Minkoff R, Engstrom TG. A long term comparison of protein turnover in subcrestal vs supracrestal fiber tracts in the mouse periodontium. Archs Oral Biol 1979;24:814-824.
32. Deporte DA. A Quantitative comparison of collagen phagocytosis in periodontal ligament and transseptal ligament of the rat periodontium. Am J Orthod 1984;85:519-522.
33. Page RC, Ammons WF. Collagen turnover in the gingiva and other mature connective tissue of the marmoset saguinus oedipus. Archs Oral Biol 1974;19:651-658.
34. Sodek J. A comparison of the rats of synthesis and turnover of collagen and non-collagen protein in adult rat periodontal tissues and skin using a microassay. Archs Oral Biol 22:655-665.
35. Iljima T, Imamura M, Tobe T. Measurement of cerebral cortex blood flow by temperature-controlled thermoelectrical flowmetry. Resp and Circ 1987;35:161-164.
36. Wunderlich RW, Folger RL, Giddon DB, Ware BR: Laser doppler blood flow meter and optical plethysmograph. Rev Sci Instr 1980;51:1258-1262.
37. Hellem S, Jacobson JS, Nilsson GE, Lewis DH. Measurement of Microvascular blood flow in cancellous bone using laser doppler flowmetry and 133 Xe - clearance. Int J Oral Surg 1983:12:165-177.