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Tissue response to orthodontic force application

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Abstract
Orthodontic appliances may profoundly influence the morphology and structure of the craniofacial complex. This paper identifies the various regions under these influences and reviews some investigations on the effect of appliances on the teeth, periodontal membrane, alveolar bone, craniofacial bones and the orofacial musculature. The complexity of reactions resulting from the interaction of these factors is highlighted. The understanding of these basic tissue reactions, the planning of simple mechanics and the monitoring of these treatment-induced changes using suitable progress record systems, is stressed as necessary if controlled treatment is to follow.

Key Words: Force systems, tissue response, biomechanics, treatment monitoring.

INTRODUCTION

Orthodontists, either knowingly or unknowingly, may elicit reactions as a result of appliance therapy in regions of the craniofacial complex quite remote from the immediate dento-alveolar structures. These various reactions may on occasion be detrimental, and the advantages of treatment must always be weighed in relationship to the unwanted or even potentially damaging side effects.

Few investigators have reported upon the long-term effects of orthodontic treatment on the periodontal tissues (Sadowsky, 1979). The gnathological aspects of our work have, however, been examined and questioned on an increasing basis over the past few years. While little basic information is available in these areas, the data relating the specific tissue reactions to our appliances has been accumulating in abundance. This paper will review some of the author's and his associates' more recent observations relating to such structures as the teeth, periodontal membrane, alveolar bone, craniofacial bones, and the orofacial musculature.

TISSUE RESPONSE

Decalcification

The teeth themselves constitute the primary site of appliance force application. Decalcification of the enamel due to free acid in band cement is rarely a problem, providing the manufacturers' mixing procedures are closely followed. However, decalcification beneath or around the margins of bands can be a severe aesthetic problem and demands careful attention by the clinician. The two most important preventive measures in this regard are the placement of well-fitting bands and careful patient oral hygiene. To improve the latter, many clinicians reinforce their own verbal efforts by using pamphlets and/or slide/tape patient education material.

The advent and widespread use of adhesive agents for direct or indirect attachment bonding to the teeth has not alleviated the decalcification problem but has merely changed the pattern. The "bull's-eye" circles of the decalcification sometimes seen on the labial and buccal surfaces of teeth following the removal of these attachments detracts markedly from the appearance of the teeth. Removal of excess adhesive from around attachment bases and good oral hygiene will help control this problem. A concomitant problem involves the interproximal areas. Well-fitting bands seal these areas of the teeth during treatment, whereas bonding leaves them exposed during an age period of high interproximal caries susceptibility, and it is incumbent upon the orthodontist to recognize this potential problem.

Root Resorption

Gross root resorption of teeth subjected to orthodontic treatment is unusual in the degree shown in Figure 1. However, it is probably true to state that most orthodontically-moved teeth show some cementum damage at the histological level. Even untreated teeth occasionally show damage, and the rat molar shown in Figure 2, for example, demonstrates such a change. Clinically, root resorption ranges from minor repaired cementum defects to marked radiologically visible apical blunting.

Pulpal Changes

The assumption is generally made that the dental pulp is unaffected by orthodontic tooth movement. Studies to examine the response of this tissue is fraught with experimental methodological difficulties. Tissue damage due to extraction or block-dissection in humans where prior tooth movement has been undertaken introduces artifacts rendering histological interpretation suspect. Studies in experimental animals have also often given conflicting results due to tissue fixation artifacts.

Recently, Holmberg (1980), undertook an

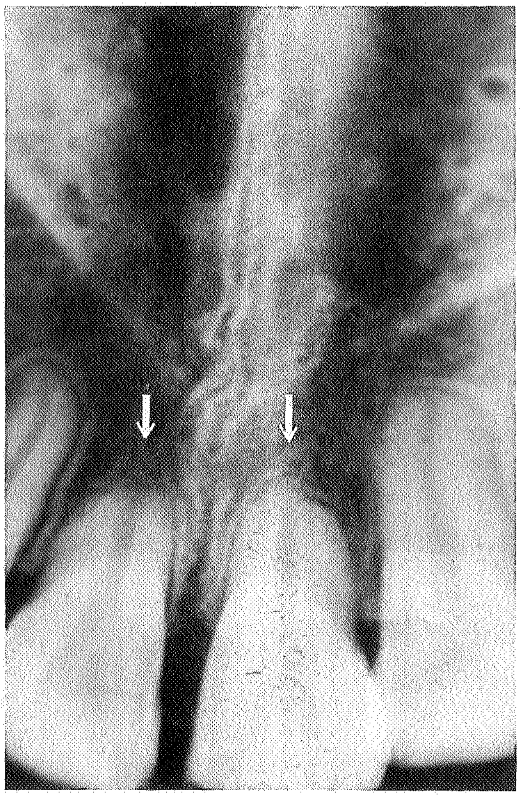

Figure 1 Upper central incisor root resorption. Orthodontic bands recently removed.

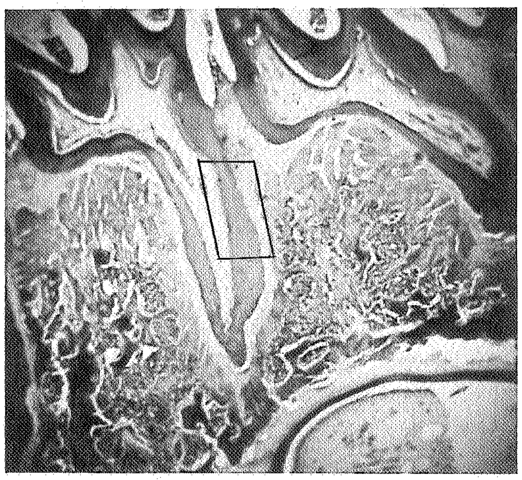

Figure 2 Photomicrograph of rat molars. Minor degrees of cementum resorption can be noted.

experiment in monkeys in which the effect of both tipping movement and intrusion of incisors were examined. Appliances and force-levels were designed to approximate those used in routine clinical orthodontics. A modification was made so that the teeth on the contra-lateral side were not subjected to appliance forces and were used as control teeth for each animal. (A careful perfusion fixation technique was used to help offset the possible occurrence of fixation artifacts.)

This study showed that following a six-week period of appliance therapy, the teeth subjected to intrusion demonstrated pulps with an increase in cellular activity and increased fibrosis. The animals given a ten-week retention period following active tooth movement showed essentially normal pulps, suggesting that pulpal reaction is transitory. Of importance in this study was the finding that intrusion is more likely to cause pulpal change than simple tipping movements, and that all changes seem to be reversible following appliance therapy.

Periodontal Membrane

The periodontal membrane is the adaptive structure involved initially in all orthodontic tooth movement. This complex and highly structured group of tissues acts as an adjustment site and behaves in many respects like an inter-bony suture. Numerous histological studies have helped document the morphological alterations of the dental-supporting tissues resulting from tooth movement. The work of Reitan (1952, 1967), is noteworthy. The classical description of the vascular, cellular and fibre-orientation alteration on the "pressure" and "tension" sides of a tooth undergoing tooth movement has been refined in recent years (Storey, 1973). Increasing efforts have also now been directed towards determining the underlying biochemical phenomena associated with these changes.

Electron microscope studies have shown that fibroblasts are able to alter their shapes and position, and the recognition that specialized types such as the myo-fibroblast with contractile properties exist, has added to our understanding of the mechanism of tooth movement. The importance of the connective tissue fibre type and orientation has led to an increase in understanding relative to treatment stability and relapse potentialities with direct clinical implications. Transeptal fiber sectioning to help control rotational relapse is one controversial example stemming from this information (Edwards, 1970).

Cellular Responses to Tooth Movements

The mechanism by which appliance forces cause cellular responses remains unclear. Davidovitch (1979) has noted that chemical and/or physical phenomena could be implicated. Prostoglandins may be involved, as may be the contents of damaged cells. He feels that cell membrane permeability is also implicated. On the physical side the "piezoelectric" effect demonstrated in mechanically stressed bone has been of direct interest in recent years.

Types of tooth movement are often described as "tipping" or "bodily"; and directions of movement as intrusion, extrusion, rotation, and proclination, etc. From a histological point of view, it is unlikely that any of these modes of movement exist in pure form. A force designed to give primarily one type of action will elicit a mixture of responses involving several combinations of these modes. This mixed reaction and the concomitant non-uniform response of the periodontal membrane and alveolar bone makes the response to appliance forces even more difficult to predict and interpret at the clinical level.

Extrusion of the teeth is probably the least damaging. The orientation of the principal fibre bundles, and a reduced likelihood of constricting the vessels in the vascular bed, may be key factors. The normal eruptive potential of teeth (even those in occlusion) may also enhance this type of movement. Animal experiments by Schneider (1965) support this contention. Also, from a clinical point of view, extrusion would seem to occur only too readily as a result of orthodontic appliance therapy.

Conversely, intrusion of teeth often proves to be a difficult manoeuvre. This movement is often cited as potentially the most traumatic in terms of tissue damage, and even pulpal reactions have been observed in experimental animals (Holmberg, 1980). The predominantly conical root shape requiring massive bone remodelling and occlusion of the vascular bed are probably important reasons for this damage. Added to the "intrusion" controversy is the limitation of some cephalometric superimposing techniques, and clinical evidence to conclusively document intrusion of teeth in our patients. At best, many appliance systems probably accomplish little more than to inhibit tooth eruption while allowing adjacent teeth to erupt, thereby resulting in a relative intrusion movement of the treated units. This is most unfortunate, in that the clinician is often most desirous of intruding certain teeth in many malocclusions where vertical abnormalities occur (for example, deep overbite and some types of open bite problems). One of the clinical problems associated with true intrusion is the shortening of the clinical crown with gingival swelling. Good home care would seem to be the only remedy for this problem.

Alveolar Bone

Following the initial response to tooth movement by the periodontal membrane, the alveolar bone becomes the site of most of the permanent adaptive change. New layers of rapidly formed bone in the "tension" areas of the socket help restore the normal width and morphology of the supporting structures (Figure 3). Providing the force levels have not caused extensive stasis and cell death on the "pressure" side, active resorption can be noted on the socket wall (Figure 4). However, in many instances due to tissue damage, no active remodelling of the socket wall adjacent to a pressure zone occurs. Instead, resorptive processes are initiated in the adjacent cancellous spaces of the alveolar bone, and the socket wall is remodelled by "undermining" resorption. This process takes time, and for this reason heavy forces result in little tooth movement beyond that accounted for by the periodontal membrane elasticity and perhaps alveolar bone flexing for two or three weeks. Later, with continued application of forces, the whole alveolar process becomes progressively remodelled and these changes will keep pace with the amount and direction of the tooth movement (Figure 5).

Craniofacial Complex

For many years clinicians considered that orthodontic appliance forces caused changes

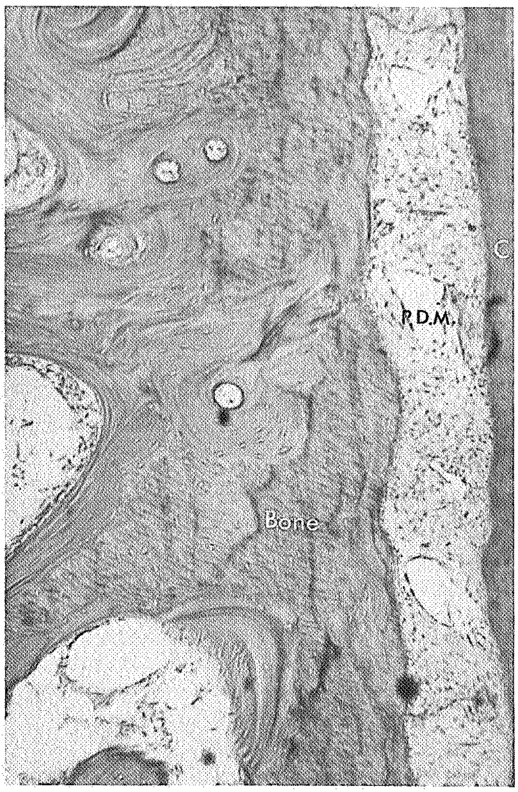

Figure 3 Photomicrograph showing the response to tooth movement in the alveolus of a monkey. The "tension" side is depicted. Cementum (C) is noted on the right side followed by the periodontal membrane (PDM). New bone formation can be seen lining the alveolar bone margins.

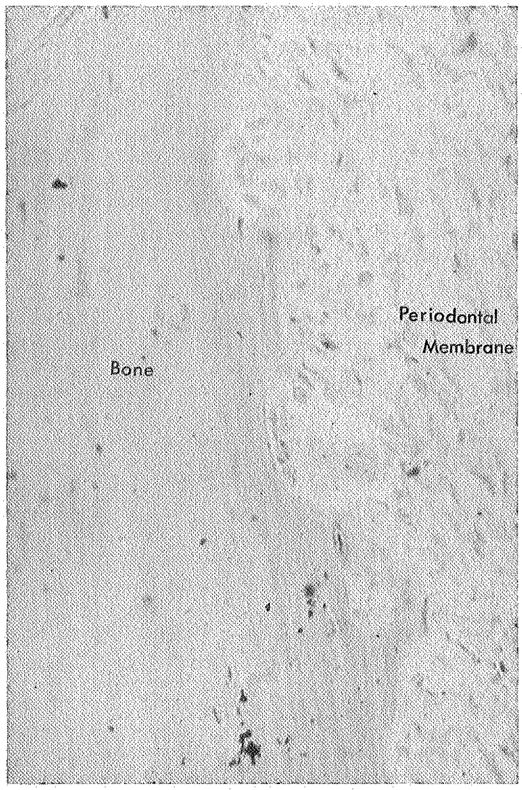

Figure 4 The "pressure" side shows active bone resorption of the socket wall adjacent to the moving tooth.

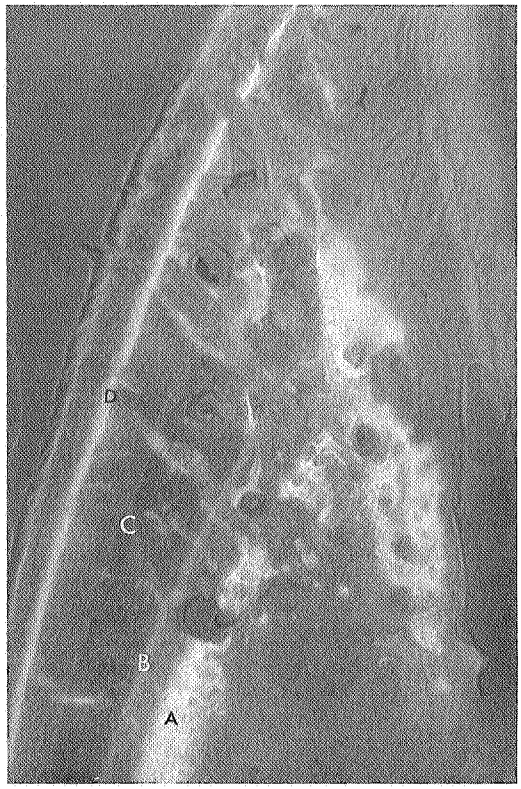

Figure 5 Photomicrograph of an undecalcified section taken under ultra-violet light. Tooth movement in this rabbit elicited a response in the alveolar bone on the outer surface of the alveolar process as can be seen by the segmented lines of bone-marking agents:
a. Terramycin c. Trypan Blue
b. Alizandria Red S. d. Terramycin

limited to the alveolar process alone. It was felt that the so-called "basal bone" could not be altered. The inherent inaccuracies and interpretation problems associated with cephalometric films probably contributed to this conclusion. From a biological point of view, however, bone cells will react to applied mechanical stimuli at any site. Provided the stimulus is transmitted further than the alveolar process there is reason to believe that remote responses should indeed occur. The craniofacial bones are designed to embody only sufficient bone mass arranged in a specific architectural configuration to ensure the dissipation of functional loads placed upon any given site. Application of orthodontic forces will also be transmitted through the head and will signal adaptive remodelling responses in the bones. The various adaptive structures and mechanisms must include, at least, the sutural systems, synchondroses, and surface apposition and resorption.

Muscle Changes

Statements which infer that whenever a conflict exists between muscle and bone it is always the bone that gives way are well accepted by many clinicians. As a result of cinefluorographic work on deglutition (Cleall, 1965) and form/function experiments on animals (Ryll, 1972), the author does not subscribe to this simplistic relationship. Work in our laboratory by Muhl et al. (1975), has now added basic biological evidence that indeed, muscle has considerable ability to adapt to changes in its length-tension parameters. The addition and subtraction of sarcomeres and periosteal muscle drift characteristics, apart from modulation of muscle function via the neurological side of the system, would all add credence to the evidence for adaptive capacity of the soft tissues.

FORCE SYSTEMS

Orthodontic v. Orthopaedic

Traditionally, intra-oral force systems have been used for the correction of malposed teeth. These have ranged from forces generated from various fixed and removable appliances, through muscle harnessing systems (functional appliances) to simply utilizing tooth drift phenomena, such as in serial extraction procedures. Of major importance, but not to be specifically discussed in this paper, is the use of craniofacial growth as a potent force in assisting the clinician to bring about the desired rearrangement of structural parts.

The increasing use of various types of extra-oral appliances has introduced new dimensions in treatment possibilities. Also, with the application of much higher loadings on these appliances, the potential for advantageous, or, on occasions, untoward modification of remote sites, has become manifest. During the past several years, the use of the term "orthopaedic" forces has become widely used to describe these heavier forces. Their application is purported to result in major changes in the bony units, with little dental alteration. Apart from the basic biological considerations which make the likelihood of force level/tissue response interactions fall into neatly defined "orthodontic" or "orthopedic" categories somewhat doubtful, our experimental studies involving both animals and clinical patients strongly suggest that this division is arbitrary and probably meaningless.

Animal Implant Studies

A radiographic cephalometric study involving metallic implants in a group of rhesus monkeys in which heavy headgears were placed was undertaken, to examine the response to these force systems (Henry, 1976). Marked changes in the position of the teeth, facial skeletal structures, and even alteration in the cranial base and back of the head were noted. Subsequent histological examination of the tissues has characterized the detailed structural changes in the sutures, synchondroses, and bony units responsible for the radiographic findings (Figure 6). Extensive tooth movement was observed, with marked evidence of undermining resorption in the alveolar process. Evidence of sutural adjustment and changes in the pattern of bone formation adjacent to the cartilaginous synchondroses in the cranial base was also seen. Finally, remodelling of the surfaces of bones also supported the radiographic suggestion of widespread altered bony contour.

Clinical Headgear Studies

A subsequent study of records in which heavy headgear forces had been applied to the maxillary complex of patients with severe Class II Division I malocclusions produced similar although less dramatic changes (Haas, 1979). This radiographic cephalometric study, in which 43 subjects were compared with a similar but untreated group, directly paralleled the major changes noted in the monkey experiment. Statistical comparisons made

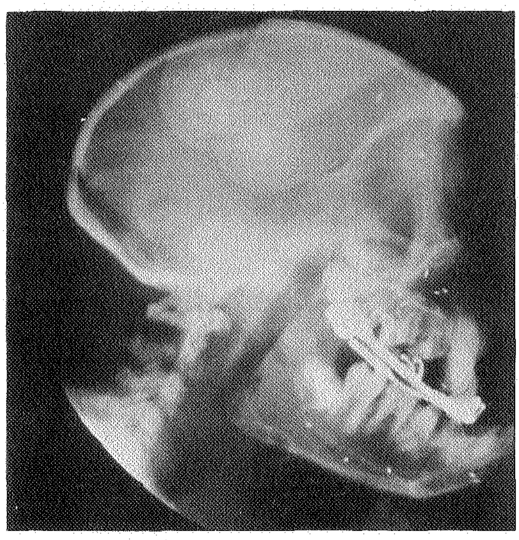

Figure 6 Cephalometric radiograph of a monkey in which metallic implants had been placed. The effects of three months of heavy headgear force on the maxillary complex has resulted in major morphological modifications. Note the gross retrusion of the maxilla in a species with a normally protrusive facial profile.

between the treated and untreated groups showed that growth and/or treatment changes were markedly different. Whereas the maxillary complex in the control group was found to be displaced downward and forward with growth, this region was noted to exhibit a downward and backward displacement in the heavy headgear group. Alterations in the maxillary dimensions, and the rotation of this structure plus changes in the growth pattern of the mandible were also demonstrated to be statistically significant. An example (Figure 7) in the form of cephalometric polygon plots shows some of the changes observed in this study.

As Newton's third law requires that every action has an equal and opposite reaction, a change in the bone morphology at the back of the skull in the above-mentioned implant monkey study subjected to heavy headgear was predictable. Indeed, a measurable bony change was noted, and this leads one to speculate the probable existence of remote reactions to extra-oral orthodontic appliances elsewhere in the head region. For example, it is conceivable that the common use of cervical neckstraps attached to tooth-borne facebows may result in altered cervical spine morphology. A radiographic investigation of this possibility is currently under way.

Tissue and Structural Interactions

The flow diagram in Figure 8 summarizes in relatively simple form some of the structural entities and intermediary tissues or mechanisms

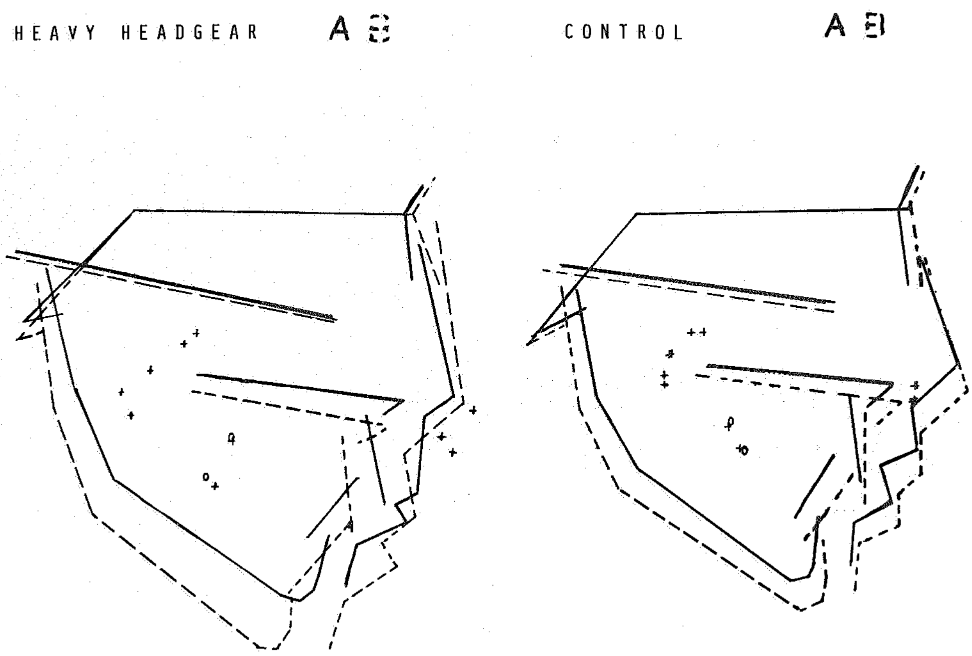

Figure 7 On the left, radiographic cephalometric polygon plots of a patient subjected to heavy headgear forces. Note the major changes in growth vectors from the normal pattern, illustrated on the right "control".

that may be involved, to greater or lesser degree, in response to appliance-generated force systems. This cybernetic system includes many direct actions and responses plus several modulating and negative feedback effects which will ensure a balanced adaptive response to appliances forces. The probable complex nature of these interactions may well be responsible for the apparent variation and unpredictability in clinical response when even relatively simple and well-controlled appliance forces are applied to the teeth. When this is added to the vagaries of growth in the late mixed dentition and early permanent dentition periods, the clinician's occasional apparent lack of precision can be understood.

Biomechanics

Provided the clinician knows the force level and direction applied by an appliance, it should be possible to predict the response of the tissues in any given situation. However, even the ability to predict the simplest types of tooth movement often seems difficult. Mulligan (1979), has recently written a series of interesting papers in which relatively simple fixed appliance force systems were discussed in terms of their fundamental components and modes of action. Mulligan astutely points out that what the clinician thinks an archwire is doing is often very different from the actual response. The use of a gable bend, for example, in the lower bicuspid region can result only in the mutual tipping of adjacent teeth, due to the balanced nature of each equal arm of the archwire (assuming similar root morphologies), and the two teeth cannot move as a unit vertically in space (Figure 9a). However, the application of unequal lever arms as in Figure 9b, results in several types of differential movement (a "two by two" appliance using round wire would be an example in which upper first molars and upper central incisors are banded). The incisors should become depressed due to the light intrusive forces placed upon them. As the attachment is situated labial to the centre of resistance of the incisors, a palatal root torquing action is possible with a round wire (cue ball effect). The reaction at the distal short lever arm ends of the archwire is to tip the molars distally, markedly. Also, there is a pronounced extrusive vector applied to the teeth. Although this is an easy type of tooth movement to accomplish, it is probably resisted somewhat by the occlusal forces of the opposing teeth. The whole unit tends to rotate in an anti-clockwise direction and the final result is some incisor intrusion. The neutralizing effect of the occlusion may be partially responsible (depending upon inclined plane cuspal relationships) for some resultant distal translation of the molars. Depending upon whether the archwire is passive (Figure 10a), stopped and advanced (Figure 10b), or tied back (Figure 10c), varying antero-posterior

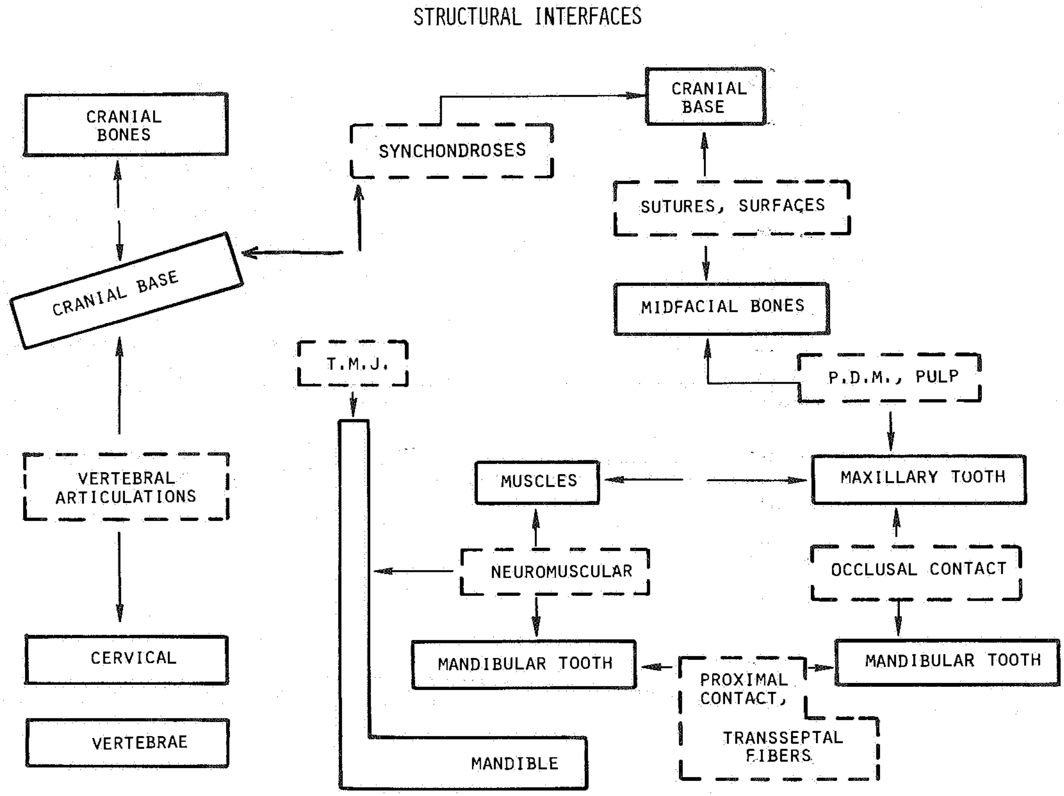

Figure 8 Diagram suggesting some of the interactions of various structural entities in the head region, and noting some of the possible modulating tissues and processes.

movements of the incisors can be accomplished. The lower example in Figure 9c shows a rectangular archwire in which anterior palatal root torque has been incorporated. The marked unopposed extrusive forces on these teeth in deep overbite cases, and especially if Class II elastics are added, may well greatly detract from the overall successful treatment of the malocclusion.

It is apparent that even with these simple appliance systems, the introduction of a few extra variables such as cuspal relationship, angulation of incisors, and archwire length will increase the possible variation in response manyfold. Furthermore, the introduction of headgears, transpalatal bars and multiple or complete banding must again add to the number of response possibilities. It is therefore little wonder that no matter how carefully the clinician plans the mechanics, the response to treatment in some instances is unpredictable.

CLINICAL SIGNIFICANCE

Despite this apparent lack of precision in our appliance handling, the orthodontist is often very successful in achieving a fairly close approximation to the desired tooth positions. The reason for this success rate may in large measure be a reflection of the adaptive capacity of the stomatognathic system rather than the clinician's expertise. Our central aim is to further increase this success rate in the correction of malocclusion, and to this end it behoves the clinician to:

(i) Understand the basic tissue reactions likely to occur in the craniofacial structures as a result of the broad categories of appliance-generated forces.
(ii) Determine from adequate diagnostic records the detailed position that each tooth (and hopefully, bony unit) should eventually occupy at the end of the treatment.
(iii) Plan the simplest and most controlled combination of mechanics to achieve these spatial results.
(iv) Monitor the changes carefully (clinically, cephalometrically, photographically, and progress study models).
(v) Be prepared to modify the mechanotherapy immediately if untoward responses are observed.

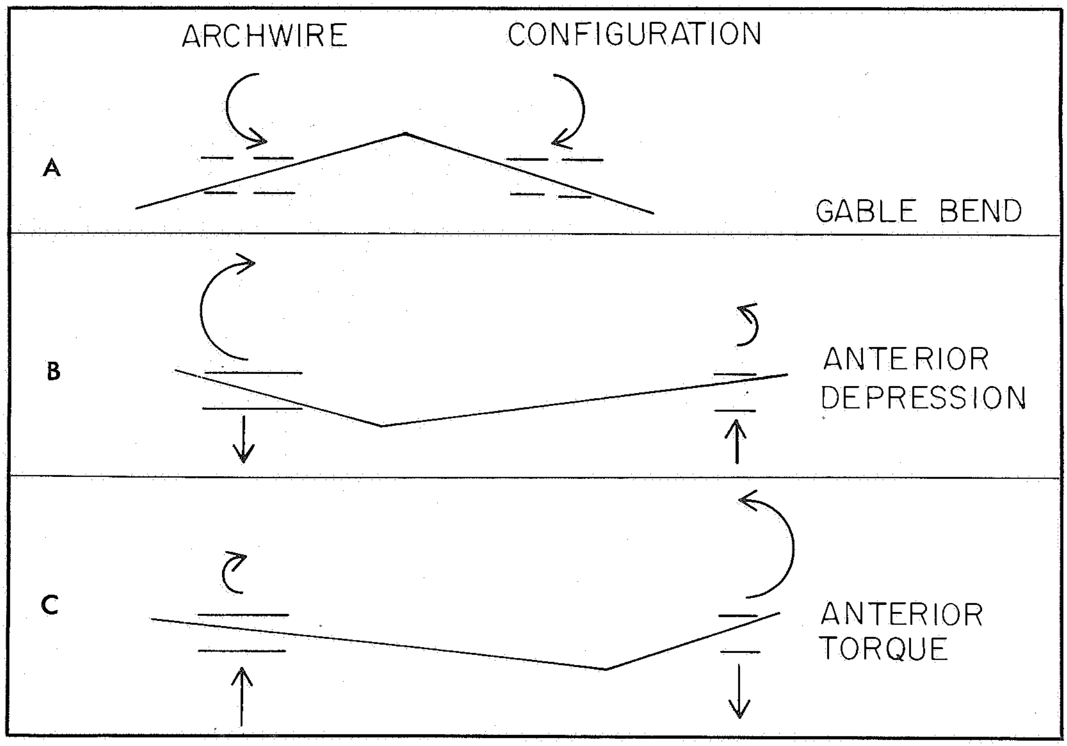

Figure 9 Showing resolution of forces in a series of simple appliance applications (modified from Mulligan).

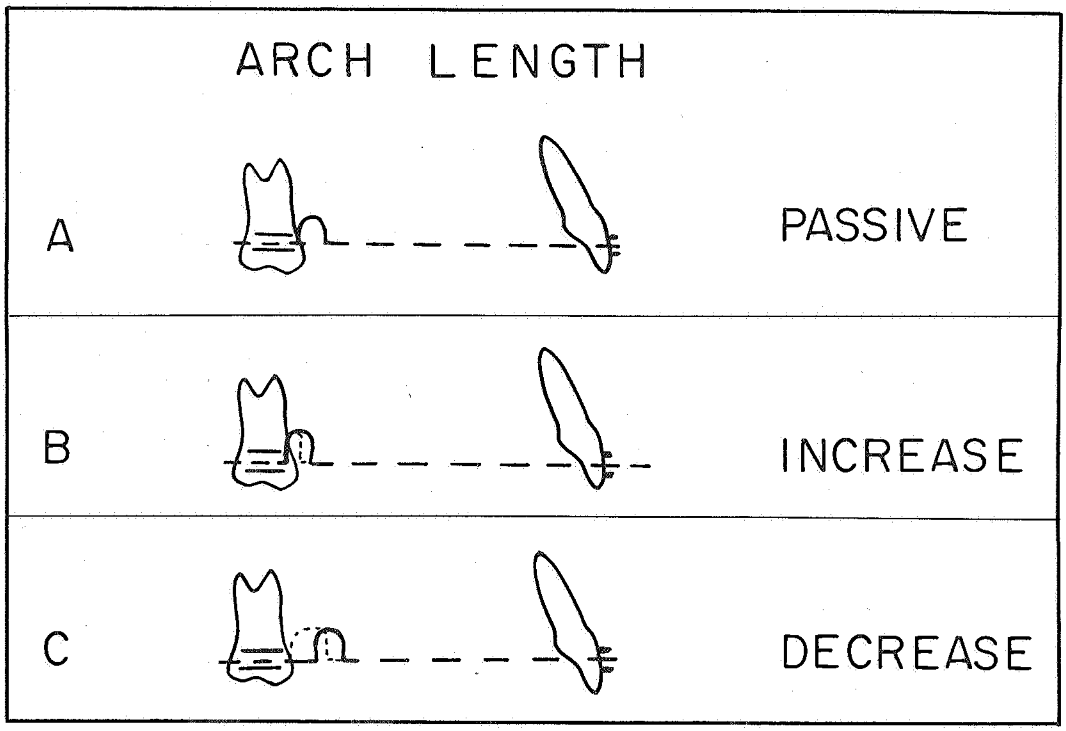

Figure 10 Change in length of an archwire will influence the resultant tooth movement.

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