THE DIRECTION OF TOOTH MOVEMENT WITHIN THE PERIODONTAL SPACE

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THE teeth are constantly subjected to forces of varying magnitude, duration, frequency and direction. Even when the jaws are at rest the teeth are subjected to gravitational forces and those generated by the lips (Parfitt, 1961) and the tongue (Gould and Picton, 1963, Lowe *et al.*, 1970). During functions such as deglutition and speech (Gould and Picton, 1963) and mastication (Lewin 1969), forces are generated which cause the teeth to be displaced in their sockets. Some of these displacements can be demonstrated on oscillographs, an example of which is shown in Fig. 1.

These forces are transmitted through the teeth to the surrounding alveolar bone by the contents of the periodontal space between the teeth and the bone; or they may be dissipated within the periodontal space.

The forces acting on the teeth during function have been classified according to their origin as direct or indirect (Dreyer and Lewin 1967). Direct physiological forces are derived from the lips and cheeks (Lear *et al.* 1965) and the tongue. Fig. 2A is an oscillograph showing simultaneous recordings of the displacements of an upper premolar in response to light tongue thrusts. Direct forces may also stem from extra-oral sources such as the fingers or force applicators. Fig. 2B is a displacement oscillograph recorded from a tooth to which a vibrator was applied; a sinusoidal oscillating displacement (a) is superimposed on the overall displacement (b).

Indirect forces stem from the muscles of mastication and those which maintain cranial posture. These forces give rise to oscillating displacements of the tooth in its socket. Fig. 3A shows such displacements during the contraction of the muscles of mastication. The oscillographs were obtained during clenching on rubber dam. Fig. 3B illustrates the oscillating displacements of a tooth when the neck is extended (a) and then flexed (b) while the subject is in this clenched position.

Mühlemann (1951) studied the amount of tooth displacement which occurred when the *magnitude* of the applied force was varied. He suggested that a force of magnitude 500 gm/wt (T.M. 500) is suitable for appraising the variations in displacement responses in health and disease (1954, 1967). Picton (1965) showed that if the magnitude of a force applied to a tooth exceeds 50-100 gm/wt there is a temporary displacement of the alveolar bone in addition to the tooth displacement.

The transfer or dissipation of forces of lower magnitude is not fully understood, although the photoelastic studies of stresses in models (Glickman *et al.* 1970) may shed some light on the problem. Körber (1962) classified the forces acting on the teeth according to the *time* in which they are active. In this way they may be classified as static, quasi-static and impulsive. When forces acting on a particle maintain it in equilibrium they are said to be static (Ferrence *et al.* 1966); and those which act on a particle causing it to move slowly are referred to as quasi-static by Körber and Körber (1967), and as semi-static by Mühlemann (1967). In contrast, while ideal impulsive forces are infinitely large and act for an infinitely short period of time, for practical purposes they are those with rapidly changing magnitude and direction: that is, in milliseconds. Ferrence *et al.* (1966) defined an impulsive force by the equation:

$$\text{Impulse} \equiv \text{Force} \times \text{Time},$$

for a uniform force, where force is equal to mass multiplied by acceleration.

Fig. 4A demonstrates the effect of a quasi-static force applied to a transducer

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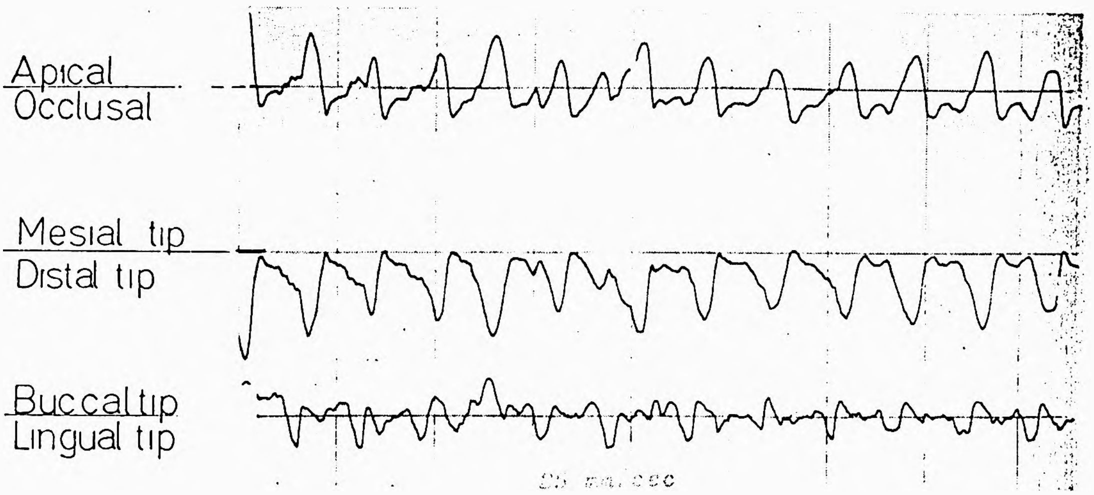
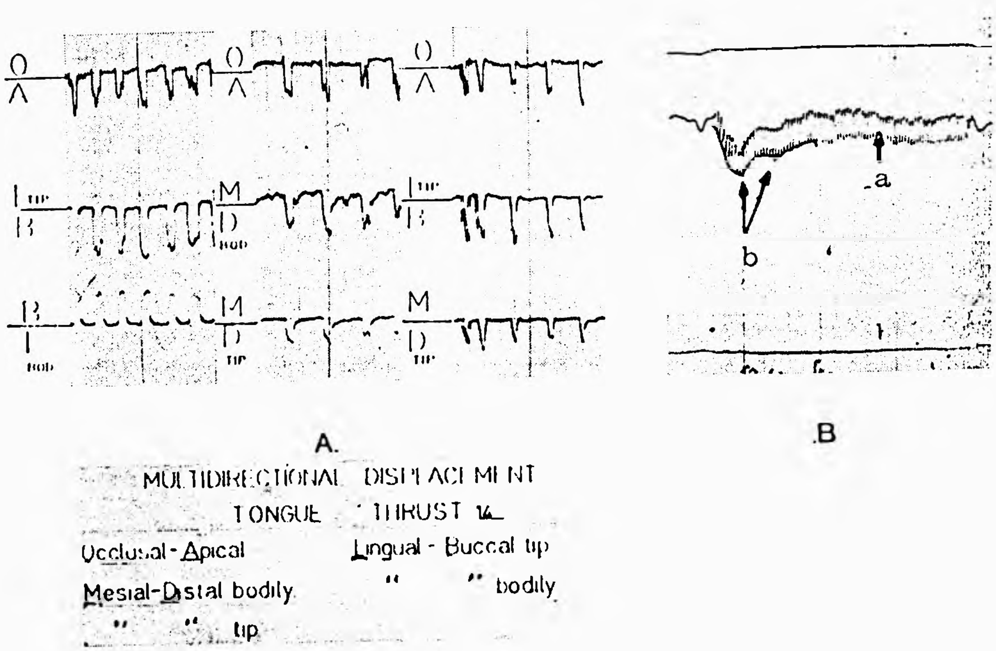

Apical
Occlusal
Mesial tip
Distal tip
Buccal tip
Lingual tip

FIG.1.


O
A
M
D
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B
a
b
MULTIDIRECTIONAL DISPLACEMENT
TONGUE THRUST
Occlusal - Apical
Lingual - Buccal tip
Mesial-Distal bodily
" " bodily
" " tip

FIG.2..

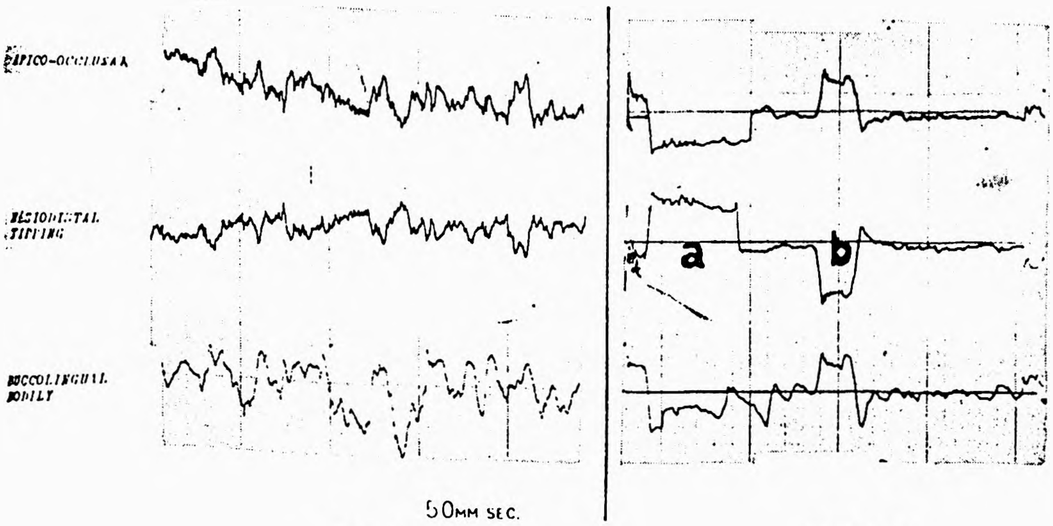


FIG.3A. FIG.3.B.

Fig. 1. The Displacements of an Upper Premolar. The three oscillographs are simultaneous recordings of three independent directions of tooth displacement detected by an omnidirectional transducer. They represent the displacements of an upper premolar when a bolus of rubber dam is confined to the occluding surface of the tooth during chewing. The cheeks and tongue are kept away from the tooth. On the upper graph, apical or intrusive displacements are read above the X-axis; occlusal or extrusive displacements are read below the X-axis. On the middle graph, mesial and distal tipping displacements are recorded above and below the X-axis respectively. On the lower graph, buccal and lingual tipping displacements are recorded above and below the X-axis respectively.

Fig. 2A. Tooth Displacements with Light Tongue Thrusts. Five independant channels were used to obtain these oscillographs. The direction of displacement is marked above and below the X-axis respectively. In this subject, at that time, the tooth was displaced in an apico-disto-buccal direction. The displacement is composed of tipping moments and bodily displacements.

Fig. 2B. An Oscillogram Showing the Displacement of a Tooth Caused by a Vibrating Applicator. The sinusoidal curves (a) are caused by the 60 cycle/minute vibrations of the applicator, while the displacements (b) are due to variations in the force used to maintain contact between the vibrator and the tooth.

Fig. 3A. Some Effects of Muscular Contraction on Tooth Displacement. The oscillographs were obtained while the subject clenched on a piece of rubber dam confined to the occluding surface of an upper premolar. An oscillatory displacement is superimposed on the overall tooth displacement.

Fig. 3B. Some Effects of Cranial Posturing on Tooth Displacement. The oscillographs were recorded in the same manner as in Fig. 3A. In addition, the subject extended (a) and flexed (b) her head.

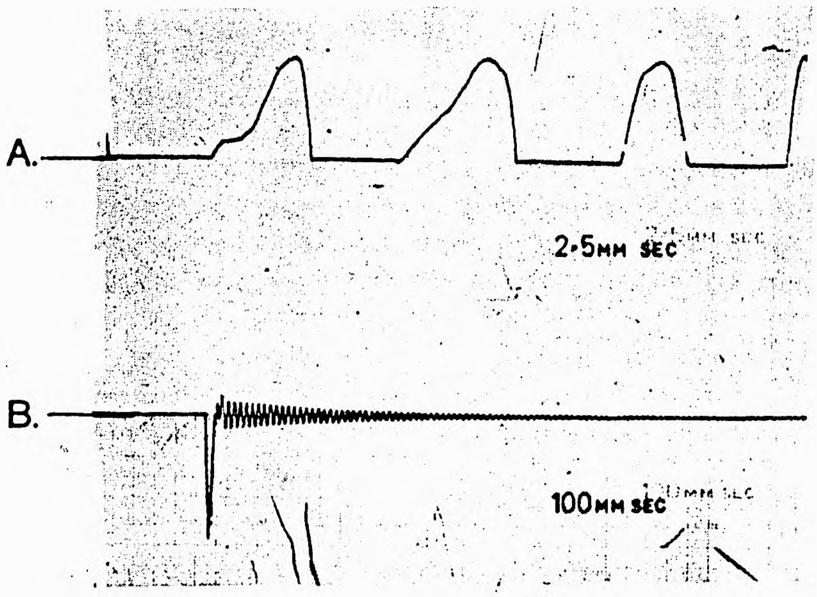


FIG.4.

FIGS. 4A AND B. MECHANICAL DISPLACEMENTS ON A TESTING JIG. A transducer was attached to a testing jig. When a quasi-static force of 6-8 seconds duration was applied a deflection of 48 microns was recorded (A). An impulsive force of 10 milliseconds duration resulted in a displacement of 54 microns (B).

on a testing jig. The duration of the displacing force varied between six and eight seconds. Fig. 4B is the oscillograph which resulted when a 10 millisecond impulsive force was applied to the same transducer on the testing jig. The effect of the time interval between successive displacements has also been studied, and Parfitt (1961) showed that if it is short enough the tooth does not have time to recover from successive displacements. These experiments, using impulsive forces, were repeated and confirmed in the present study (Fig. 5).

Picton (1962) tried to control the *direction* of an applied force. He produced an intrusive force on a tooth by measuring its mesial and distal displacement while he applied the force. Parfitt (1967) attempted to apply forces in an axial direction by measuring the labial and palatal displacements while he applied the force. Elsewhere in the literature reviewed by Mühlemann (1967) references are made to the *general direction* of tooth displacement in response to applied forces. Lewin (1970) described a transducer capable of registering the directional components of *in vivo* tooth displacements. Of the six possible displacements three are shown in Fig. 1 and five in Fig. 2A.

It is unlikely that static forces act on the teeth in a living subject. The oscillatory displacements that occur with muscle contraction and the pulsatory displacements of a tooth in its socket in rhythm with the carotid pulse (Hofmann and Diener 1963) suggest that forces of physiological origin are composed of a great number of impulsive forces of varying *direction*, magnitude, duration and frequency. Externally generated quasi-static forces have been widely used to gain information regarding the periodontal responses to applied forces; in these instances teeth are mechanically displaced and the displacement is measured by mechanical meters (Mühlemann, 1954), but it has not been shown that the direction of

CONTACTLESS TRANSDUCER

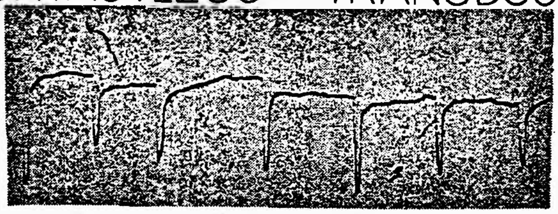
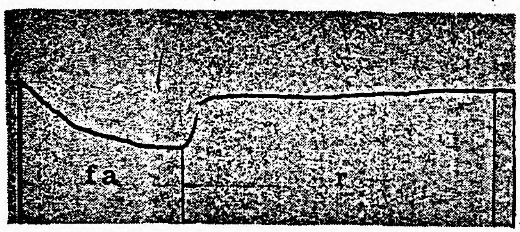


FIG.5.



1·18 SEC 200 GM ASYMPTOTIC RETURN 3·48 SEC.

FIG.6.A.

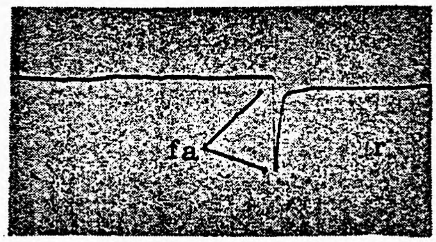


FIG.6.B.

FIG. 5. SUCCESSIVE DISPLACEMENTS DETECTED WITH A CONTACTLESS TRANSDUCER. The transducer was in close proximity to an upper premolar. The tooth was lightly tapped with an opposing tooth. The displacement is progressive as the tooth does not have time to return to its original position.

FIGS. 6 A AND B. THE ANALYSIS OF THE PERIODONTOGRAM (see text). 6A. A periodontogram obtained using a quasi-static force. Period of force application (fa); period of recovery (r). 6B. A periodontogram obtained when using an impulsive force.

displacements in response to forces of physiological origin is the same as the response to mechanically generated forces.

Picton (1962) and Picton and Davies (1967) used the muscles of mastication to produce force in their experiments. However, their method of positioning the transducers in the mouths of their subjects prevents the opposing teeth coming into close approximation or contact. At levels of contact other than those used by them the direction of tooth displacement may be different.

Fig. 1 demonstrates a decided distal tipping while a piece of rubber dam is chewed on. The mesial inclination of the molar teeth and the predominant mesial displacements noted by Picton (1962) do not suffice to substantiate the thesis that there is a predominant unidirectional mesial resultant of force acting on the teeth. Other factors need to be considered (Dreyer and Lewin 1967).

If the amount of displacement of a tooth is plotted against the magnitude of an applied force, a graph called a 'tooth movement curve' is produced (Mühlemann, 1954). When such curves result from electronic devices they are called periodontograms and can be recorded directly by an oscilloscope or an oscillographic recorder. A transducer used to sense tooth displacement may be placed in contact with, attached to, or a small distance from the tooth. The last-mentioned is called a contactless transducer by Körber and Körber (1967). In a periodontogram the time element is automatically recorded because the calibrated paper advances at a known speed.

The tooth movement resulting from the application of a force recorded on a periodontogram may be described as a graphic representation of the restraining influence of the supporting structures on a tooth which is being displaced by an applied force.

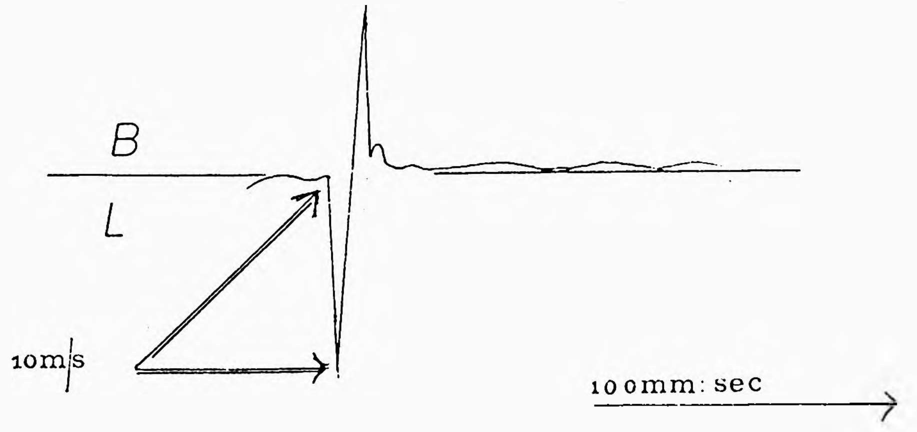


FIG.7.

FIG. 7. A PANTOGRAPHIC TRACING OF A PERIODONTOGRAM (IMPULSIVE FORCE). The rebound phenomenon was recorded from a contactless transducer. The same phenomenon can be recorded from an attached transducer (Fig. 8). The 2X enlarged tracing was made from the original recording with a pantograph.

It has rather characteristic features irrespective of the point on the crown of the tooth where the displacement is measured. Fig. 6A, which analyses a typical periodontogram, was obtained with a contactless transducer. It was suggested by Mühlemann (1951) that the tooth is initially displaced within the periodontal space. According to Picton (1965) and Bien (1966), there is a tissue and fluid displacement from the region of compression to the region of tension of the periodontal fibres at this time. There is then an incremental reorientation of the tensioning periodontal fibres within the periodontal space; and this is followed by a displacement of the bone of the socket which Parfitt (1961) has shown to be in linear proportion to the log of the force applied. On release of this force there is an accelerated recoil, followed by a relatively slow 'asymptotic' return. The former is attributed to a recoil of the bone; the latter results from redistribution of fluid and tissue contents of the periodontal space. Kurashima (1965) attributed these changes to the visco-elastic properties of the contents of the periodontal space. Parfitt (1961) suggested that in the slow asymptotic phase the distance moved is a logarithmic function of time.

When an impulsive force is applied to a tooth the periodontogram which results may have some of the features of one produced by a quasi-static force. Fig. 6B is a periodontogram obtained by using an impulsive force on a tooth in proximity to a contactless transducer. There is the expected rapid initial displacement of 10 millisecond duration. This is followed by a 20 millisecond recoil to the asymptotic phase; its duration is shorter (0.5 seconds) than the asymptotic phase in the quasi-static periodontogram of Fig. 6A.

Fig. 7 is a pantographically enlarged (2X) tracing of a periodontogram obtained with a contactless transducer and an impulsive force. The impact was applied on the labial face of an upper premolar. The rapid displacement towards the palate, marked L, was followed by a rapid rebound towards the cheeks, marked B. This was followed by another recoil to the phase of asymptotic return. The impact lasted for 10 milliseconds, the rebound and recoil 10 milliseconds, and the asymptotic return 0.5 seconds. The dif-

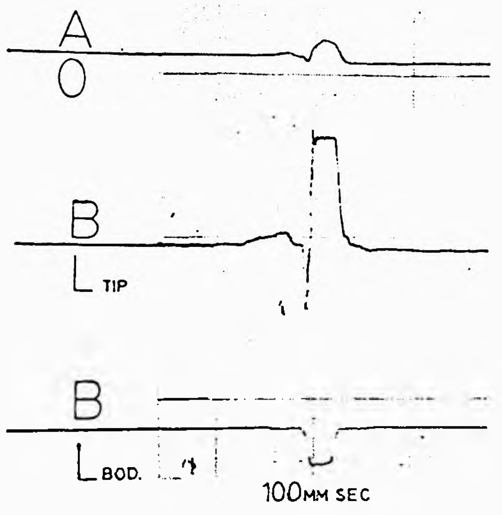


FIG.8.

FIG. 8. THE RESOLUTION OF AN IMPULSIVE FORCE. The impulsive force is resolved into vectors by the restraining influence of the periodontium. The displacement was recorded on three independant directional channels with an omni-directional transducer. The sensor was attached to the tooth being investigated.

ferences in the displacements shown in Figs. 6B and 7 may be due to the magnitude, time and direction of the applied impulse, or it could be due to differences in periodontal response to non-uniform impulsive forces.

Fig. 8 is a periodontogram recorded simultaneously on three independent directional channels. An impulsive force was used. The impact was applied to the labial face of an upper premolar to which an omnidirectional transducer was attached. On the apico-occlusal channel (A/O) there is a short initial extrusive or occlusal displacement followed by an intrusive or apical displacement. On the bucco-lingual tipping channel (B/L tip) there is a relatively slow, then rapid palatal tipping displacement followed by a rapid buccal rebound. Just below the greatest buccal deflection on oscillation occurs which persists while the tooth remains buccally displaced for 50 milliseconds. There is then a rapid 12 millisecond recoil to a very short asymptotic phase.

The oscillograph in this channel differs from that obtained when the same channel was used to record mechanically-produced displacements on the testing jig (Fig. 4). On the channel recording bucco-lingual bodily displacements (B/L bod.), a bodily palatal displacement occurs which has the same duration as the oscillation in B/T. tip. channel. The three simultaneously recorded periodontograms differ from each other. Because the impulsive force is common to all three, the variations may be attributed to the restraining influence of the periodontium which dissipates the impulsive force; the initiating impulsive force is resolved into impulsive forces with different directional scalars by the restraining influence of the periodontium.

In addition to the oscillations of a tooth within the periodontal space, the tooth itself may oscillate when struck with an impulsive force. These oscillations may be detected when resistance strain gauges are cemented to enamel of teeth *in vivo*. Körber and Körber (1967) observed them from transducers cemented into dentine. Fig. 9A shows a sustained palatal displacement with a 200 cycle oscillation; the latter may be due to an oscillation of the tooth substance itself, the tooth oscillating within the periodontal space, or the frictional contact of the force applicator with the tooth.

Fig. 9B is an oscillogram showing a similar oscillation in the sustained portion of the deflection (a). The oscillogram was

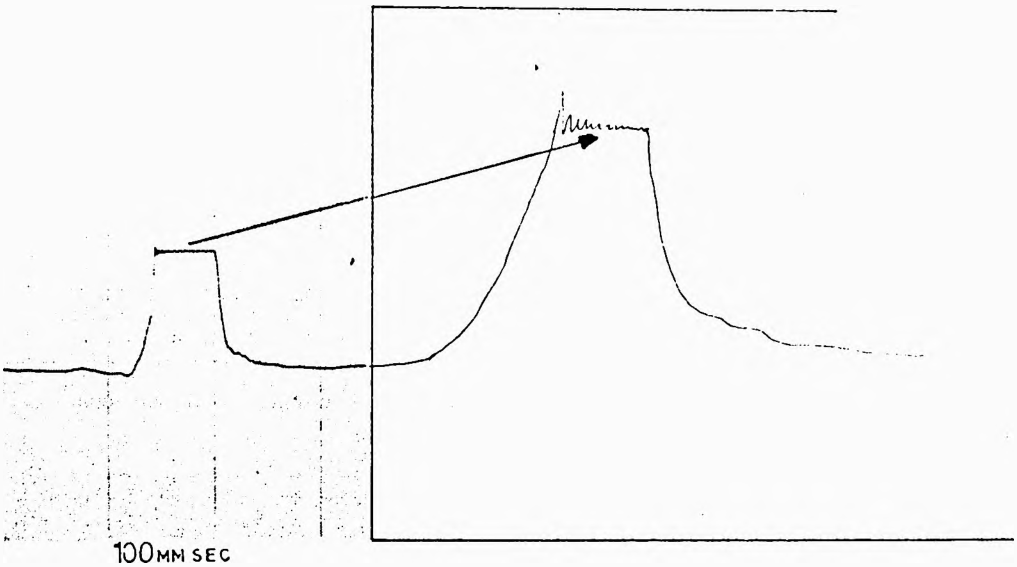


FIG. 9A

FIG. 9A. OSCILLATIONS OCCURRING DURING DEFLECTION.

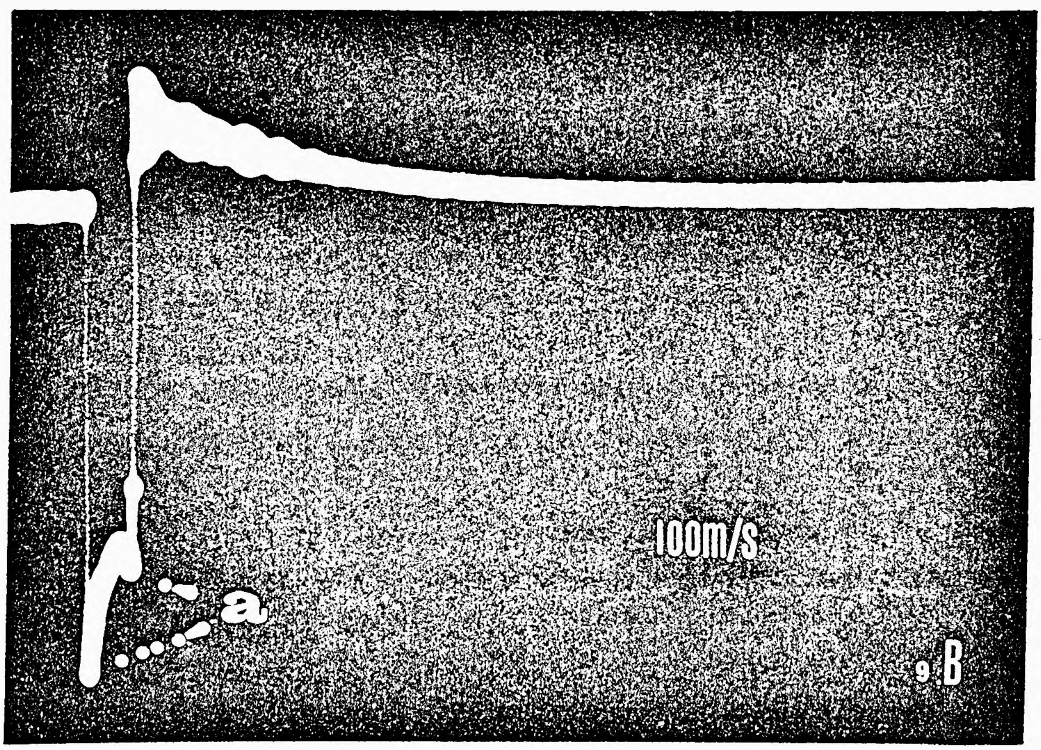


FIG. 9B. AN OSCILLOGRAM OF AN IMPULSIVE FORCE APPLIED TO A TRANSDUCER ON A TESTING JIG.

obtained from a transducer on the testing jig and is attributed to frictional contact.

A single periodontogram gives a one-dimensional representation of the periodontium's three-dimensional restraining influence, which is composed of many vectors with different directional scalars.

If these could be resolved for a given applied force it should be possible to determine which part of the periodontium is most affected by the applied force. In view of the many and varied responses to the application of force to the teeth, and the clinical implication of the resultants of the forces acting on, and through the teeth (Dreyer and Lewin, 1967), an omnidirectional transducer has been designed and produced, and is in use for further investigations (Lewin 1970).

SUMMARY

The forces that act on the teeth have been described in terms of their origin, magnitude and period of activity. Although attempts have been made to apply forces with unidirectional resultants to a tooth, the resolution of the direction of tooth displacement in response to applied forces of intra- or extra-oral origin requires further clarification.

The restraining influences of the periodontium on tooth displacement caused by forces acting on the teeth have been interpreted from the periodontogram. Multiple, simultaneous periodontograms show some of the directional aspects of tooth displacements and offer a means of interpreting such movement.

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REFERENCES

BIEN, S. M. 1966. The pressure gradient in the periodontal vasculature. Transactions of the New York Academy of Sciences Ser. 11, vol 28, 4. pp 496-506.

DREYER, C. J. and LEWIN, A. 1967. Chronic Periodontitis. *J. dent. Assn. S. Africa*, vol. 22, 133-170.

FERRENCE, M., LEMON, H. B., STEPHENSON, R. J. 1966. *Analytical Experimental Physics*. 3rd ed. University of Chicago Press.

GLICKMAN, I., ROEBER, F. W., BRION, M., PAMEIJER, J. A. N. 1970. Photoelastic analysis of internal stresses in the periodontium created by occlusal forces. *J. Periodont.* vol. 41; 1, 30.

GOULD, M. S. E., PICTON, D. C. A. 1963. An evaluation of a method of measuring forces exerted by the tongue on the teeth. *Brit. dent. J.* vol. 114; 5, 175.

HOFMANN, M., DIEMER, R. 1963. Die pulsation des zahnes. *Dtsh Zahnartzl Zschr* vol. 18; 1268.

KÖRBER, K. H., KÖRBER, E. 1967. *Patterns of Physiological Movement in Tooth Support*. The Mechanisms of Tooth Support, 148; J. Wright and Sons, Ltd.

KÖRBER, K. H. 1962. Elektronisches messen der zahnbeweglichkeit. *Dtsh Zahnarztl Zschr*, vol. 16, 605.

KURASHIMA, K. 1965. Viscoelastic properties of periodontal tissue. Bull. *Tokyo Med., Dent.* University, vol. 12, Kokubyo Z. 30.

LEAR, C. S. C., CATZ, J., GROSSMAN, R. C., FLANAGAN, J. B., MOORREES, C. F. A. 1965. Measurement of lateral muscle forces on the dental arches. *Arch. oral Biol.* vol. 10, 669-689. Pergamon Press.

LEWIN, A. 1970. The direction of tooth movement within the periodontal space: the omnidirectional transducer, design and construction. *J. dent. Assn. S. Africa*, vol. 25, no. 9.

LEWIN, A. 1969. The direction of tooth movement in response to masticatory forces. *J. dent. Res.*, 49:699.

LOWE, R. D., KYDD, W. L., SMITH, D. 1970. Swallowing and resting forces related to lingual flange thickness in removable partial dentures, *J. pros. Dent.* 23, 3; 279.

MÜHLEMANN, H. R. 1951. Periodontometry. A method for measuring tooth mobility. *Oral Surg, Oral Med, Oral Path*, vol. 4, 1220.

MÜHLEMANN, H. R. 1954. Tooth mobility. The measuring of initial and secondary tooth mobility. *J. Periodont.*, vol. 25; 22.

MÜHLEMANN, H. R. 1967. Tooth mobility. A review of clinical aspects and research findings. *J. Periodont.* vol. 38, 686-708.

PARFITT, G. J. 1961. The Dynamics of a tooth in function. *J. Periodont.*, 32; 102.

PARFITT, G. J. 1967. *The Physical Analysis of the Tooth Supporting Structures*. The Mechanisms of Tooth Support, 154, J. Wright and Sons Ltd.

PICTON, D. C. A. 1962. Tilting movements of the teeth during biting. *J. dent. Res.* vol. 41, 1252.

PICTON, D. C. A. 1965. On the part played by the socket in tooth support. *Arch. Oral Biol.* vol. 10, 945.

PICTON, D. C. A., DAVIES, W. I. R. 1967. *Distortion of the Socket with Normal Tooth Mobility*. The Mechanisms of Tooth Support. pp 157, J. Wright and Sons.