CHRONIC PERIODONTITIS

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PART 1.

THE HEALTH OF THE PERIODONTAL TISSUES

SUMMARY

The terms "remote" and "local aetiological" factors are described. It is suggested that aetiology be used in its wider sense to include predisposing and precipitating factors. The terms "superficial" and "deep environment" in the periodontal tissues are used to indicate the anatomical sites which may be affected by periodontal disease.

Previous investigations indicate that the primary site affected by the aetiological factors responsible for many of the periodontal syndromes may be the epithelium or the underlying soft tissues. It is suggested that the role of the calcified structures in relation to periodontal syndromes requires further investigation.

The term "healthy tissue" means that its inherent characteristics and the environmental factors acting on it give rise to a co-ordinated cellular structure and metabolism. Under these circumstances its intra- and extracellular environment maintains an organised physical and chemical relationship which is capable of purposeful variation.

The intracellular environment allows the cells to utilise their metabolites for essential anabolic and catabolic processes which may be adversely affected by inherited and physico-chemical factors. Some inherited metabolic disorders affectting the intracellular environment already have been described (Harper 1965). It is possible that better experimental techniques may reveal additional structural disorders which are responsible for disturbed intracellular metabolism. The majority of known intracellular environmental disturbances are associated with physico-chemical factors.

The extracellular environment is influenced by remote and also by local factors. These are not always easily separated but the former generally affect the homeostatic mechanisms designed to limit the variations in the extracellular environment of all constituent cells of the organism. Factors which tend to alter only the extracellular environment of a limited number of cells are considered local.

If these statements are true, then variations of the remote factors affecting the periodontal tissues of human beings may alter the extracellular environment of these cells either to stimulate, maintain or depress their metabolic processes.

An alteration of these remote factors beyond their optimal ranges eventually must be mirrored in the health of the periodontal tissues. Mild alterations which cause no obvious morphological changes but nevertheless produce metabolic disturbances, are, probably, to some extent responsible for the term 'lowered resistance.' Profound variations of the remote factors may, on the other hand, alter the metabolism of the affected cells to such an extent that frank disturbances in the

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cellular elements of the periodontium are produced.

Thus remote and local factors both play a part in maintaining the health of the periodontal tissues and may, either singly or collectively, alter cellular environment. All such alterations do not necessarily produce abnormal metabolic processes which cause pathological states of affected cells. Pathological changes, however, will occur *in all age groups* if the environmental changes are of sufficient magnitude and duration.

There is a variety of pathological lesions which collectively are referred to as periodontal disease, periodontal syndromes, pyorrhoea alveolaris, or chronic periodontitis. The clinical and histological picture of chronic periodontitis does not necessarily indicate either the initial or the intermediate steps of its pathogenesis. Hence an inflammation in the overlying soft tissues of the periodontium—gingivitis—may in fact be an initial stage in its development, yet these inflammatory changes are not generally so classified. By the same token the loss of periodontal bone, though unassociated with the other manifestations, for example pocket formation, may be a stage in its development.

In chronic periodontitis many of the pathological changes appear to share common precipitating or predisposing factors. It therefore is unlikely that any single factor acting independently can be wholly responsible for this classical syndrome.

The complex mechanism of the pathogenesis of chronic periodontitis necessitates that the term "aetiology" be used in its wider sense to include predisposing and precipitating factors (Fig. 1).

In the same way that the aetiology of periodontal disease may be a combination of many factors, so may the primary site at which the initial lesion occurs, vary. The numerous aetiological factors held responsible for periodontal syndromes do not all initially affect the same tissues of the periodontium. Those primarily affected and the pathogenesis of the various periodontal syndromes may be usefully correlated as suggested in Fig. 2. The terms "superficial" and "deep environment" and "periodontal modula-

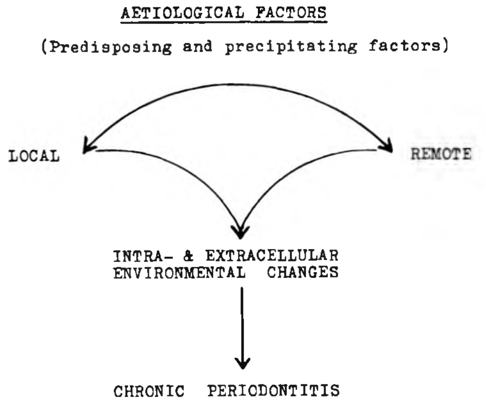

FIG. 1.

tion" have been introduced to indicate certain, as yet undefined, changes in the periodontal tissues.

The terms "superficial" and "deep" as applied to environmental alteration in the periodontal tissues (Fig. 3) indicate the different sites which may be affected by the aetiological factors. Although these terms are employed to differentiate the periodontal tissues into two anatomical levels, they may also be used to indicate the sites where reversible, and possibly irreversible changes occur in the periodontal tissues. Thus "superficial" environmental alterations refer to changes in the tissues not directly affecting the attachment of tooth to bone; they are reversible and disappear when the aetiological factors are removed.

Disturbances affecting the attachment apparatus are referred to as "altered deep environment." These disturbances may be extensions from the superficial form, or triggered *de novo* in the attachment apparatus. Alteration in the deep environment may result in changes which are either reversible or irreversible. If they are reversible the affected tissues will heal and leave no observable change after the aetiological factors have been removed. If, however, the effects of the disturbance are irreversible, then the altered attachment apparatus can no longer be considered normal for that particular age group, nor can it spontaneously heal even when the aetiological factors have been eliminated.

Despite the doubt concerning the mechanism whereby certain local aetio-

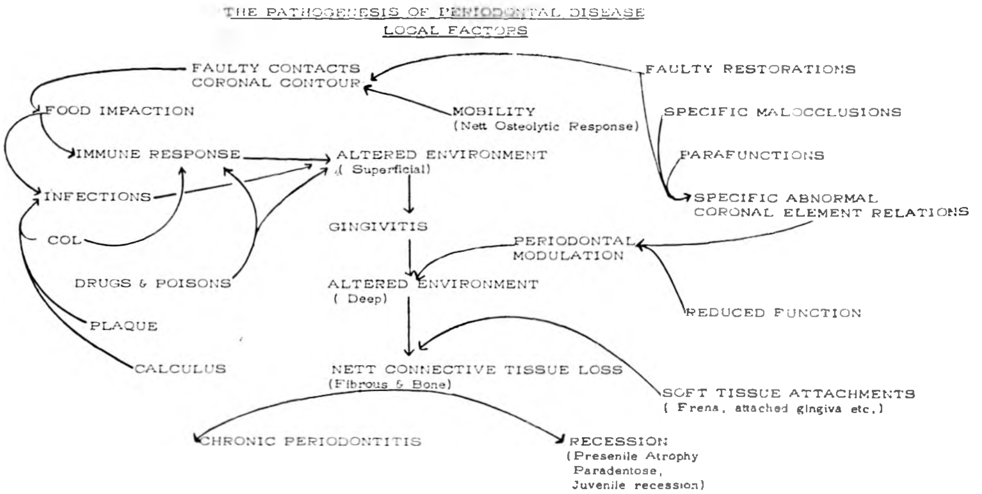

FIG. 2.

logical factors alter the cellular environment, or how this altered environment eventually affects the metabolism of the cells of the periodontal tissues, it is evident that such changes do occur. Since many apparently unrelated local factors may play a part in the production of chronic periodontitis, it is suggested that environmental alteration is the common denominator in the pathogenesis of the disease.

"Periodontal modulation", which refers to the changes that occur in the periodontal ligament as a result of functional stresses, will be discussed later.

If the aetiological factors are grouped according to the site at which they have their initial effect, it is clear that they may primarily affect the epithelium, its underlying connective tissue, the other soft tissue components of the periodontal membrane or the calcified structures. Thus

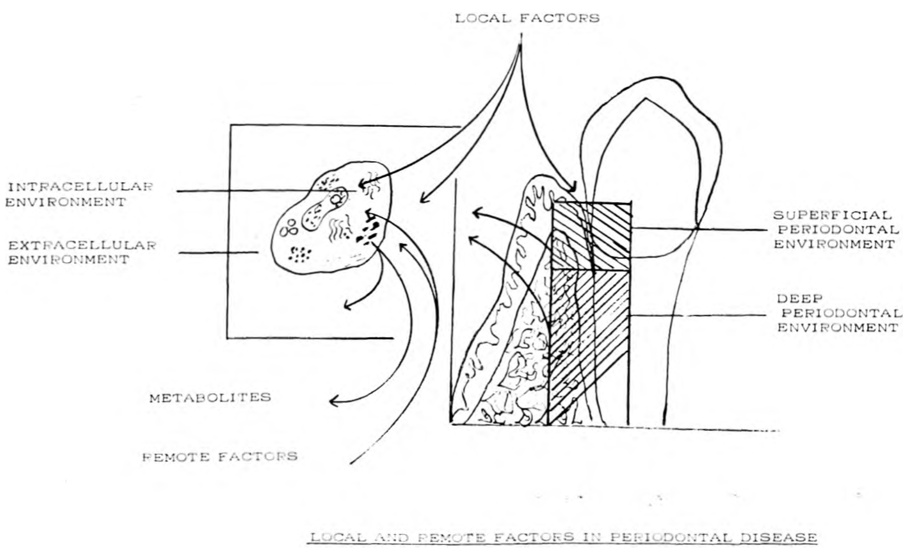

FIG. 3.

Cohen (1959) postulated that the initial lesion of pyorrhoea alveolaris may be due to the friable nature of the col epithelium. Furthermore, crevicular epithelium may be damaged initially by food impactions, tartar, plaque, endo- and exotoxins and other irritants and thus cause the primary lesion.

Burch and Jackson (1966) suggested that auto-immunity plays a part in the production of periodontal disease by the production of auto-antibodies which affect the cells normally responsible for maintaining the attachment of tooth to bone. These authors therefore suggest that this aetiological factor acts primarily on the connective tissue of the periodontal membrane. In addition, foreign proteins have been implicated in immunological studies of periodontal disease (Rizzo, Mitchell 1966).

The soft tissues probably are also the site of action of various hormonal imbalances, blood dyscrasias, drugs and vitamin deficiencies. All these and many other aetiological factors that have been suggested by Held (1963) act primarily on the epithelium and adjacent soft tissues, either to predispose to or precipitate the pathological changes associated with periodontal syndromes.

Since the role of the calcified structures in relation to the periodontal syndromes has perhaps not received the attention it deserves, some of the factors affecting the maintenance of these structures and their relationship to some of the soft tissues are discussed in subsequent parts of this paper.

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PART 2.

THE DEPOSITION, REMOVAL AND MAINTENANCE OF BONE

SUMMARY

The concept of bone balance is discussed. The systemic and local factors which affect bone balance are described. It is suggested that any factor which tends to produce a negative bone balance can predispose to or precipitate the loss of periodontal bone.

Vital bone is constantly undergoing reformation. If the volume of its calcified tissue is to be maintained two opposed dynamic processes, resorption and deposition, must be in equilibrium to preserve a bone balance or steady state. Any alteration in the relationship between these processes affects the volume of calcified tissue and consequently the morphology of the bone.

If the resorptive processes are greater than those of deposition, the bone will be in a negative balance; the effect of this on the morphology of a bone depends on the degree of imbalance as well as on the time during which the condition prevails. If there is a marked preponderance of one phase over the other, the time for an overall change to take place is short. The most rapid changes occur if the osteoclastic activity is increased and the osteoblastic activity decreased. If there is sufficient time lapse, the extent to which the osteoclastic activity outstrips the osteoblastic processes need be only small to produce a maximum change. Conversely, an osteoblastic response is evident in a comparatively short time if the osteoclastic activity is decreased while that of the osteoblastic is increased. Given enough time, a positive bone balance will result with a small increase of the osteoblastic phase over the osteoclastic phase.

A localised negative bone balance can lead to a complete loss of bone such as may be seen in the jaws after the removal of

TABLE 1.—BONE BALANCE

Negative: Localized complete loss of bone or more generalized osteoporosis. Dependent on duration and degree of imbalance.	(1) Increased osteoclastic activity. (2) Decreased osteoblastic activity. (3) Combination of 1 and 2.
Steady State:	Steady state between osteoblastic and osteoclastic activity.
Positive: Localized or generalized osteosclerosis. Dependant on duration and degree of imbalance.	(1) Increased osteoblastic activity. (2) Decreased osteoclastic activity.

teeth. If it is more generalised it leads to osteoporosis*.

Similarly if osteoblastic activity exceeds osteoclasis the end result will be localised or generalised osteosclerosis (Table 1).

The relative osteoblastic and osteoclastic activities determine whether the bone is in a steady state (balance), a negative or a positive balance. These balances are independent of the amount of resorption and deposition of bone, provided they occur at the same rate and within given limits of time.

The maintenance, loss or reformation of bone around the teeth is governed by the local osteolytic and osteoblastic processes. As an imbalance between them is a characteristic feature of many periodontal syndromes, any of the factors that may give rise to such imbalance may play a part in the pathogenesis of these syndromes.

SYSTEMIC FACTORS

(1) *Dietary*

An adequate intake, absorption, transfer and utilisation of all the nutrients from the gastrointestinal tract are important for the growth, development and maintenance of bone. Since most of the important aspects of this subject are well documented, only certain features of metabolic adaptation to dietary variation will be discussed.

Although there are certain minimal requirements regarding the type and quantity of food ingested, the metabolic processes of humans exhibit a remarkable degree of adaptation to qualitative and quantitative variations in food intake. Thus on a restricted caloric intake the individual loses weight as protein and depot fat are employed to maintain the anaerobic and aerobic metabolic processes. During such a phase a minimum amount of carbohydrate is utilised.

By other metabolic processes the human can also cope with certain variations in the mineral intake.

Irving (1950) found that a group of individuals who had been on a calcium intake of 1,160 mg. per day lost 2·0 gms. of calcium during the first eight weeks when their intake was reduced to 500 mg. per day. During the next nine weeks, however, they stored 3·2 gms. of calcium on the same intake.

There are instances where the compensatory mechanisms against excess of certain nutrients are less effective. Experimentally, a hypervitaminosis D produced a hypercalcaemia which was most marked during the first five days; at the same time there was a less constant and less pronounced hyperphosphataemia. Normal calcium concentrations were recorded by the fifth day of the experiment. The excess of vitamin D led to widespread calcification in soft tissues such as the trachea, heart, aorta, kidney and lungs. This condition developed after treatment had ceased.

In avitaminosis D the parathyroid glands may become enlarged (Weinmann

*A reduction in the amount of bone without any change in its chemical composition.

and Sicher 1955). In the earlier stages there is increased secretion from these glands with a resultant increased excretion of phosphorus. Calcium is withdrawn from the bones to maintain the calcium-phosphorus balance in the blood. The treatment for a patient suffering from avitaminosis D is, of course, to administer vitamin D. Its indiscriminate use, however, is fraught with danger because of the intimate relationship of the parathyroids, calcium metabolism and this substance.

Excesses of vitamin A tend to influence adversely the moulding effect of the soft tissues on bone. This is an explanation given for the exostoses found with hypervitaminosis A. For this reason and those mentioned in connection with hypervitaminosis D, care must be exercised in the prescription of multivitamin preparations for the treatment of periodontal syndromes.

2 *Hormonal factors*

(*a*) *Parathyroid glands.* Rasmussen (1961) isolated the hormone of the parathyroid. This hormone has both a calcium mobilising and a phosphaturic activity in the same molecule. It is believed that the prime function of the parathyroid is to maintain, within narrow limits, the calcium ion concentration in the plasma. Parathyroidectomy produces hypocalcaemia, hyperphosphataemia, hypophosphaturia, hypocalciuria and a decrease in the number of osteoclasts in the bones of experimental animals. The hypocalcaemia is caused mainly by a lack of mobilisation of calcium from the bones, but it may also be due to the increased excretion by the kidneys and a reduced absorption from the gut. Heller *et al* (1950) showed that the injection of parathyroid extracts increases the rate of formation of osteoclasts and resorption of bone in all parts of the skeleton. Apart from the known effects of the parathyroid glands, a dysfunction can cause a loss of lamina dura (Gardner *et al* 1963). In this manner a hyperparathyroidism, even in its mildest form, may act as a predisposing factor in the loss of bone associated with periodontal syndromes.

(*b*) *Thyroid.* The secretions of the thyroid glands affect the growth and development of bone from an early age. Besides being associated with endochondral bone formation it also affects non-endochondral osteogenesis because of the generalised osteoporosis which is seen in hyperthyroid patients. According to the experimental evidence of Tapp (1966), thyroxine appears to increase bone resorption; and Frost (1963) stated that both resorption and deposition of bone are increased, the degree of variation being proportional to the severity of the thyroid dysfunction.

The isolation of calcitonin from the thyroid gland throws new light on the relation of this gland to calcium metabolism. Calcitonin lowers the plasma calcium and simultaneously lowers the plasma phosphate. It can perform these functions in nephrectomised animals. This suggests that the effect of calcitonin on calcium and phosphate levels in the blood is produced by their deposition in bone (Lancet annotations 1964). Despite the effects that thyrocalcitonin may have on bone balance, the experimental and the clinical evidence suggests that the negative bone balance of chronic periodontitis is more likely to be enhanced by a hyper- than by a hypo-function of the thyroid glands.

(*c*) *Ovarian steroids.* Ovarian steroid deficiency influences endochondral and intramembranous ossification in the growing skeleton. The degree to which it affects the various bones depends on their developmental stage. The administration of oestrogen inhibits growth of bone in all young animals. Cooke (1955) demonstrated that its prolonged use in human subjects may result in hyperossification. Bernick and Ershoff (1963) found that in rats it produces a sclerosis of the interradicular bone of the molar teeth. Anderson (1950) stated that atrophic processes which chiefly affect the spine of adult women are not signs of senility, but are due to a deficiency of oestrogens.

In the same way that some types of osteoporosis may be associated with oestrogen deficiences, so, too, may these deficiencies predispose to the loss of bone in chronic periodontitis.

(*d*) *Pituitary gland.* The results of hypophysectomy or the administration of pituitary extracts must be viewed in the light of the influence this gland exerts on the other endocrine glands. It was shown by Becks *et al* (1945) that endochondral bone growth stops after hypophysectomy; and by Walker *et al* (1952) that growth hormone restores this defect. The osteoporosis which may be associated with acromegaly suggests that hyperactivity of the pituitary gland could, in part, be responsible for a negative bone balance in the jaws.

(*e*) *Adrenal gland.* The adrenocortical hormones, cortisone in particular, produce osteoporosis in bone (Curtis *et al* 1954). Stafne and Lovestedt (1960) recorded an osteoporosis of the jaws associated with hypercortisonism. These observations suggest that an imbalance of the adrenal corticoids may either predispose to or precipitate a negative bone balance in the periodontal bone.

(3) *Congenital factors*

An acquired osteoporosis can only be associated with a negative skeletal bone balance which existed at some previous time. However it is not necessarily acquired; it is seen in osteogenesis imperfecta and in certain instances in muscular dystrophy in children. This group, which has not received the attention it deserves, was termed by Frost, in 1964, congenital osteoporosis.

LOCAL FACTORS

(1) *Transmission of force to bone*

The mechanical functions of the skeleton include the resistance of the organism to gravitational forces and to those emanating from muscular activity associated with posture, locomotion and mastication. Yet the periosteal surface of bone cannot withstand direct high pressure for any length of time without going into a negative balance. This phenomenon may be accounted for in part by the fact that the soft tissue, periosteum and endosteum immediately adjacent to the bone become anoxic when subjected for too long to direct pressure higher than the local capillary blood pressure.

When the surface of bone is normally subjected to a direct force of some magnitude, the periosteum is protected by a tissue which either converts the pressure into tensional forces or is thick enough to distribute it over a large surface. Thus the forces directed on to bone may either be dissipated in the overlying soft tissue, or be transmitted to the calcified material as direct pressure through cartilage, or as tension through soft tissue, or as a combination of these factors. For example, the mass of muscle and fat overlying the ischial tuberosities serves to distribute the force over the pelvis while an individual is sitting. This relieves the tuberosities of the bulk of the force. The periosteal surfaces of two bones in a joint usually are covered by articular cartilage rather than by periosteum so that the forces acting on the bones are transmitted to them through avascular cartilaginous layers rather than the vascular periosteum. Similarly the various ossification centres which remain un-united by the time the bones become weight-bearing are separated by means of cartilage. Hence the epiphyseal cartilages transmit the direct pressure from bone to bone and also serve as interstitial growth centres. The sutures of the skull, because of their fibrous elements, convert direct pressure between adjacent bones into tensional forces. These specialised functional sites also allow appositional growth to increase the size of the skull.

The periodontal ligament is similar in many respects to the edentations of a suture. The fibrous elements in both sites convert the transmitted force from pressure to tension on the periosteum of the bone and the cementum of teeth, while still allowing a positive bone balance for growth. Variation of the bone balance must also occur while the teeth are undergoing functional changes in position.

The forces applied to the surface of bone may be described as constant or intermittent. Since these terms are purely relative, their interpretation has led to considerable controversy. Most writers dwell on the time factor, not on magnitude of the pressure. Perhaps an important difference between intermittent and constant forces is their effect on the blood supply and thus on the metabolism of the periosteum or endosteum. A direct pressure to the periosteum will be intermittent, if, firstly, the duration of such pressure is shorter than the time taken for the cells of the periosteum to become anoxic; and secondly, if the release of pressure is sufficient for an adequate blood supply to be re-established between periods of pressure.

Within the limits of tolerance, intermittent pressure on the surface of bone will be resisted and will even lead to the formation of new bone, while a constant pressure which interferes with the blood supply will lead to resorption at the site of application of the pressure.

Weinmann and Sicher (1955) concur that one type of bone which is almost exclusively under tensile forces is the layer of the dental alveolus to which the suspensory fibres of the periodontal membrane are attached. However there are many other areas where either direct pressures are converted to tensional pressures or where only pure tensional pressures act. Examples are the tendinous insertions of muscles, part of the sutural systems of the body and some mucogingival junctions.

(2) *Inflammation and hyperaemia*

An inflammatory hyperaemia of the soft tissues immediately adjacent to bone tends to cause a negative bone balance. Yet new bone formation, especially of the endochondral type, occurs in a very vascular tissue. The reason for the osteoclastic response in bone adjacent to inflammatory hyperaemias is open to speculation. It may be attributed to factors such as the toxic end-products of the inflammation, bacterial toxins, auto-immune reactions, changes in the oxygen/carbon dioxide concentrations, hydrogen ion concentration, direct pressure effects, or the reduction of tensional stimuli from disorganised connective tissue.

It is not clear whether the hyperaemia which stimulates a negative bone balance must be associated with an infective process or whether it also occurs when hyperaemia is traumatic in origin. The direct effects the products of an infective process have on bone balance are, therefore, still speculative. Burch and Jackson (1966) have suggested that in the periodontal membrane auto-immune reactions, which are also associated with hyperaemia, may be implicated in the negative bone balance.

The effects of altering the oxygen/carbon dioxide concentration on the cell types in tissue culture have been described by Basset (1964); and Goldhaber (1965) showed how active osteoclasts are in tissue cultures where the oxygen concentration is increased. This suggests that the negative bone balance associated with hyperaemia may be partly due to an associated variation in the oxygen/carbon dioxide concentrations.

The inflammatory reaction and its associated hyperaemia which occurs in periodontal syndromes may, therefore, be responsible for the loss of bone. The total loss, however, may not be due to the hyperaemia, nor may it be the prime factor initiating the negative bone balance of chronic periodontitis.

(3) *Temperature*

Variation in temperature may affect the deposition and resorption of bone. Senile osteoporosis affects the axial more than it does the appendicular skeleton. Normally there is also a considerable drop in temperature between the arterial and venous side of the vascular system of the leg. It can therefore be suggested that the temperature of the bone surface may influence the amount of deposition and resorption of bone in it. Except in the instance of mouth breathers, however, variations in the temperature of periodontal bone does not seem to be an important factor in the production of a negative bone balance in the jaws.

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PART 3.

PERIODONTAL MODULATION

SUMMARY

The effects that functional forces have on the periodontal ligament are discussed. The changes that occur in the periodontal ligament as a result of alteration of the functional stresses have been termed "periodontal modulation." It is suggested that a primary and secondary mechanism is utilised for the transmission of masticatory forces through the periodontal ligament.

A correlation between the forces that are applied to bone and its morphology has engaged the attention of many writers. The orientation of trabeculae in long bones, especially the femur, clearly indicates how the internal architecture of bone is influenced by functional stresses. The external structure of a bone is also affected by these stresses. The remodelling of bone to align malposed fracture fragments can be mainly attributed to this cause; the formation of many superstructures of bone are intimately related to muscular attachments; further, the diminution of the alveolar process after the loss of teeth is an example of the relationship between the external morphology of a bone and the functional stresses transmitted by the teeth to the jaws. It may therefore be concluded that functional stresses markedly affect bone balance.

Since the bone comprising the alveolar process is, presumably, anatomically and physiologically similar to that of other bones, the teeth, because of their protruding crowns, afford a unique opportunity to study the transmission of force to bone and the effects of such force on the stressed bone.

The response of the periodontal ligament and associated bone to functional forces may be divided into acellular and cellular changes. The relationship between these changes has not been determined, nor has the mechanism which stimulates the cellular response been elucidated. Yet orthodontic practice is dependent on these changes.

The available evidence indicates that, after eruption, the relationship of the teeth to each other and to the jaws is, to a large extent, controlled by the interplay of forces acting on the teeth and related bone. These functional forces, independent of the *rate* at which bone is being deposited or resorbed, will in one instance help to maintain a bone balance and thus prevent a depression of the teeth, and in another instance they will stimulate either a negative or a positive bone balance which allows the teeth to alter their positions in the jaws.

These apparently anomalous reactions perhaps can be explained by correlating the *nature* of the forces and their *transmission* through the periodontal ligament to bone with some of the local factors affecting osteogenesis and osteoclasis.

THE TRANSMISSION OF FORCE THROUGH THE PERIODONTAL LIGAMENT TO BONE

If the fibrous elements of the periodontal ligament are solely responsible for the transmission of force to bone, then, because of the arrangement of the principal fibres, the application of an intrusive force to an incisor will tend to distort the bone and thus reduce the socket size (Fig. 1A).

Picton (1965) showed that horizontal thrusts up to 1·0 kg. on an upper anterior tooth of a monkey produced a corresponding labial and palatal distortion of the adjacent alveolar process. Similar intrusive thrusts produced buccal and palatal displacement of the alveolar process (Fig. 1B), which indicates that the sockets had been dilated by these thrusts. The distortion of the bone suggests that a thrust on a tooth either reduces a constant tension between the tooth and the bone or produces a positive pressure in the periodontal ligament. The latter is more probable: the arrangement of the fibres in the periodontal ligament is such that if they are under constant tension the tooth tends to be extruded from its socket.

However, if a positive pressure is maintained in the periodontal ligament throughout the time a force is applied to a tooth, the difficulty of depressing teeth would require re-evaluation; or the concept that direct pressure or reduced tension (discussed below) on a periosteal surface produces a negative bone balance must be altered. There is no evidence which suggests it is necessary to alter this concept.

Clinically, a displacing force such as the application of a separating elastic between two teeth, which initially causes no visible effect, will soon result in their displacement. If the separating elastic is then removed there is a rapid repositioning of the affected teeth. This phenomenon, together with the increased pressure developed in the periodontal ligament and the bony response associated with the application of force to a tooth, indicates that a force acting on a tooth is at first resisted by a transient, reversible mechanism. This mechanism inhibits rapid root movement and may serve to protect the fibres which ultimately resist the stress. The evidence suggests that the periodontal tissues resist displacing forces acting on the tooth by a primary and secondary mechanism.

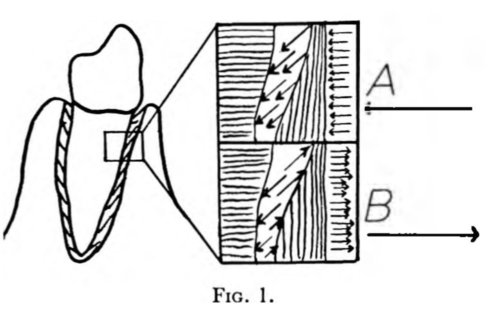

FIG. 1.

There are several ways in which the primary resistance mechanism of the periodontal ligament, which seems to act as a shock absorber between tooth and bone, can be explained.

The resistance may be attributed to the gradual displacement of blood from the vessels in the compressed portion of the periodontal ligament, where it has been shown, the blood supply becomes ineffective under excessive pressures. This indicates that pressure applied to the periodontal ligament forces the blood out of the periodontal vessels. If the calibre of the vessels is simultaneously controlled by a nervous mechanism, they make an effective hydraulic system. If this system constituted the whole of the primary mechanism, the associated reduction in blood supply would not be conducive to the subsequent cellular changes which occur if the pressure is maintained. Additional or alternate explanations must be sought to account for the primary resistance mechanism of the periodontal tissues.

Excluding the cells and fibres, which probably have a major role in the secondary mechanism, the extracellular water and ground substance may also play a part in the primary mechanism. The water content of the extra- and intracellular material is, apart from crystalloid and colloid content, dependent on the relationship between the hydrostatic pressure in the capillaries and the tissues they supply. A decrease in capillary blood pressure or an increase in the hydrostatic pressure in the tissue provides circumstances which favour the loss of extra- and intra-cellular water. Differences in the hydrostatic pressures in the tissues will also tend to be reduced by a flow of intra- and extra-cellular water from higher to lower pressure areas. To summarise, the application of a force to a tooth which causes localised or generalised increase in the hydrostatic pressure of the tissues of the periodontal ligament may result in a redistribution or a loss of intra- and extra-cellular water.

The transfer of water could form part of the primary resistance mechanism which, although resisting displacement, still allows for a certain degree of root movement. If the displacing force acting on the tooth is maintained long enough a transfer of water eventually will be followed by a proportionate decrease in the cellular and/or acellular contents of the periodontal ligament that is under pressure. This reduction is necessitated by the loss of water from the tissue which eventually interferes with the normal exchange of metabolites.

The constituents of the ground substance may be in the form of either a gel or a sol. If these constituents together with a certain amount of bound and unbound water, move from high to low pressure areas in the periodontal ligament through the fibrous cellular elements, they too can take part in the primary resistance mechanism. Certain gels may be altered to the sol form by mild physical forces. If similar gel to sol changes occur in the periodontal ligament when a tooth is subjected to stress, the movement of the ground substances in the ligament will be facilitated.

It is suggested that if the increase in pressure in the periodontal ligament is transitory it is withstood by the primary resistance mechanism: a buffer system which precedes the secondary resistance mechanism.

THE SECONDARY RESISTANCE MECHANISM

The fibrous elements are concerned with the secondary resistance mechanism; and as the cellular elements are intimately associated with formation, and possibly with the orientation of the fibres, their production and function are also considered as part of this mechanism. The role of the oxytalan and reticulin fibres in the transmission of forces from the root of a tooth to bone is not clearly understood.

There is no doubt that the collagen fibres are orientated so that they can best resist the forces applied to a tooth. It is also evident that their orientation is such that they appear to convert the forces applied to the teeth into tensional forces on bone. Hence, except for the pressure developed in the periodontal ligament during the period that the primary mechanism is active, the collagenous fibres appear to minimise, if not eliminate, a subsequent direct pressure effect on the adjacent bone. Direct pressure on the bone could of course occur if the force disrupted the periodontal fibres.

How the collagenous fibres of the periodontal ligament become rearranged in a definite pattern when the forces applied to the teeth are altered is still not clear. The authors could not demonstrate any histologically detectable effect on the fibres when orthodontic forces were applied to the teeth for various periods immediately after death, and in spite of fixation of the specimen while the applied forces on the teeth were maintained. The experiments showed that if alterations in width and fibre arrangement of the periodontal ligament are present on histological sections, the tooth must have been subjected to certain forces during life. The arrangement of the fibres suggests that the periodontal ligament had adjusted itself to withstand these forces to the best mechanical advantage.

The experiments also showed that orientation of the periodontal fibres is a vital process; and that the orientated fibres were not necessarily under tension when the specimen was prepared.

All the changes, the most striking of which is the alteration in fibre arrangement brought about by an alteration of the functional stresses on a tooth, are embodied in the term *periodontal modulation*.

The speed with which the fibres become orientated and the minimal amounts of cementum that are formed during the orientation phase suggest that the existing fibres may become disintegrated or partly degraded. If the now-free fibres from the lamina dura approximate the free fibres attached to the cementum, they may be reconstituted to form fibres following different paths from cementum to bone.

Whatever the mechanism may be, the

reorientation of fibres which occurs as a result of an alteration of the forces applied to a tooth indicates that the periodontal fibres tend to be arranged in such a way that they can resist any normal force applied to a tooth. The magnitude and duration of all the vectors of force acting on the teeth determine the resultant of force at a given time during a 24-hour period. If the orientation of the fibres in the periodontal ligament is directly related to the forces applied to the tooth, then the greatest number of fibres should be under tension when the direction of the force applied corresponds to the resultant of the forces normally acting on the tooth. The direction of this force is then along the *functional axis* of the tooth.

THE SECONDARY RESISTANCE MECHANISM AND ROOT FORM

The reorientation of the fibres to alter the functional axis of a tooth is limited by the root form.

The cemental and bony surfaces to which the periodontal fibres are attached are roughly parallel to each other in all planes; hence the alignment of the fibres can never be such that they oppose a compressive force in a given part of this ligament. This form of displacement will always be resisted by fibres situated elsewhere in the periodontal ligament. It is therefore possible that the fibres in the periodontal ligament, where pressure is being applied all day, may not only have *no* tensional stimulae on them, but may also be compressed. In normal function, however, so many different vectors are applied to the teeth that it is more likely that these fibres are subjected to *reduced tensional stimulae* rather than a complete lack of such stimulae.

If the roots of single-rooted human teeth were conical and the fibre arrangement was ideal, such a root could well resist equal and opposite vectors of force. If one of the masticatory forces were to predominate, the fibre arrangement could be altered so that more fibres would resist the predominating vector of force. There must also be a reduction in fibres resisting the other vectors of force. For obvious reasons the arrangement of fibres of a conical-shaped root to resist horizontal forces perpendicular to the root, is limited.

The mechanism whereby the forces acting on the teeth are transmitted to bone has not been settled, but the resultants of these forces do cause alterations in the periodontal membrane—periodontal modulation. These resultants are determined by the vectors and points of application of the forces acting on the teeth, the root and coronal morphology of the teeth, the relationship of opposing teeth and the pattern of mastication.

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PART 4.

THE FORCES ACTING ON THE TEETH

SUMMARY

The forces acting on the teeth have been divided into direct, when the muscle itself exerts pressure on the teeth, and indirect when the forces are transmitted through the jaws, periodontal ligament and the teeth. The direction of these forces has been examined in the position of maximal occlusal contact in and during mastication.

With minor exceptions the forces acting on the teeth are derived from the individual's own muscles. The application of these forces may be either direct, when the muscle itself exerts pressure on the teeth, or indirect. Indirect forces are transmitted through the jaws, periodontal structures and the teeth. This occurs when the teeth are brought into occlusion or when solids are interposed between them, and there is contraction of the muscles of mastication.

The forces acting on the teeth are described as labial, buccal, lingual, mesial, distal, apical and occlusal, depending on the direction of actual or potential displacement of their crowns (Fig. 1). When a combination of forces act on a tooth, the resultant of the forces determines the direction in which it tends to be displaced (Fig. 2). Directly opposing forces in respect of a single tooth will annul each other if they are equal, or reduce the effect of the greater force if they are unequal (Fig. 3).

Since the resultants of the forces acting on the teeth are mainly dependent on the nature of the muscular activity, they vary considerably for a given period of time. For the sake of convenience they were examined during a 24-hour period. This analysis deals with the forces acting on the teeth under conditions where the jaws are at rest, the teeth are in occlusal contact, and during the muscular activities of mastication and speech. Forces derived from appliances and habits are not discussed.

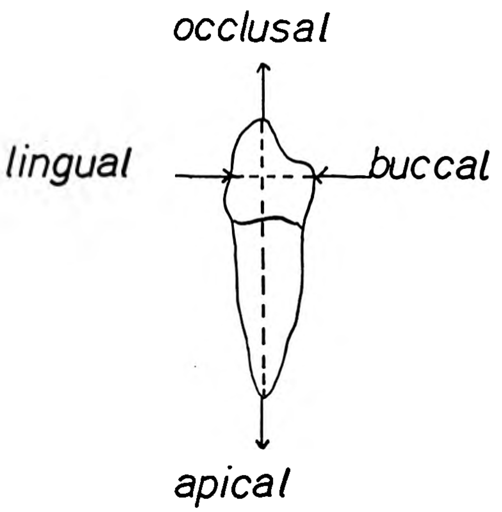

FIG. 1.

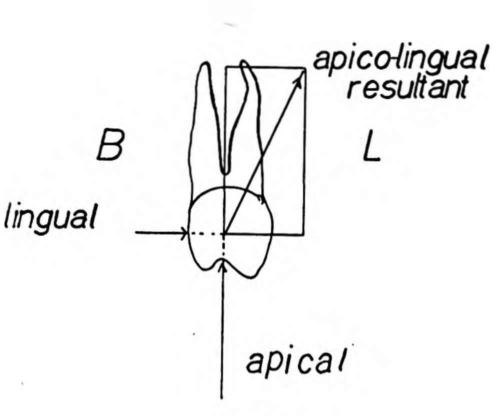

FIG. 2.

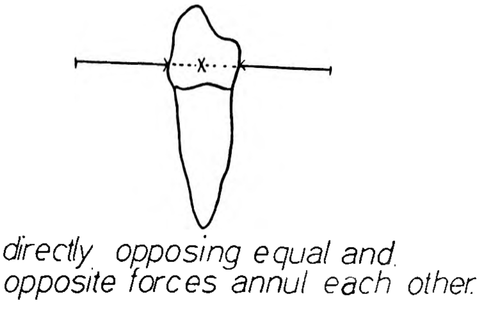

FIG. 3.

LABIAL OR BUCCAL FORCES

These tend to displace the teeth towards the lips or cheeks.

DIRECT LABIAL OR BUCCAL FORCES

These are derived from the activity of the tongue and other muscles associated with mastication, swallowing and speech, or from the passive tongue while in the resting position.

In an ideal dentition the crowns of opposing maxillary and mandibular teeth are not in the same vertical plane. Therefore the mandibular incisors and canines should be subjected to a greater direct labial force than their maxillary counterparts; and the mandibular premolars and molars should be subjected to a greater direct buccal force than their maxillary counterparts (Fig. 4).

INDIRECT LABIAL AND BUCCAL FORCES

(1) *In occlusion*

If the occlusal contacts are ideal (Part 6) there may be a buccal component of force acting on the maxillary molars and premolars while the teeth are being brought into maximum occlusal contact. On that stage being reached, in addition to these buccal forces, the maxillary molars and premolars may be subjected

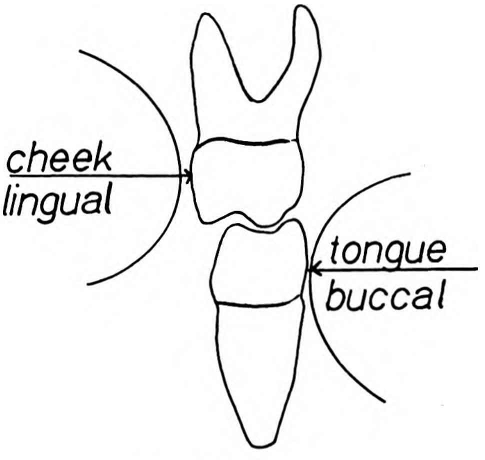

FIG. 4.

to distobuccal components when the position of maximum occlusal contact does not coincide with centric relation (Lewin 1963). The cusps guide the teeth into occlusion inducing an anterior movement of the mandible. The upward and backward pull of the elevator muscles exerts a distobuccal component on the maxillary molars and premolars. The occurrence of this component is not uncommon. Posselt (1962) found that, in 53 per cent of dentitions exhibiting an overjet of more than 6·0 mm., the mandibular position in centric relation does not coincide, in the antero-posterior plane, with its position when the teeth are in maximum occlusion.

(2) *During mastication*

The terminology used to describe the movements of the condyles within the temporomandibular joint is open to question. 'Rotating condyle', though often referred to in prosthetics, is not strictly correct, but rather than introduce another term it is retained. Similarly 'translating condyle' is retained despite its sometimes arched movements through the planes in which it moves.

(*i*) *Balancing side with translating condyles*
The presence of a bolus between opposing molars and premolars is necessary for the transmission of indirect forces to these teeth (Fig. 5). The nature of these forces is influenced by the texture of the bolus and its position relative to the teeth. In addition the indirect labial forces exerted on the molars and premolars are affected by the degree and distribution of occlusal

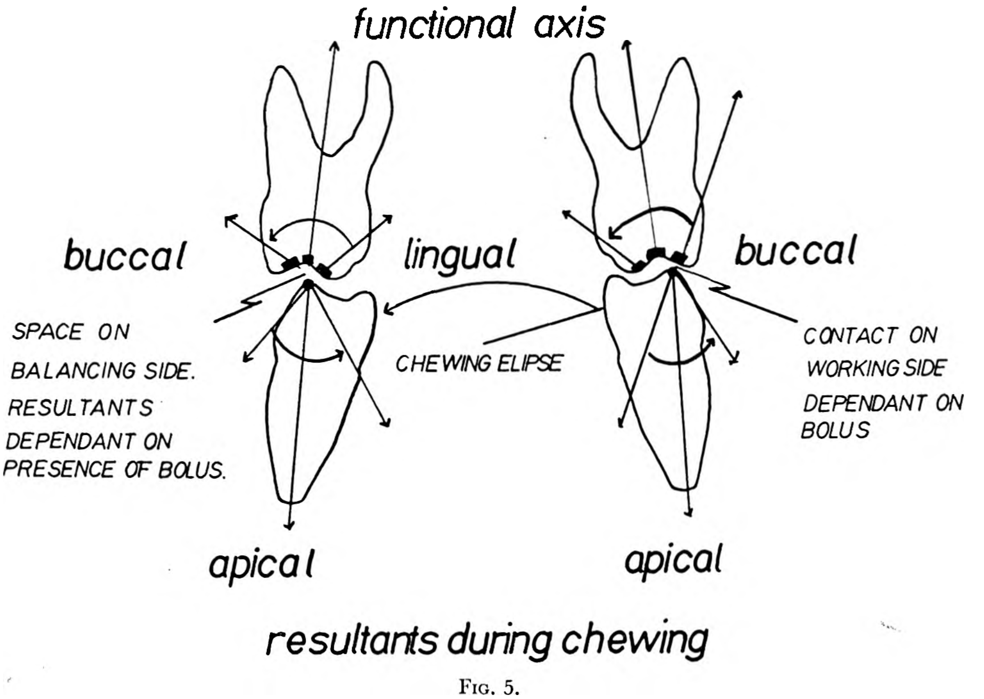

FIG. 5.

attrition (Parts 3, 5 and 6), and the pattern of mastication (Parts 5 and 6)

(*ii*) *Working side with rotating condyles* Apart from the fact that the interposition of a bolus between the teeth is not necessary for the transmission of indirect forces, the same factors as mentioned in (*i*) will determine the labial component of the forces acting on the molars and premolars (Fig. 5). Attrition of the posterior teeth will tend to decrease the labial and lingual components of force acting on them.

When the pattern of mastication is within the arcs formed by the projection of the lingual concavities of the maxillary canines, l.c.m.c. (Fig. 6 and in Part 7), they and the incisors may be subjected to a labial component of force on the balancing and working sides during mastication. On the other hand if attrition of the incisors and the cusps of the maxillary and mandibular canines has produced flat incisal surfaces that come into contact during mastication (Fig. 7), the lower canines and incisors will, with or without the interposition of a bolus, also be subjected to a labial component of force. This is because the effect of frictional resistance of opposing surfaces of the teeth during contact produces resultants with opposite vectors. The frictional component of a lingual vector would have a labial resultant.

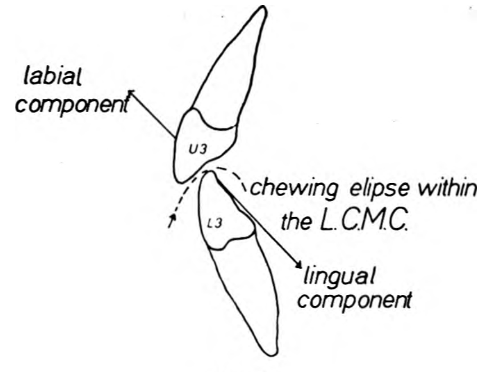

FIG. 6.

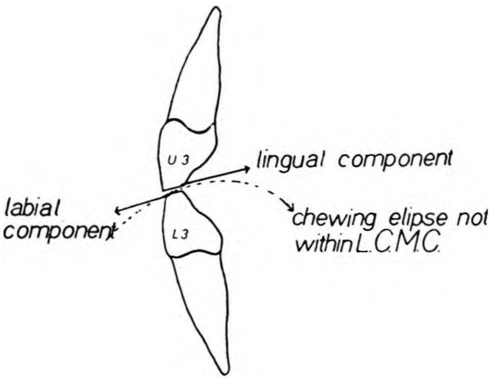

FIG. 7.

LINGUAL FORCES

These will tend to displace the teeth towards the tongue in the mandible and towards the palate in the maxilla.

DIRECT LINGUAL FORCES

The lingual forces which stem from the lips and cheeks exert a force on the teeth during resting posture (tonic contraction), and during the more marked muscular activity associated with swallowing, sucking, speech and mastication (Fig. 4).

The forces acting on the teeth while the mandible is at rest are of a lesser magnitude than those exerted when there is more muscular activity, but they nevertheless are present most of the waking hours; and the main forces acting on the teeth during muscular activity appear to be associated with the opening movement of the jaws and the mastication of food. Clenching of the teeth, without active contraction of the labial and buccal musculature, seems to produce a minimal increase of the lingual forces.

INDIRECT LINGUAL FORCES

(1) *In occlusion*

Given ideal cusp fossa or cusp embrasure contacts, the mandibular incisors and canines, and to a lesser extent the mandibular molars, may be subjected to a lingual force when the teeth are brought into maximum occlusal contact. The force exerted on the mandibular molars may in addition have a mesiolingual component if centric occlusion does not coincide with centric relation. The mesial component of force which may become active in centric occlusion is discussed in Part 5.

(2) *During mastication*

The lingual forces acting on the molars and premolars are dependent on the factors enumerated in the labial forces (2 (*i*)). The molars and premolars will, with or without the interposition of a bolus, tend to be displaced lingually or palatally during mastication (Fig. 5).

If the pattern of mastication is within the l.c.m.c. a lingual force will be applied to the mandibular canines of the working and balancing sides during mastication. With worn tips of the maxillary and mandibular canines, the pattern of mastication may no longer be within the l.c.m.c. and the maxillary canines will also be subjected to a lingual component of force during mastication.

During the first phase of the incisive movement the maxillary incisors are subjected to a lingual component of force due to the frictional resistance of opposing surfaces. The duration of this lingual force is increased if attrition of the maxillary and mandibular incisors has produced flat incisal edges. The lower incisors will, depending on the degree of attrition, be subjected to a lingual force during the latter part of the incisive movement (Figs. 6 and 7).

APICAL FORCES

The term apical force implies that the force will tend to displace the crown towards its apex. However, variations in root shape and number complicate its use to such an extent that it will be employed to indicate a force which tends to produce a uniform depression of the tooth in its socket. (See functional axis in Parts 3 and 4.)

(*i*) *Direct apical forces.* Although the complete interposition of the cheeks and tongue between the maxillary and mandibular teeth is considered abnormal, direct apical forces which originate from the lower lip may act on the maxillary incisors and canines; and apical forces arising from the resting tongue may act on the lower molars and premolars.

(*ii*) *Indirect apical forces.* (*a*) Dempster *et al* (1963) have demonstrated that the 'long axes' of the premolar teeth in 'normal' occlusion are virtually in the same straight line. It is therefore possible that when ideal crown form and cusp fossa or cusp embrasure relationships are present, a purely apical force may act on the premolars when these teeth are in maximum occlusal contact—a position in which the molars and premolars will have more apical force applied to them than will the canines and incisors. In many dentitions maximum occlusal contact does not result in contact between the mandibular incisors and the maxillary incisors. Dependent on the degree of overjet, marked incisal attrition of the incisors and canines tends to increase the apical component of force on these teeth (Part 7).

(*b*) During the incision and mastication of the bolus all the teeth may be subjected to apical forces. Furthermore, the resultants of the forces acting on the teeth may also be apical. For example, a number of forces acting against the dental arcade such as the pursing of the lips and other indirect forces exerted during incision, may produce apical resultants.

OCCLUSAL FORCES

These are the forces which tend to displace a tooth towards the occlusal plane.

DIRECT FORCES

The direct occlusal forces acting on the teeth are thought to be minimal. After eruption they may arise because of a tooth's marked curvatures at its cervical margin. These cervical curvatures may be a factor responsible for the overeruption of a tooth where there is no active antagonist present.

INDIRECT FORCES

In the ideal occlusion indirect occlusal forces could be evoked by the adherence of material to the maxillary and mandibular teeth. During the eruption of the teeth, especially in the mixed dentition, and when their mesial and distal convexities are not in apposition at the points of greatest convexity, an occlusal resultant may be present when the teeth are in maximum occlusal contact and during mastication.

The analysis of the direct and indirect forces acting on the teeth shows that although their crowns may, at a given time, be subjected to a single vector, they will have multiple vectors of force applied to them when the period is more prolonged. The effects that altered crown form (attrition) may have on some of the vectors applied to the teeth have been mentioned. The periodontal modulation initiated by the different vectors acting on them is, however, further influenced by the resultants of the direct and indirect forces. For this reason periodontal modulation is also modified by tooth morphology, occlusal contact and the pattern of mastication.

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PART 5.

THE RESULTANTS OF THE FORCES APPLIED TO THE CROWNS OF THE TEETH

SUMMARY

The manner in which the morphology and relationship of the teeth modify the forces that are applied to them is discussed. Root form is analysed and it is suggested that root morphology dictates the axis along which a force may place the greatest number of periodontal fibres under tension—the functional axis of the tooth. The effects that cusp form, the path of closure, and the relationship of the maxillary and mandibular teeth have on the resultants of the forces acting on the teeth are described.

The forces acting on the teeth, their transmission to bone and their effect on periodontal modulation were dealt with in Parts 3 and 4. The manner in which these forces are modified by the morphology and relationship of the teeth will be analysed. The effects of these resultants on periodontal modulation are discussed.

THE EFFECT OF ROOT FORM ON THE RESULTANTS OF THE FORCES ACTING ON THE TEETH

A straight, conical-shaped root can have a periodontal fibre arrangement which allows the tooth to resist equal and opposite forces independent of their points of application. If the magnitude and duration of one force predominates over the other forces applied to such a tooth, the subsequent periodontal modulation will result in a fibre arrangement best suited to resist the predominating force. The *number* of fibres that can be orientated to resist either a buccal, lingual, mesial or distal force is limited when the root has a conical shape, as compared with more specialised root forms.

Alteration of the root form, even without an increase in its surface area, will allow an orientation of a greater number of periodontal fibres to increase the resistance of roots to horizontal displacements in a particular plane.

The triangular-shaped root of the maxillary canine allows more than half of the periodontal fibres attached to the root to orientate so that they can resist labial forces (Fig. 1).

The resistance of the root to horizontal forces predominantly in one plane can also be increased by curving the root in the opposite direction. Comparing a tooth to a first class lever illustrates this: a right-angled curvature in the opposite direction to which the force is applied will transmit part of the displacing force towards the apex of the root. As a result a greater number of periodontal fibres are placed under tensional resistance (Fig. 2).

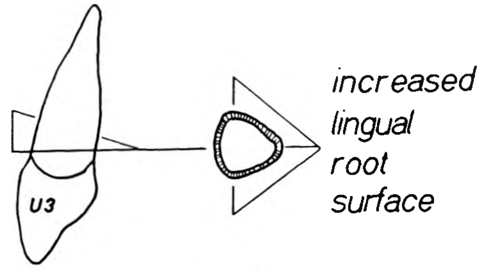

FIG. 1.

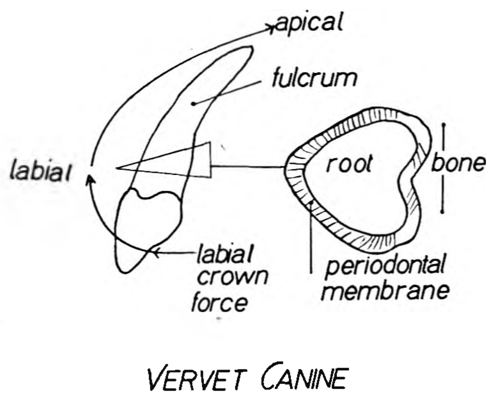

FIG. 2.

The maxillary canines of the vervet monkey, which are subjected mainly to labial components of force, have roots which are triangular or even V-shaped in cross-section (Fig. 2); and they have marked palatal curvatures. In the human, where rotatory as well as labial forces acting on the maxillary incisors and canines predominate, a similar but less defined root-shape and curvature is seen.

For mechanical reasons alone, an ideal root form to resist forces which have a predominantly horizontal component in one plane would not be a straight, conically shaped root.

Examination of humans and other anthropoids indicates that a correlation may exist between root form and the vectors of force applied to the teeth both in occlusion and during mastication.

Although the morphology of the crown form of the maxillary and mandibular incisors is basically the same (Part 6), their root form is dissimilar. An analysis of the forces acting on these opposing teeth shows them to be subjected to different vectors of force and consequently different resultants of force.

The curvatures of the apical thirds of the roots, which are more variable, received attention elsewhere (Dreyer 1955).

The vectors of force to which these teeth are subjected already have been discussed (Part 4). As the root form of the human dentition has been meticulously described by Wheeler (1965), there is no need to describe the correlation of those factors in the other teeth.

Specialisation of root form makes it possible for the tooth to have a *functional axis:* that along which a force will place the greatest number of periodontal fibres under tension, and which need not correspond to the long axis of the tooth (Fig. 3). The functional axis for a given root form can be altered only within limits by a rearrangement of the periodontal fibres. The more specialised the root form becomes the less compensation by fibre rearrangement is possible if the vectors of force acting on a tooth are changed.

In human teeth, angulation of the roots to the occlusal surface may be due either to crown form or to curvature of the root itself. Except in the premolars the mesial height of the crowns of the permanent teeth tends to be greater than the distal height. Under these conditions the trunk of the roots has an initial or primary angulation to the occlusal or incisal surface. Curvature of the root or secondary curvature is, when present, more or less consistent in the coronal two-thirds; in the apical third it is variable and possibly related to the migration of the tooth during root formation. It is not confined to the antero-posterior plane: the roots of the mandibular canines and premolars appear to have a lingual curvature while those of the molars tend to have a buccal curvature.

The application of an apical force, orientated at right angles to the incisal edge or occlusal surface and applied to the centre of the crown of a tooth with a primary or secondary distal curvature, will give rise to an apico-mesial resultant. This resultant, generally referred to as the anterior component of force, tends to produce a mesial movement of the tooth. Thus when two teeth with such root

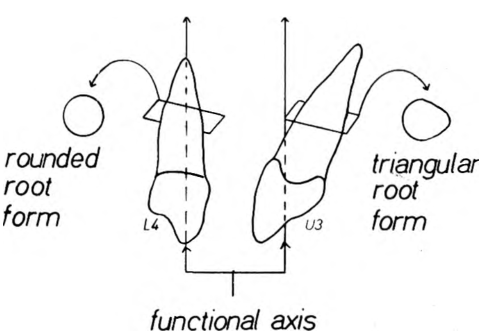

FIG. 3.

angulations are brought into full occlusal contact as a result of contraction of the muscles of mastication, the resultant of the force, which is at right angles to the occlusal planes of these teeth, will be in an apico-mesial direction (Fig. 4). If the roots of the mandibular molars also have a buccal curvature the resultant will be in an apico-mesio-lingual direction. Conversely, if the roots of the molar teeth have a mesial curvature, occlusal contact will result in an apico-distal resultant or posterior component of force.

With the same masticatory force the anterior or posterior component of force may be augmented by increasing the angulation of the roots relative to opposing teeth or by various other factors which will be discussed later.

Root angulation can result in both anterior and posterior components being active in the same dental arch. Hence the curvature of the roots of the first and third molars of the rat is such that the first molar is subjected to a posterior and the third molar to an anterior component of force when the teeth are brought into occlusion (Dreyer 1965).

Although it has been suggested that the roots of most human teeth tend to have primary and secondary distal curvatures, it is not uncommon to find dentitions where the roots have minimal inclinations and appear almost straight (Fig. 5). Furthermore the presence of distal root curvatures does not necessarily mean that

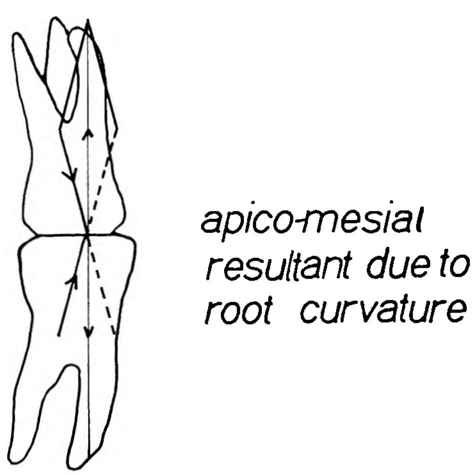

FIG. 4.

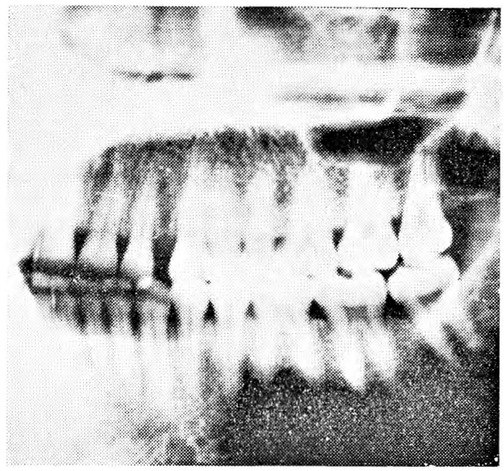

FIG. 5.

the teeth concerned will be subjected to an anterior component of force: the location of the areas of contact between them, their inter-relationship, and the pattern of mastication also affect the resultants of the masticatory forces.

THE EFFECT OF THE RELATIONSHIP OF THE MAXILLARY AND MANDIBULAR TEETH ON THE RESULTANTS OF THE FORCES ACTING ON THE TEETH

Varying the position of occlusal contact between the teeth will alter the resultants of force applied to them irrespective of their root form.

In order to study this problem the relationship of the teeth will be classified: first in relation to opposing teeth; secondly in relation to a transverse plane. Although the findings are equally applicable to all teeth, cuspless molariform teeth will be used for descriptive purposes.

When viewed from the buccal or lingual side the relationship of non-rotated, untipped (see later), occluded molar teeth may be classified according to the antero-posterior position of the mandibular molar relative to its opposing maxillary molar (Fig. 6).

The two occlusal planes may be directly opposite each other (AP.1)—a relationship of the molars which most authorities consider normal. In this relationship the site of application of the masticatory forces on the molars will not tend to alter their resultants when transmitted through

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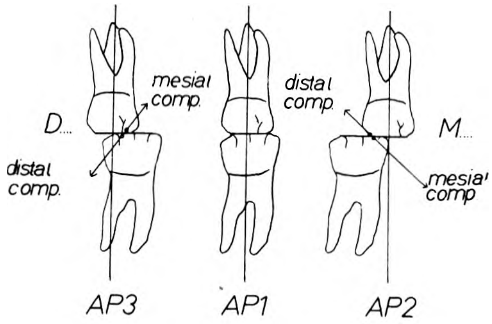

FIG. 6.

the roots; it appears to provide circumstances which allow the masticatory forces to pass through the functional axes of these teeth to stimulate the whole of the periodontal ligament.

The mandibular molar may be distal to the maxillary molar (AP.2) or mesial to it (AP.3).

In the absence of contact points and perverse muscular activity the mandibular molar will be subjected to a force which will tend to tip it mesially, and the maxillary molar distally, when the molars are in AP.2 relationship. The vector of force and thus the direction in which the molars will tend to tip is reversed in the AP.3 relationship.

When the molar teeth are in AP.2 or AP.3 relationship and the crowns of the teeth are inhibited from free movement by contact points, the tipping force is reciprocally transmitted to and shared by the adjacent teeth. Under such circumstances most of the apical forces may still be transmitted via the functional axes (L8, Fig. 7) and there need not be an increased anterior component of force (see arrows).

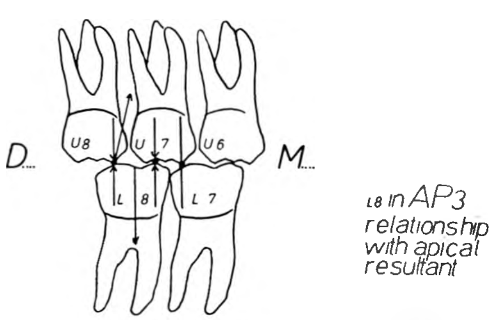

FIG. 7.

To classify the relationship of the molars in the bucco-lingual plane, the occluded teeth must be viewed from their mesial or distal aspects. For ease, non-rotated, cuspless molars are used in the description of the classification (Fig. 8). If the position of the mandibular molar is compared with a plane running mesio-distally and bisecting the coronal third of the buccal roots of the maxillary molar, its buccal surface may directly underlie the reference plane (BL.1) or be buccal to it (BL.2) or be lingual to it (BL.3).

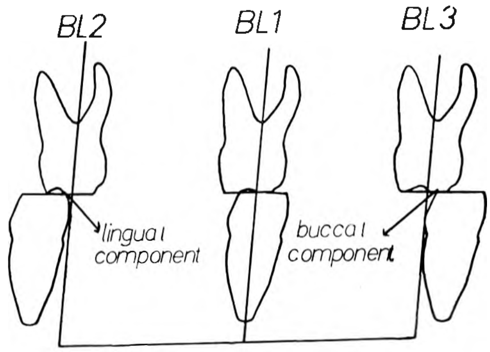

FIG. 8.

By changing the site of application of the masticatory forces the BL relationship can alter their resultants. In the BL.1 position they will tend to be transmitted via the functional axes of the molars. In the BL.2 position they will tend to tip the upper molar buccally and the lower molar lingually. On the other hand the upper molar will tend to tip lingually and the lower buccally in the BL.3 molar relationship.

Thus an essential step in the assessment of the forces acting on the molars is to determine the relationship of the occluding molars in both the planes described.

Another way in which the teeth may influence the resultants of the masticatory forces is by their angulation to adjacent and opposing teeth. One method of determining this angulation is to relate the position of the teeth to a transverse plane in the following manner:

A catenary curve joining the distal surfaces of the mandibular third molars is drawn so that it overlies the mid-incisive incisor point. The angulation of the molars is then determined by relating their position to the plane formed by joining the arcs of this curve.

Antero-posteriorly

(1) There is no tipping in any of the AP or BL positions (Figs. 6 and 8).

(2) The maxillary or mandibular tooth can be tipped mesially or distally and be in any of the AP/BL positions (Fig. 9).

(3) The maxillary or mandibular tooth can be tipped lingually or buccally in any of the AP/BL positions (Fig. 10).

The effect of mesial, buccal, distal or lingual tipping of a tooth on the resultant of the masticatory forces acting on that tooth will be determined by the position of occlusal contact established with its antagonist during masticatory movements. Examining the mesially-tipped mandibular molar in antero-posterior plane (Fig. 9) suggests the following:

(i) Molars not in the AP.1/BL.1 relationship can be caused by abnormal growth of the skull or be due to a bodily displacement or a rotation of the teeth. The rotation about a fulcrum situated in the root area is referred to as tipping.

(ii) The initial tipping of the molar L8 would not have occurred if the resultant of the masticatory forces passed down the functional axis of the tooth. This tooth was subjected to an anterior component of force prior to its tipping.

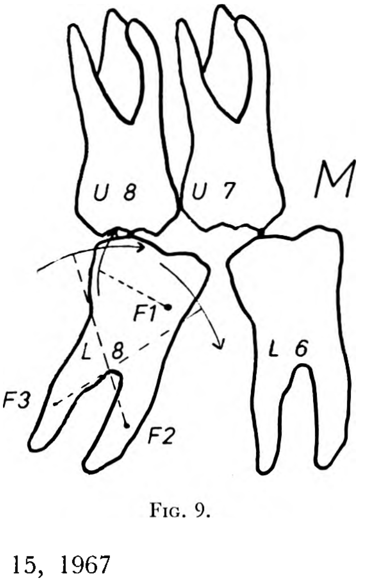

FIG. 9.

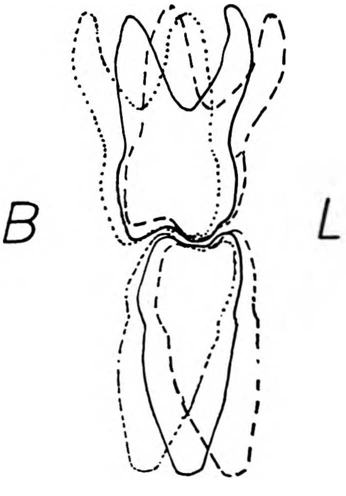

FIG. 10.

(iii) During the initial phase of tipping the occlusal contact of L8 when in AP.1/BL.1 would tend to raise the distal border of the crown. This alteration in occlusal contact would deviate the resultant of the masticatory forces towards the functional axis to inhibit tipping. In this case the resultant must still have been in the apico-mesial direction as L8 continued to tip.

(iv) The point about which the tooth tips in the antero-posterior plane, the fulcrum, probably varies during the tipping process. The fulcrum will tend to be located away from the occlusal surface; if it was in that area it would necessitate a considerable amount of depression or attrition of one or both of the opposing molars (Fig. 9, F1). It will also tend to be located posterior to the middle of the tooth; if it was located on the anterior root, the tipping process would again have to be accompanied by a considerable amount of depression or attrition to produce a minimal amount of mesial movement (Fig. 9, F2). On the other hand if it was located in the region of the posterior root, the crown of the affected tooth would move mesially and less depression of the roots (mostly anterior root) would be necessary for this movement (Fig. 9, F3).

(v) While the occlusal forces of the tipping molar will initially oppose the anterior component of force they will, depending on the location of the fulcrum, supplement it after a certain degree of tipping has occured.

This classification of the molar relationship renders it easy to appreciate the resultants of the masticatory forces acting on the teeth. To emphasise the point, the AP.1/BL.1 position of the molars tends to direct the masticatory forces along the functional axes of these teeth thus stimulating the majority of periodontal membrane fibres. This could occur irrespective of the presence of cusps, or the presence or absence of contact points between the teeth.

The role of the cusps

To analyse the effects the cusps exert on the masticatory forces it is necessary to determine the cusp fossa or cusp embrasure relationship relative to the tooth and the opposing teeth.

If a mandibular molar is viewed from its mesial surface so that the buccal and lingual cusps are on the same horizontal plane, the roots will be orientated obliquely to a line at right angles to it; the obliquity is towards the side of the buccal cusps (Fig. 11, B). If on the other hand the tooth is orientated so that its long axis is at right angles to a horizontal plane, the lingual cusp appears higher than the buccal cusp (Fig. 11, D).

Similarly, if the maxillary molar is viewed from its mesial aspect so that its buccal and lingual cusps are on the same horizontal plane, the buccal roots will be orientated above the buccal cusps. A projection of their axes passes through the centre of the crown. The palatal root

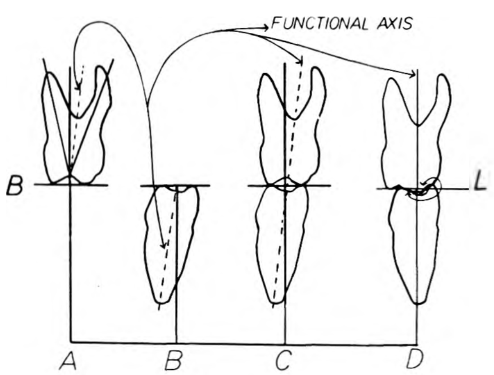

FIG. 11.

is angulated towards the palate. Its axis also passes through the centre of the crown (Fig. 11, A).

When the long axes of the buccal roots are at right angles to the horizontal plane, the mesiolingual cusp appears higher than the buccal cusps (Fig. 11, D). The tubercle of Carabelli, when present, may be on the same plane as the buccal cusps.

The effect these crown-root relationships have on the resultants of the masticatory forces in the BL.2 position is shown in Fig. 11, C. The molars are occluded in such a manner that their palatal and buccal cusps are on the same horizontal plane. If the site of contact between the opposing teeth does not affect the resultants, then the maxillary molar could be subjected to an apico-buccal component and the mandibular molar to an apico-lingual component (Fig. 11, C). In the BL.1 relationship these buccal and lingual components are opposed by the angulation of the teeth and the crown form. The buccal and palatal cusps of the molars are not normally on the same horizontal or vertical plane (crown morphology allows for bucco-lingual tipping). Further, the effects the points of contact and therefore the points of application of the masticatory force will have on the resultants will also tend to annul these buccal and lingual components.

A masticatory pattern within the l.c.m.c. is associated with longer periods of contact between the lingual surfaces of the mandibular buccal cusps and the buccal surfaces of the palatal cusps than on the corresponding surfaces of other cusps (see Part 7). The crown and root relationships of the molars seem to indicate that during function the maxillary and mandibular molars will be subjected to buccal and lingual components of force respectively. The angulation of these teeth to each other and to the skull, however, suggests that the resultants of the masticatory forces are apical, passing through the functional axes of their roots (Fig. 11, D).

If the premolars are examined from their mesial aspects, the long axes of the occluding maxillary and mandibular premolars will tend to form an obtuse angle with each other. This angle points buccally, suggesting that a buccal component of force can be generated during muscular contraction with the premolar teeth in occlusion. If the premolars are examined as described, it will be seen that the points of contact between opposing teeth also tend to produce apical resultants of force.

When the maxillary molar is viewed from the buccal aspect it is apparent that the mesial cusps are larger and higher than the distal cusps. When this tooth is placed on a horizontal plane its roots appear to slope distally. Many dental anatomists have remarked on the close similarity, except for size and proportion, of the mandibular and maxillary first permanent molars and their deciduous counterparts (Kraus and Jordan 1965). There is a difference of opinion as to which are the larger and higher cusps in the mandibular primary molar. The authors have noted that the distal cusp of the mandibular permanent molar appears smaller; and that whereas the mesio-buccal and disto-buccal cusps vary considerably, the two lingual cusps more or less correspond in size. However, if the buccal and lingual cusps are orientated on the same horizontal plane the roots appear to slope distally.

When the maxillary and mandibular molars are articulated and viewed from the buccal aspect, their roots form an obtuse angle orientated mesially (Fig. 12). This angulation will tend to complement the anterior component of force derived from crown-root angulation previously described, if the masticatory forces are equally distributed over the whole crown. However the occlusal contact of the maxillary molar is with the distal two-thirds of the mandibular molar (the maxillary molar does not articulate in the mesial fossa of the mandibular molar). The effect of this site of application of the masticatory force is to offset the apico-mesial component (anterior component) of force resulting from the distal angulation of the molar roots (Fig. 12).

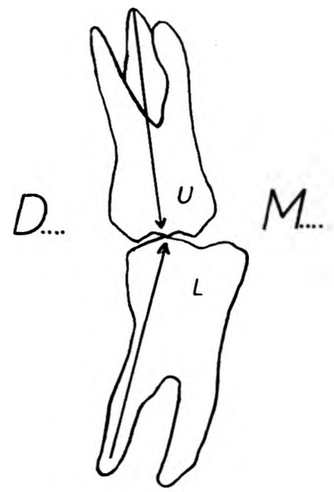

FIG. 12.

Effects of mandibular movement on the forces acting on the teeth

It is undecided whether mandibular movement from the rest position to maximum occlusal contact is a hinge movement in the temporo-mandibular joints or one which allows a simultaneous approximation of all the teeth (Ramfjord and Ash 1966). If the latter is the case, opposing teeth in the AP.1/BL.1 position will transmit the occlusal forces down their functional axes as long as the masticatory forces do not tend to displace the mandible in the antero-posterior or medio-lateral planes. Under these conditions opposing teeth, as illustrated in Fig. 13, cannot all transmit the given masticatory force (F) down their functional axes.

The position of maximum occlusal contact is a transient relationship of the

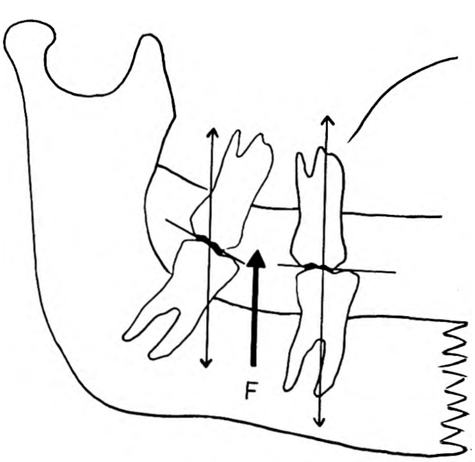

FIG. 13.

teeth in the chewing cycle during which the directions of the masticatory forces can vary. This variation will depend on the state of contraction of the different muscles of mastication (Fig. 14). For example contraction of the masseter muscle (M) or the internal pterygoid muscle (IPt) can individually or collectively give rise to a force RD acting on the molars.

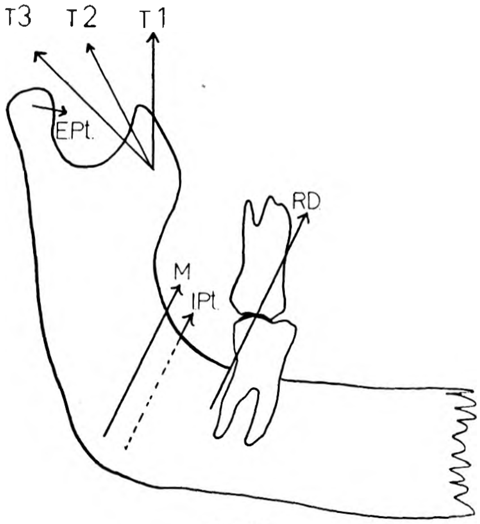

FIG. 14.

It is probable that simultaneous contraction of all the masticatory muscles while the teeth are in maximum occlusion is uncommon; it would also be difficult to determine the direction of mandibular movement due to such contraction. It is likely that the activity of the individual muscles varies during a chewing cycle and may further be affected by the position and nature of an interposed bolus.

The manner in which the directions of the masticatory forces change during mastication is determined by the timing of the contraction of the different masticatory muscles. The forces generated by the contraction of the antero-medially orientated masseter, internal pterygoid and anterior fibres of the temporal muscles will tend to pass through the functional axes of the third, second and possibly the first maxillary and mandibular molars if they are orientated as in Fig. 15A and in the AP.1/BL.1 relationship.

Contraction of the central parts of the temporal muscle will, on the other hand, tend to exert a vertical force on the mandible. Under these conditions the teeth in the second premolar region can transmit these indirect forces down their functional axes if they are orientated as shown in Fig. 15B. Contraction of the posterior part of the temporal muscle will exert an upward and backward force on the mandible. If this occurs during the chewing cycle these forces may pass down the functional axes of the canine and first premolar teeth if they are orientated as shown in Fig. 15C.

Thus the transmission of the masticatory forces through the teeth is, apart from the factors previously described, dependent on the orientation and sequence of contraction of the muscles of mastication.

The examination of the relationship of the molar and premolar teeth and the effects of the path of mandibular movement on the forces acting on the teeth during mastication suggest that:

(1) In order for the masticatory forces to be ideally transmitted via the functional axes of the roots they should be in an AP.1/BL.1 relationship.

(2) Masticatory forces can be transmitted via the functional axes of the roots if the opposing teeth are in the AP.1/BL.1 relationship, and their orientations are in harmony with the action and sequence of contraction of the muscles of mastication.

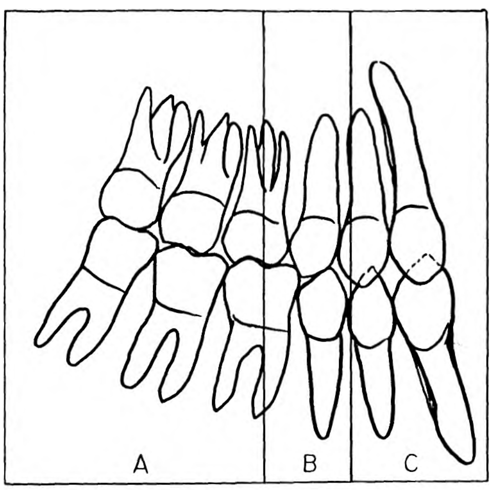

FIG. 15.

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PART 6.

THE EFFECTS OF THE CORONAL ELEMENTS, PROPRIOCEPTION AND NEUROMUSCULAR CO-ORDINATION ON THE TRANSMISSION OF FORCE THROUGH THE TEETH

SUMMARY

A detailed description of the coronal elements of a maxillary premolar and molar is given to show the similarities between these two teeth. The occlusal contact between a maxillary and a mandibular first premolar is used to demonstrate the occluding points and thus the points of application of the masticatory forces between these teeth. The relationship of a reflex pattern of mastication to tooth position and coronal element configuration is discussed.

Indirect forces (Part 4) may be exerted on the teeth during function whether or not a bolus intervenes. Without the presence of a bolus the transference of the masticatory forces is dependent upon contact between the occluding surfaces of the opposing teeth.

In the unworn dentition the occlusal one-third of the crown, the occlusal table, is made up of ridges, grooves and pits which are referred to as the coronal elements; these elements influence the points of application of the masticatory force as well as its direction through the tooth, and thereby the resultants of the vectors developed during occlusal contact. In other words, even if the root form, crown form, crown-root angulation, relationship of the maxillary to the mandibular teeth, axial inclination and the pattern of mastication tend to produce resultants which pass along the functional axes of the teeth, these resultants can still be altered by the articulation of the coronal elements, which ultimately determine the nature of the contact between opposing teeth.

The coronal elements are common to all human teeth, but they are more defined in some than in others. The greatest degree of differentiation is expressed in molariform teeth and Kraus and Jordan (1965) see a comparative ontogenetic pattern between incisiform and molariform teeth; this is based partly on the degree of differentiation and complexity. Those comprising the occlusal tables of human teeth are very similar. This becomes apparent when the coronal element configuration of the maxillary first premolar and first molar are compared (Fig. 1).

In the premolar a marginal ridge runs both mesially and distally in a curve to join the buccal cusp tip to that of the lingual cusp. From these tips, radiating towards the centre of the occlusal table in many instances, are the buccal and labial triangular ridges. Like the marginal

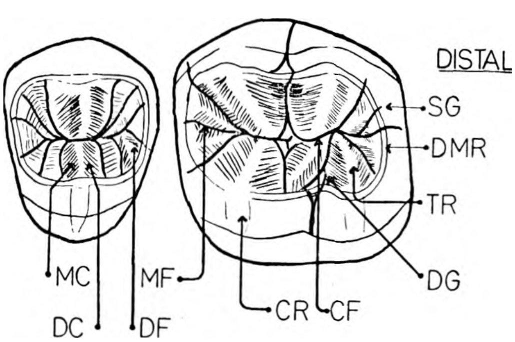

FIG. 1.—The coronal elements.
DC, distal curvature; DF, distal fossa; DG, developmental groove; DMR, distal marginal ridge; CR, central ridge; CF, central fissure; MC, mesial curvature; MF, mesial fossa; SG, supplemental groove; TR, triangular ridge.

ridges, these are curved and have rounded apices. Each triangular ridge has a mesial and distal inclined curvature. The depression, usually occupied by a pit, formed by the mesial inclined curvatures of the buccal and lingual triangular ridges and the mesial marginal ridge is referred to as the mesial fossa; and that bordered by the distal curvatures of the buccal and lingual triangular ridges and the distal marginal ridge is referred to as the distal fossa.

A central fissure joins the pits of the mesial and distal fossae and not infrequently bi- or trifurcates as it crosses the mesial and distal marginal ridges. These bi- or trifurcations sometimes demarcate small assessory cusps. Supplemental grooves radiate from the central fissure towards the buccal and lingual aspects of the marginal ridges. On the buccal and lingual faces of the crown a central ridge radiates from the cusp tip towards the cervical margin. A cusp may therefore be considered as the confluence of the mesial and distal marginal triangular and central ridges.

The molar tooth has a similar coronal element configuration except that the number of cusps and fossae is increased. In the maxillary molar two triangular ridges radiate from the mesio-lingual cusp. The more distal of these ridges forms part of the oblique ridge. The other part is formed by the triangular ridge of the distobuccal cusp. The distal inclined curvatures of these two triangular ridges and the distal marginal ridge outline the distal fossa of the maxillary molar. In molariform teeth the buccal and lingual cusps are demarcated by developmental grooves.

The cusps may occlude in fossae or fissures of opposing teeth. An example of the former is evident when the buccal cusp of the mandibular first premolar occludes in the mesial fossa of the maxillary first premolar. Since the occluding surfaces of the coronal elements of unworn teeth are all curved, the points of contact between these occluding teeth will be located on the occluding ridges (Fig. 2).

(*a*) The mesiobuccal marginal ridge (relative to the central ridge) of the mandibular first premolar occludes with the mesial marginal ridge of the maxillary first premolar. (MBMR with MMR, Fig. 2.)

(*b*) The distobuccal marginal ridge (relative to the central ridge) of the mandibular first premolar occludes with the mesial curvature of the triangular ridge of the buccal cusp of the maxillary first premolar. (DBMR with MCTR, Fig. 2.)

(*c*) The distal curvature of the triangular ridge of the buccal cusp of the mandibular first premolar occludes with the mesial curvature of the triangular ridge of the lingual cusp of the maxillary first premolar. (DCTR with MCTR, Fig. 2.)

(*d*) The mesial curvature of the triangular ridge of the buccal cusp of the mandibular first premolar occludes with the mesial marginal ridge of the maxillary first premolar. (MCTR with MMR, Fig. 2.)

If these contacts between the premolars influence the masticatory forces being transmitted along the functional axes of the teeth, then any uncompensated variation will upset the balance of the forces acting on these teeth causing either tooth movement, excessive attrition or mandibular deviation. Thus the rotation of many maloccluded teeth may be the

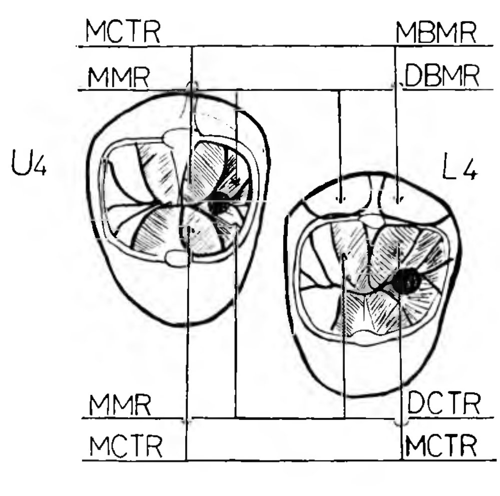

FIG. 2.—The articulation of the coronal elements.

DBMR, distobuccal marginal ridge of buccal cusp, L4. DCTR, distal curvature, triangular ridge of buccal cusp, L4. MBMR, mesiobuccal marginal ridge, L4. MCTR, mesial curvature, triangular ridge of buccal cusp, L4. MMR, mesial marginal ridge, U4.

result of an earlier or existing imbalance of the forces acting on these teeth due to inharmonious coronal element configuration and occlusion.

The genetic and environmental factors influencing the coronal morphology and all the other factors which may cause malocclusions contribute to the fact that in the human dentition ideal coronal element relationship and occlusion is the exception rather than the rule. In spite of the numerous factors which may cause malocclusion, ideal cusp-fossa relationships on most if not all the teeth are still found in some unworn dentitions. If these ideal relationships are compared with those of Friel (1927) the differences set out in Table 1 will be noted.

If the detailed occlusion of the coronal elements are studied it will be seen that in dentitions exhibiting early signs of attrition, the attrition facets, in many instances, can be related to malocclusions caused by inharmonious coronal element configuration or incorrect tooth position (Part 7).

The above analyses of the relationships of the coronal elements indicate the points of application and the site of the masticatory force acting on the teeth in a

TABLE 1.—THE OCCLUSION OF THE YOUNG ADULT (FRIEL, 1927) AS COMPARED TO AN IDEAL CUSP-FOSSA RELATIONSHIP (THOMAS, 1965).

Cusp	*Cusp-Fossa*	*Young Adult*
Buccal cusp of mandibular first and second premolars.	Mesial fossae of the maxillary first and second premolars.	The first premolar occludes in the division between the maxillary canine and first premolar. (Marginal ridge or embrasure.) The second premolar occludes in the division between maxillary first and second premolars. (Point of cusp in mesial groove of maxillary second premolar).
Mesiobuccal cusp of mandibular first molar.	Mesial fossa of maxillary first molar.	In the division between the maxillary first premolar and first molar.
Mesiobuccal cusp of mandibular second molar.	Mesial fossa of maxillary second molar.	In the division between the maxillary first and second molars, or the mesial groove of maxillary second molar.
Distal cusp of mandibular second molar.	Distal fossa of maxillary second molar.	When present, in distal fossa of maxillary second molar.
Distal cusp of mandibular third molar.	Distal fossa of maxillary third molar.	When present, in mesial side of distal fossa of maxillary third molar.
Triangular ridge of buccal cusp of maxillary first premolar.	Supplemental groove on buccal marginal ridge of mandibular first premolar.	Embrasure between the mandibular first and second premolars.
Triangular ridge of buccal cusp of maxillary second premolar.	Supplemental groove on buccal marginal ridge of mandibular second premolar.	Embrasure between the mandibular second premolar and first molar. Mesial to apex of embrasure.
Triangular ridge of mesiolingual cusp of mandibular second molar.	Mesial outer curvature relative to central ridge of mesiolingual cusp of maxillary second molar.	Embrasure between the maxillary first and second molars; slightly distal to apex of embrasure.
Triangular ridge of mesiolingual cusp of mandibular third molar.	Mesial outer curvature relative to central ridge of mesiolingual cusp of maxillary third molar.	Embrasure between the maxillary second and third molars; slightly distal to apex of embrasure.

given (static) coronal element occlusion.

Mastication changes the magnitude, the direction and the points of application of the forces applied to the teeth (Part 4). The manner in which it effects the vectors of force so applied is dependent on its pattern, the arrangement and articulaticn of the teeth and their coronal elements, and the nature of the bolus composition. If a hard bolus is to be masticated it will require greater muscular exertion and consequently the magnitude of the forces transmitted through the teeth will be increased. Provided these forces do not exceed the capabilities of the primary and secondary resistance mechanisms they will not produce traumatic effects in the periodontal ligament. Proprioception and neuromuscular co-ordination, which are discussed later, may play a part in limiting the amount of force that can be transmitted through the teeth.

The pattern of mastication described by Posselt (1962) and Beyron (1964) is that of mandibular movement relative to the fixed maxilla which approximates the mandibular teeth to the maxillary teeth for the shearing of a bolus. It is individual and irregularly-shaped in the vertical, horizontal and antero-posterior planes of the head, alternating irregularly to the right and left sides. For purposes of description and treatment it has been resolved into right and left lateral and protrusive excursions. These voluntary motions usually are executed in an opposite direction to the pattern of mastication, although they may form part of it. Because this pattern can be resolved into a cycle of events it has been referred to as the chewing cycle; in the unimpaired dentition it is involuntary, but it may be brought under the control of the volition.

Many factors play a part in the pattern of mastication: in addition to the hardness of the bolus and the articulation of the coronal elements, it is influenced by proprioception and neuromuscular co-ordination. The muscular activity associated with the subconscious performance of chewing indicates that the pattern is controlled by reflex activity. Some proprioceptors involved in these reflex arcs are located in the periodontal membrane.

Posselt (1962), in discussing the intercuspal position, suggested that repeated stimulation is necessary to maintain the reflex arcs associated with the muscular activity of the chewing cycle. He contended that the reflex is obliterated if the contact between cusps is prevented for prolonged periods: for instance by the wearing of a bite guard or bite plate. Clinical experience has shown that if the appliance is removed and the tooth position has not altered, the reflex can readily be reinstated. This evidence points to the fact that repeated stimulation of the periodontal proprioceptors is necessary to maintain the reflex arcs; and that these arcs influence the pattern of mastication if the occlusion of the coronal elements is observed prior to their reinstatement.

The basis for D'Amico's (1958) concepts on canine protection is its position in the anatomical arch, its length above and below the occlusal plane, its size, and its ability to receive proprioceptive stimuli.

The mechanism of neuromuscular co-ordination has engaged the attention of Silverman (1962).

Beyron's (1964) study of the Australian Aborigines, whose teeth show pronounced signs of wear, disclosed a greater horizontal component in their pattern of mastication than that which obtains in Europeans. This can be attributed to the difference in reflex arcs arising from the periodontal proprioceptors of teeth which have and have not undergone marked attrition.

Theoretically it should be possible to change the reflex arcs by altering the stimulus applied to the periodontal proprioceptors. Lewin (1963) has shown that if the cusps on the teeth are so co-ordinated as to guide the mandible into a terminal hinge closure or into a forward acquired position, a different pattern of mastication may become established in reconstructed dentitions. Its effects on the transmission of forces through the teeth may be exemplified by again referring to Beyron's research on the Australian Aborigines: the greater horizontal component in the pattern of mastication may cause the mandibular canine to first occlude buccally rather than lingually to the maxillary canine on the same side.

Although the lingual concavities of the maxillary canines, l.c.m.c., are not the only factors influencing the amount of horizontal deviation, they have been chosen to represent that pattern of mastication which brings all the mandibular buccal cusps to occlude first on the lingual curvatures of the maxillary buccal cusps of the same side. Conversely, the dentitions of the Australian Aborigines and the South West African Bushmen exhibit a pattern of mastication which is not within the l.c.m.c. In both these races the lingual curvatures of the mandibular buccal cusps first occlude with the buccal curvatures of the maxillary buccal cusps.

It is evident that the ideal arrangement of the teeth and articulation of the coronal elements together with an unperverted pattern of mastication allows the transmission of the masticatory forces to pass down their functional axes; and that it permits the periodic tensional stimulation of all the fibres of the periodontal ligament through mesial, distal, buccal and lingual, as well as rotational movement of the teeth during mastication.

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PART 7.

ATTRITION

SUMMARY

The intrinsic and extrinsic factors responsible for attrition are enumerated. The effects of attrition on the relationship of the maxillary to the mandibular teeth are described. The reasons for the changes that occur in the occlusion are discussed.

Stedman (1961) defined attrition as the wearing away by friction or rubbing. In both man and animal attrition of the teeth starts as facets of wear on the enamel or on the enamel and cementum. As it progresses it involves the dentine and this eventually may lead to exposure of the pulp. Although any part of the clinical crown of a tooth may be subjected to the condition it is more commonly found on the coronal elements, which ultimately may disappear entirely. When other parts of the teeth are involved it is termed abrasion. This type of wear will not be considered.

Attrition of the teeth may be caused by extrinsic and intrinsic factors. Although abrasiveness of the food and the nature of the muscular activity are probably the most important of the former, there must be included dietary or locally-produced chemicals, and tooth brushes and pastes and other mechanical cleansing aids which cause a dissolution of the tooth material.

The intrinsic factors are the physico-chemical properties of the enamel and dentine and the occluding relationships of the coronal elements of the maxillary and mandibular teeth. The importance of the latter is indicated by the fact that the dentitions of persons with similar diets do not exhibit the same degree of attrition. It appears that the greater the inco-ordination of the coronal elements during mastication the more pronounced is the wear of the teeth.

The rate of attrition increases if the

intrinsic and extrinsic factors act at the same time. The speed at which it can progress is referred to by Schweitzer (1964); his records show that 3·0 mm. of tooth substance may be lost in three years. The rate of wear also depends on the stage it has reached; once the dentine has been penetrated it becomes more rapid.

The occluding surfaces that have undergone attrition are not really as flat as they often are interpreted to be. They are crossed by shallow but progressively wider grooves; these may be attributed, at least to some extent, to the lips of enamel bordering the abraded coronal elements. If the resultant faceting is correlated with the occluding parts of opposing teeth it will be seen that the enamel lips fit the dentine grooves they have created and which appear to have been gouged out by them during mastication.

A less effective cutting mechanism thus emerges—to the detriment of the teeth. Though compensated by increased height in the teeth, a similar cutting principle obtains in the hypsodont dentition of the horse.

THE CHANGES THAT OCCUR AS A RESULT OF ATTRITION

At two and a half years, in a normal dentition, the maxillary deciduous incisors overlap their mandibular counterparts (Friel 1927). Prior to their loss this overbite is often replaced by an edge-to-edge relationship. This change, usually accepted as normal, is due to either a forward growth of the mandible or to its repositioning.

In adults a similar loss of incisor overlap and overjet is frequently observed. Since the growth factor is negligible in dentitions not complicated with disturbances in the remote factors (Parts 1 and 2), the changes are caused mainly by the decrease in the vertical dimension of the face; on a purely mechanical precept, as the molar teeth become worn the jaws meet closer together and the mandibular incisors move further forward.

The forward relationship of the mandible can be deduced by comparing the molar and premolar relationship in worn and unworn dentitions (Friel 1927). As the wear increases the interproximal surfaces of the teeth become flattened or hollowed out and eventually what originally was a class I becomes a class III (Angle) relationship.

In primitive peoples attrition is found on the incisor as well as on the buccal teeth. If it is sufficiently severe as to result in a forward movement of the mandible, there should be progressive attrition of the lingual concavities of the maxillary incisors and canines. This was not a common finding on the models of Bushmen dentitions examined nor is it evident in all the photographs in Beyron's (1964) treatise on the Australian Aborigines.

Schweitzer (1964) observed that a loss of tooth material may lead to an increase in alveolar bone. The authors can confirm this: they found that many patients with marked attrition do not exhibit a demonstrable decrease in the vertical dimension of the face nor an increase in the interocclusal freeway space. It therefore is reasonable to suggest that in dentitions with attrition of the molar and premolar teeth the vertical dimension of the face may be maintained by a compensating increase in the alveolar bone. This process of course depends on the remote and local factors affecting bone formation providing the circumstances necessary for a positive bone balance.

Beyron (1964) found that in Australian Aborigines with marked attrition there is a difference between the habitual position of maximum occlusal contact and the most retruded position of the mandible. This also proved to be the case in Caucasians with severe wear of the teeth who were examined by the authors.

It is apparent from the foregoing that attrition may result in: a forward movement of the mandible when there is a loss of vertical facial height; its repositioning; a change in the position of the teeth; a combination of all three.

Prehensile activity, made possible by the overjet and overbite, subjects the incisor teeth to attrition which is, initially, divorced from that which mastication induces on the incisors and the occlusal surfaces of the buccal teeth.

TABLE 1.—A COMPARISON OF TEETH WITH AND WITHOUT ATTRITION.

Factor	*Attrition*	*Without Attrition*
Cusp form.	The triangular and marginal ridges show varying degrees of faceting. Finally the cusps are erased.	There may be slight wear associated with maloccluded teeth.
Relationship of opposing teeth.	A tooth-to-two-teeth relationship exists.	A tooth-to-tooth, or a tooth-to-two-teeth relationship exists.
Level of canine above occlusal plane.	The canines are on the same occlusal plane as the incisors and buccal teeth.	The canines are above and below the mandibular and maxillary occlusal planes respectively.
Contact Points.	These are worn and tend to be contact areas rather than points. When viewed from the occlusal aspect they may be straight buccolingually or curved. There is a suggestion that one contact has worn into the other.	These are contact points formed by the curved proximal surfaces of adjacent teeth.
Cusp contact with embrasure.	Since the cusps are worn and the contact areas broad, contact of cusp with embrasure is minimal.	Where there is a cusp-fossa relationship this cannot occur. However, great variation is found with the distolingual and distobuccal cusps of the upper molars.
Incisors.	The incisive edges of the incisors are worn and appear flat. Occlusal forces may have apical or frictional lingual components.	The incisive edges are rounded. Incision subjects these teeth to apicolabial and rotatory vectors.
Overbite and overjet.	There is little overbite but there is overjet in the most retruded position of the mandible in the Australian Aborigines.	There is an overbite and an overjet in the most retruded position of the mandible.
Monson's Curve.	Flattened or reversed.	This tends to be spherical.
Bennet Movement.	Studies of the pattern of mastication suggest there may be increased Bennet movement.	In the young adult there is minimal Bennet movement.
Prematurities.	Because of the attrition these are minimal in eccentric movement. Friction is increased.	When cuspal co-ordination is present there is minimal interference and friction.
Crown-root ratio.	The crown height is proportionately less than unworn crown height. The lever arm is decreased, but friction is increased.	The crown height is proportionately greater than in attrition. Where the coronal elements are co-ordinated there is less friction. The lever arm is potentially greater.
Apparent mandibular position.	This appears to be forward. The inference may be based on tooth relationships rather than skeletal pattern.	The mandible may or may not be forward. The teeth maintain normal relationships.
Habitual closure and centric relation.	There may be a considerable difference.	There may be a marked difference in dentitions exhibiting marked overjet.

Coronal element interferences are often relieved by wear. Co-ordinated coronal element configuration and the co-ordination achieved by attrition do not necessarily have the same impact on the periodontal ligament and the alveolar bone. In the latter the increased frictional resistance alters the resultants of the forces applied to the teeth and thus the periodontal modulation.

The effects of attrition (altered crown form) on the resultants of the forces acting on the teeth were discussed in Part 5. However there are other factors involved, which are included in the accompanying table. In its compilation it was assumed that the dentitions were normal (Angle class I) prior to attrition, hence they were compared with those in which the teeth were normal and unworn.

Depending on tooth morphology, the pattern of mastication, and the relationship between the maxillary and mandibular teeth, attrition may affect the resultants of the forces acting on them with a detrimental or beneficial effect on periodontal modulation.

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PART 8.

MALOCCLUSION AND PERIODONTAL MODULATION

SUMMARY

Orthodontic tooth movement is characterised by a negative bone balance on the side of the root to which it is moving and a positive balance on the side from which it is moving. Masticatory forces producing tooth movement will evoke a similar response in the periodontal bone. The effects of inhibiting such tooth movement have been analysed. It is shown that in many instances the loss of periodontal bone can be related to uncompensated resultants of force acting on these teeth. It is concluded that the inhibition of tooth movement, while the resultants of the masticatory forces tend to displace the tooth which produces a periodontal modulation, causes a loss of periodontal bone.

Lewin (1964) stated that a tooth in traumatic occlusion can respond in a number of ways:

(1) The interference can be worn away by attrition.

(2) The tooth can move so that the traumatic influence is no longer effective.

(3) The mandible can deviate during function producing a parafunction; this in turn can, in time, result in a realignment of all the teeth.

In the same article he speculated that paradontal disease may supervene in cases of occlusal trauma only if these mechanisms are inhibited or impaired.

Some of the factors influencing periodontal bone were discussed in Parts 2 and 3 and it was suggested that, in addition to others, a reduction in tension of the periodontal fibres and the subsequent periodontal modulation is associated with a nett osteolytic response in the affected bone. The response of this modulation to orthodontic tooth movement was investigated by Reitan (1951, 1962), Macapanpan *et al* (1954) and Langeland (1966). Their researches confirmed clinical observations: that there is bone resorption on the side to which a tooth is moving, the reduced tension side, and a deposition of bone on the side from which the tooth is moving, the tension side. These reactions have been related to the age factor by Reitan (1954); and orthodontic treatment of adults shows that among them, too, there is periodontal modulation with its resultant bony changes.

It therefore is clear that, while the resultants of the forces acting on a tooth are angulated to the functional axes and are such that they cause a periodontal modulation, the tooth will, theoretically, continue to move to any position in the jaws.

Tooth movement caused by the resultant of masticatory forces may, however, be inhibited by a number of factors: faulty contact points; inharmonious coronal element relationships; perverted musculature; habits.

The effect of the inhibition depends on the type of the restraint. When it is induced by muscular forces, these vectors of force, together with those derived from mastication, may produce a resultant corresponding to the functional axis of the tooth. Under these circumstances the tooth is not likely to move; all the fibres of the periodontal ligaments are stimulated and the periodontal bone probably will continue to be in a steady state.

An entirely different episode can be expected when the prevailing condition leads to part of the periodontal fibres remaining unstimulated: the periodontal modulation should be comparable with that which occurs during orthodontic tooth movement. If this assumption is correct, the fibres in the region of reduced tension will lose their typical arrangement and the associated bone will tend to be in a negative balance. Depending on the nature and duration of the displacing resultant of the masticatory forces and its inhibition, a loss of bone eventually should become detectable clinically.

It was decided to determine whether the inhibition of tooth movement, when the resultant of the masticatory forces tends to displace it, may be correlated with the loss of supporting bone. For this purpose an investigation was undertaken; besides clinical evaluations, radiographs and casts of periodontally-involved dentitions were examined. The inhibition was manifest in the majority of cases and present but less obvious in the rest.

A. LOSS OF PERIODONTAL BONE IN THE MOLAR AREA.

Example 1. The effect of inhibiting tooth movement while the resultant of the masticatory forces tends to promote it is illustrated in Fig. 1. The resultant of

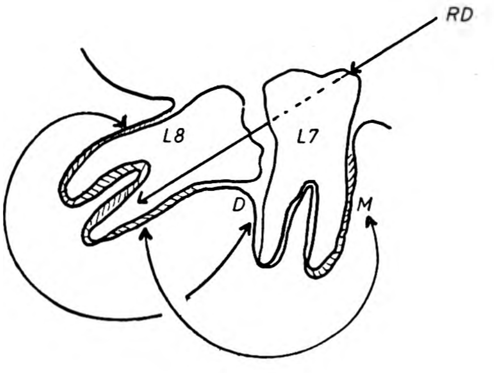

FIG. 1

the masticatory forces tends to move the molar tooth L7 in the direction RD, thus producing a state of tension on the upper mesial sides (M) of the periodontal membrane.

The same resultant will also tend to place the fibres on the upper distal sides (D) in a state of reduced tension. If the molar tooth, L8, was not present, then L7 would move in the direction RD, until it reached a point where the resultant of the masticatory force no longer acted in this direction. The presence of the tooth, L8, orientated as shown, affected the periodontal modulation of the molar L7 as follows:

The resultant of the masticatory force on L7, RD, was transmitted down the functional axis of the molar L8. The molar L8 thus became an effective barrier to the distal movement of L7 even though soft tissue was interposed. While the direction of the resultant, RD, remained unaltered, the modulation of the periodontal membrane on the distal side (D), caused by reduced tension, would maintain a nett osteolytic response; and on the upper mesial side (M) of L7 it would be osteogenic.

The clinical examination of this patient showed that the distribution of the periodontal bone loss corresponds to the regions of reduced tension in the periodontal ligament.

Example 2. Loss of a molar tooth in the mandibular arch not infrequently is responsible for the form of tooth movement depicted in Fig. 2: L8, distal to the lost tooth, tips mesially; and L6 moves distally with or without tipping. As a result

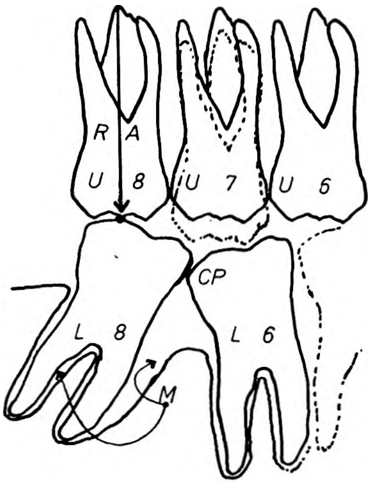

Fig. 2.

of these movements (the forces tending to create them were discussed in Parts 4, 5 and 6), and perhaps because of some extrusion of the molar L8, the contact point at CP becomes so orientated that further tipping is prevented.

The transmission of force along the axis RA which, during the early stages of tipping may have tended to erect the molar L8, now evokes on it a mesial resultant of force from the maxillary molar. Since the nature of the contact point, CP, does not allow mesial movement of the lower molar, L8, or a deflection of the force down its functional axis, the periodontal fibres on the mesial aspects of the root, M, tend to be in a state of reduced tension.

The position of the maxillary molar, U7, also helps to maintain the state of reduced tension on the mesial aspects of the molar L8. As previously described, the location of the fulcrum in the tipping molar is affected by tooth morphology and the resultant of the forces applied to the tooth. If the fulcrum is situated in the vicinity of the posterior root the reduced tension will be greater on the mesial aspect of the mesial root than on the mesial side of the distal root.

Clinical examination showed that the greatest loss of bone occurred anterior to the mesial root and to a lesser extent on the same surface of the distal root. The areas of reduced tension in the periodontal ligament thus correspond to the areas of periodontal bone loss.

The circumstances referred to above are seen in various combinations of tooth tippings and bodily movements in dentitions referred to as having "posterior bite collapse" (Amsterdam 1964), but it is clear that the loss of a posterior tooth does not always give rise to them; adjacent and opposing teeth may become realigned to transmit the masticatory forces through their functional axes (Part 5). Fig. 3 shows how an upper molar, U7, and a lower molar, L7, can move and become so orientated to each other that the resultant of the masticatory forces may still pass along their functional axes. The spacing between the teeth in this figure is intentional; it does not imply that spaces between the teeth will, on their own, prevent reduced tensional effects.

Example 3. In the foregoing examples the forces acting on the teeth and their correlation to the loss of periodontal bone were analysed in relation to opposing teeth. This example was chosen because in it the functional forces acting on one tooth are transferred via contact points to adjacent teeth (Fig. 4).

The resultant of the functional forces acting on L8 pass down its functional axis. Those acting on U7 have a mesio-apical component thus tending to tip U7 mesially. Since this tipping is inhibited by U6, part of the mesio-apical component is

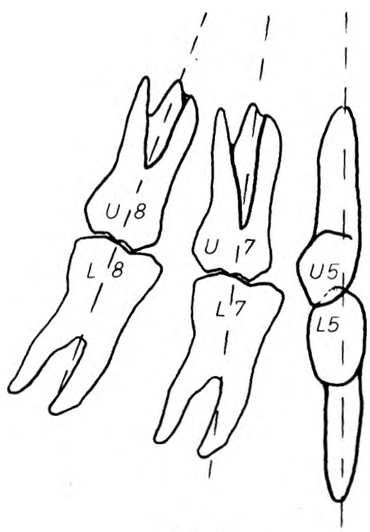

Fig. 3.

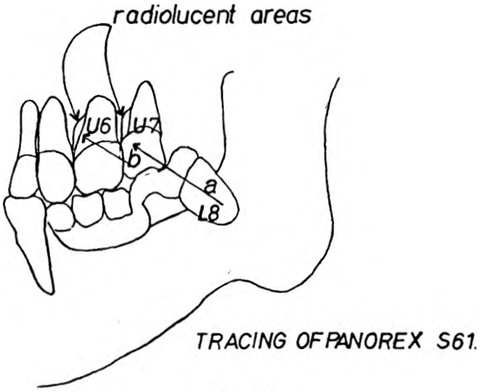

FIG. 4.

transmitted to this tooth. This force, added to others acting on U6, gives rise to a mesio-apical resultant of force. Fig. 4, a tracing of a radiograph, shows marked loss of bone on the mesial aspect of the root of the upper molar, U7, and a lesser degree of bone loss on the same aspect of the adjacent molar, U6. The lower molar, L8, does not exhibit such bone loss.

The resultants produced by the transmission of the masticatory forces to adjacent teeth which cause a reduced tension in the periodontal ligament may be correlated with the distribution of bone loss seen in this and in similar cases examined.

Example 4. A deviation of the resultant of the masticatory forces away from the functional axes and a subsequent inhibition of tooth movement can readily occur if both tooth position and coronal element configuration play a part; such altered transmission of force in the anteroposterior direction is shown in Fig. 5. The maxillary first and third molars, and the mandibular

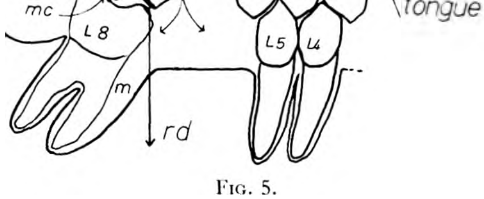

FIG. 5.

first and second molars have been lost. The second maxillary molar, U7, and the third mandibular molar, L8, have tipped mesially.

The triangular ridges of the mesiobuccal and mesiolingual cusps of the lower molar, L8, occlude in the central fossa of the upper molar, U7. The resultant, rd, does not act down the functional axis of L8 and therefore tends to tip it forward. However, the distal curvature of the distal marginal ridge of U7, dc, occludes with the mesial curvatures of the triangular ridges of the distobuccal and distolingual cusps of L8, mc, preventing L8 from tipping forward. This inhibition produces a reduced tension on the mesial root of L8, m. The occlusion of the lower molar, L8, in the central fossa and on the mesial curvatures of the two distal triangular ridges of the upper molar, U7, produces a resultant of force which is transmitted along the functional axis of this tooth.

If compensatory attrition had occurred on the distal curvatures of the distal marginal ridge of U7 and on the mesial curvatures of the triangular ridges of the distobuccal and distolingual cusps of L8, the tipping of L8 would not have been inhibited at this stage. When compared with the bone loss of the other teeth, the loss of periodontal bone on the mesial side of L8 is obvious. The distribution of this bone loss corresponds to that part of the periodontal ligament which is in a state of reduced tension.

The effects of adverse coronal element occlusion are further illustrated in Figs. 6 and 7.

Apart from the loss of bone, the relationship of the coronal elements of opposing teeth may be altered in other ways: by the mesial migration of teeth associated with wear of contact points or by the restoration of cariously involved teeth. Migration may not only alter the contact point relationship but also the coronal element relationships to each other; the maxillary and mandibular teeth may move forward at unequal rates during interproximal attrition or if concomitant rotation takes place together with inequality of attrition. Certain types of coronal element relationships may similarly affect the resultants of the

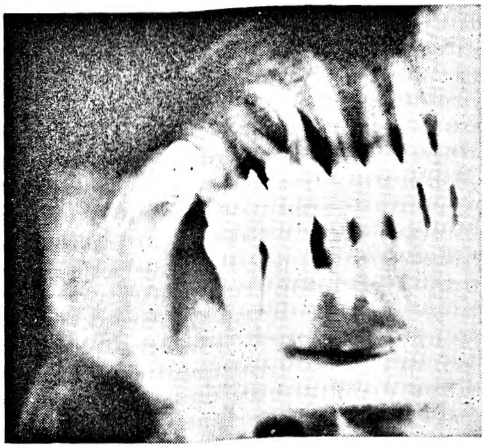

FIG. 6.

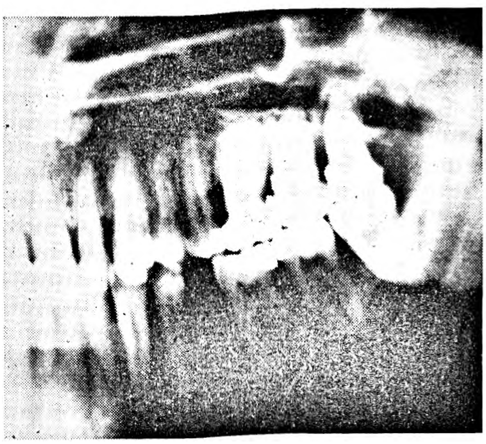

FIG. 7.

masticatory forces in the buccal and lingual directions.

This effect is illustrated in Fig. 8. When the teeth are brought into occlusion the lingual cusp of the maxillary molar exerts an apico-buccal component of force on the mandibular molar (initial contact). The buccal tipping movement is restricted, however, by the buccal incline of the triangular ridge of the lingual cusps of the mandibular molar acting on the lingual incline of the triangular ridges of the lingual cusps of the maxillary molar (stop). This type of occlusion therefore can be expected to produce a state of reduced tension in the buccal aspect of the mandibular molar. There need be no change in the periodontal bone of the upper molar if the masticatory forces are transmitted along its functional axis. In this figure the mandibular molar roots appear to have lingual inclinations because of the initial tipping of the tooth.

Uncompensated disturbances in the coronal element configuration can and do take place concomitantly in both the buccolingual and the mesiodistal directions. When these disturbances are correlated with tooth position, the pattern of mastication, the l.c.m.c. and abnormal lateral movements of the mandible (so-called excessive Bennet movement), all of which act to alter the direction and points of application of the masticatory force, the resolution of the interplay of these diverse factors is not simple. However, where such resolution is possible the localized loss of bone adjacent to teeth is usually associated with resultants of force which do not pass along their functional axes. These resultants were not compensated for by sufficient mandibular repositioning, tooth movement or attrition.

B. LOSS OF PERIODONTAL BONE IN THE INCISOR AREA

Example 1. The effect of inhibiting the movement of an incisor while the resultants of the masticatory forces tend to move it is illustrated by the labioverted lower incisor (Fig. 9).

The maxillary incisor, U1, occluding with the lingual concavity of the lower incisor, L1, directs the resultant of forces acting on this tooth in a labial direction; and when active, the tongue will supplement this labial component of force. The apical forces acting on L1 are reduced as U1 cannot occlude with its incisal edge.

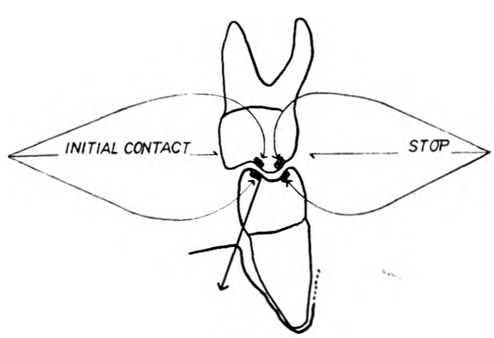

FIG. 8.

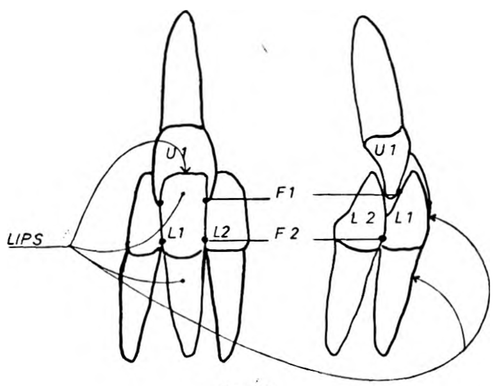

FIG. 9.

However the direct forces derived from the upper lip may compensate for the reduction of apical stimulation.

The protrusion of L1 will increase the direct lingual forces derived from the lips. The influence of these forces will depend on their magnitude and on the relationship between L1 and its opposing and adjacent teeth: they inhibit labial movement of the crown of the tooth or, if they are of sufficient magnitude, they may cause it to tip lingually with the fulcrum either at F1 or F2; and this will lead to the root being displaced labially. Most of the forces acting on L1 will thus tend to produce a labio-apical resultant. Clinical examination showed that this labioverted lower incisor is often associated with varying degrees of loss of supporting bone; and that the greatest loss customarily occurs over the buccal aspects of the roots of such teeth.

This distribution of bone loss suggests that when the limit of periosteal bone deposition is reached and the forces emanating from the lip further inhibit movement of the tooth, the consequent negative bone balance causes the localized recession of bone. It is concluded that a correlation exists between the loss of periodontal bone and the forces exerted on such a labioverted lower incisor.

Example 2. The effect of altered crown form (attrition) of the lower incisors on the resultants of the masticatory forces were described in Part 4. The apico-labial forces acting on the lower incisors may be related to the loss of supporting bone seen in some dentitions with this degree of wear.

Example 3. The loss of bone between the incisors in both the mandible and the maxilla with an apparent alignment of the crowns and roots and an apparent absence of local and remote aetiological factors, is not uncommon. In these dentitions an analysis often shows that the resultants of the forces acting on canine and incisor teeth are altered.

Apart from variations in the labio-lingual plane the maxillary canine can be mesial to, directly overlap, or be distal to the mandibular canine; and they can be in various degrees of rotation in any of these mesiodistal relationships. In most cases they will have mesial, distal, buccal or lingual vectors of force exerted on them by volitional positioning of the mandible; it is on their relationship that the extent of these vectors depends. When it is such that the occluding surfaces of these teeth are subjected to a mesial resultant of force (Fig. 10), their tendency, in maxilla or mandible, is to move in a mesio-buccal direction. This movement is resisted by the lateral incisor and in some measure by the direct pressure of the lip.

Part of the mesial force is transmitted through the proximal contact of the lateral incisor and, to a lesser extent, the other incisors. The resultant forces exerted on the canines and laterals is thus predominantly in one direction.

With a similar canine-incisor relationship on the opposite side of the arch the resultant of force will again be predominantly in the mesial direction.

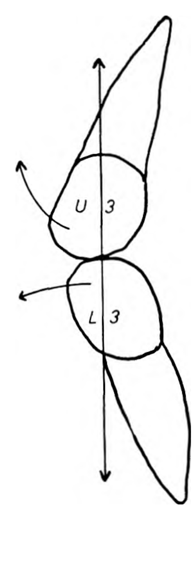

FIG. 10.

The two resultants arising from the canines may be equal. However, they are not opposite. If the incisors were in a straight line between the canines and the resultants of the forces acting on the canines were *medial*, these two forces could cancel each other and even act as osteoblastic stimulae. However, the incisors are not in a straight line and the resultant acting on the canine is mesial. The curvature of the arch alters the resultants of the forces arising from the canines in such a way that lingual components may be produced on the incisors (Fig. 11). Where mesial components persist a larger area of lower incisor root surface is subjected to reduced tension on the mesial aspects of these roots (Part 5).

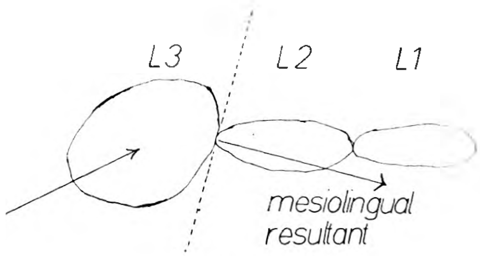

FIG. 11.

In many patients the loss of bone in the incisor region which could not be accounted for by other aetiological factors, could be related to abnormal resultants originating from malposed canines.

The canine relationship described can also be associated with imbricated mandibular incisors. In such cases the imbrication need not have been caused by the specific canine relationship initially, but may be perpetuated by it. Eventually this relationship gives rise to resultants which may be correlated with the distribution of the bone loss in the incisor region.

Although the authors' analysis indicates that periodontally-involved dentitions are associated with, and therefore may be initiated by malocclusions which deviate the resultants of the masticatory forces away from the functional axes, all malocclusions do not necessarily cause a deviation of the resultants of the functional forces. Where deviations are produced which cannot be compensated for by the fibrous arrangement of the periodontal membrane, adverse periodontal modulation must supervene. This may have a bearing on a recent study which showed that, except for class II malocclusions, no correlation can be established between periodontal disease and malocclusion (Gould and Picton 1966).

The results of this investigation do not show a cause and effect relationship between a state of reduced tension in the periodontal ligament and the loss of periodontal bone; at present this relationship is accepted as the mechanism responsible for tooth movement in orthodontics. The findings do show that a loss of supporting bone may be correlated with inhibition of tooth movement while the resultants of the masticatory forces tend to displace that tooth. It is suggested that such inhibition of tooth movement causes a periodontal modulation which in areas of reduced tension results in the loss of periodontal bone.

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