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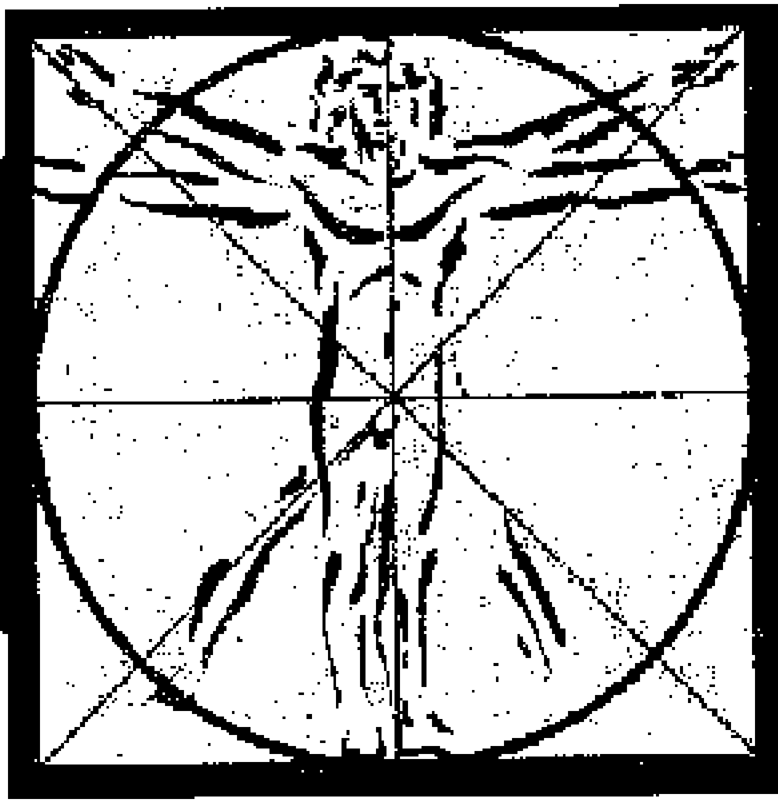

CONCEPTS OF MECHANICS AND BIO-MECHANICS

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MECHANICS AND BIOMECHANICS

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CONCEPTS OF
MECHANICS AND BIOMECHANICS

by Robert M. Ricketts, D.D.S., M.S.

CHAPTER ONE: APPLIED MECHANICS AND BIOLOGIC LAWS

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CHAPTER ONE
APPLIED MECHANICS AND BIOLOGIC LAWS

INTRODUCTION

Positive and precise control have been sought by orthodontists through the use of fixed appliances. With them, a rapid treatment became an underlying but candid objective. The main attraction of the "Edgewise" mechanism was that all teeth could be corrected simultaneously. Teeth were to be corrected relative to each other in the individual arches while coexisting intermaxillary elastics were to accompany the whole maxillo-mandibular correction.

Because it had been found that with intermaxillary elastics a Class II molar relationship could be corrected in three months, it was reasoned that all the other teeth, with lesser root size, should be corrected at the same time. This was described in 1928 by Brodie, to his later chagrin, because with that technique anchorage was grievously lost and the face was unattractively elongated. Concurrent use of elastics is still taught with the Begg approach which is significantly high in extraction rates. The question keeps presenting itself regarding forces, quick results, and the wisdom of "tipping". The argument also deals with safety, or tissue preservation.

It should be borne in mind that at the time of the promotion of the Edgewise appliance by Angle most clinicians also assumed that intermaxillary traction stimulated mandibular growth. However, this was before the advent of cephalometrics, wherein science could play a role in more exactly determining treatment changes. Less attention was given to the manner in which movements were accomplished. Only the results were the objective regardless of the consequences.

A concept of limitation developed as a result of those early Edgewise procedures. Five negatives in particular were especially limiting. First was the belief in the impossibility of tooth intrusion. Second was the inability to safely produce ridge modification with expansion, particularly in the lower incisor area. Third was the inability to move molars distally. Fourth was no possibility of maxillary orthopedics. Fifth was the unpredictability of practically any result in terms of growth or mandibular behavior. If these in general were improbables, then the answer was extraction and mandibular rotation for closed bite (Fig. 1-1).

Popularity of Mechanics

In the application of Bioprogressive Philosophy, no specific technique is identified. Rather, a combination of many modalities are to be employed in a sequence. This is in marked contrast to being advised, that the Edgewise bracket with the rectangular wire were "all that is needed" or that round wire with a Begg bracket will accomplish all objectives. Computer composites clearly show, however, that different results are achieved when different mechanisms are employed. Standard Edgewise technique non-extraction opened the mandible 3° while Bioprogressive, with upper and lower utility arches, actually closed the chin slightly (Fig. 1-2).

The concern is not with the type of bracket employed, but with how it is to be used, where it is applied or what is to precede it, and the differences in the objectives deemed possible. These issues form the basis for major differences within the profession and are the subject of this manual.

DOCTRINE OF LIMITATIONS

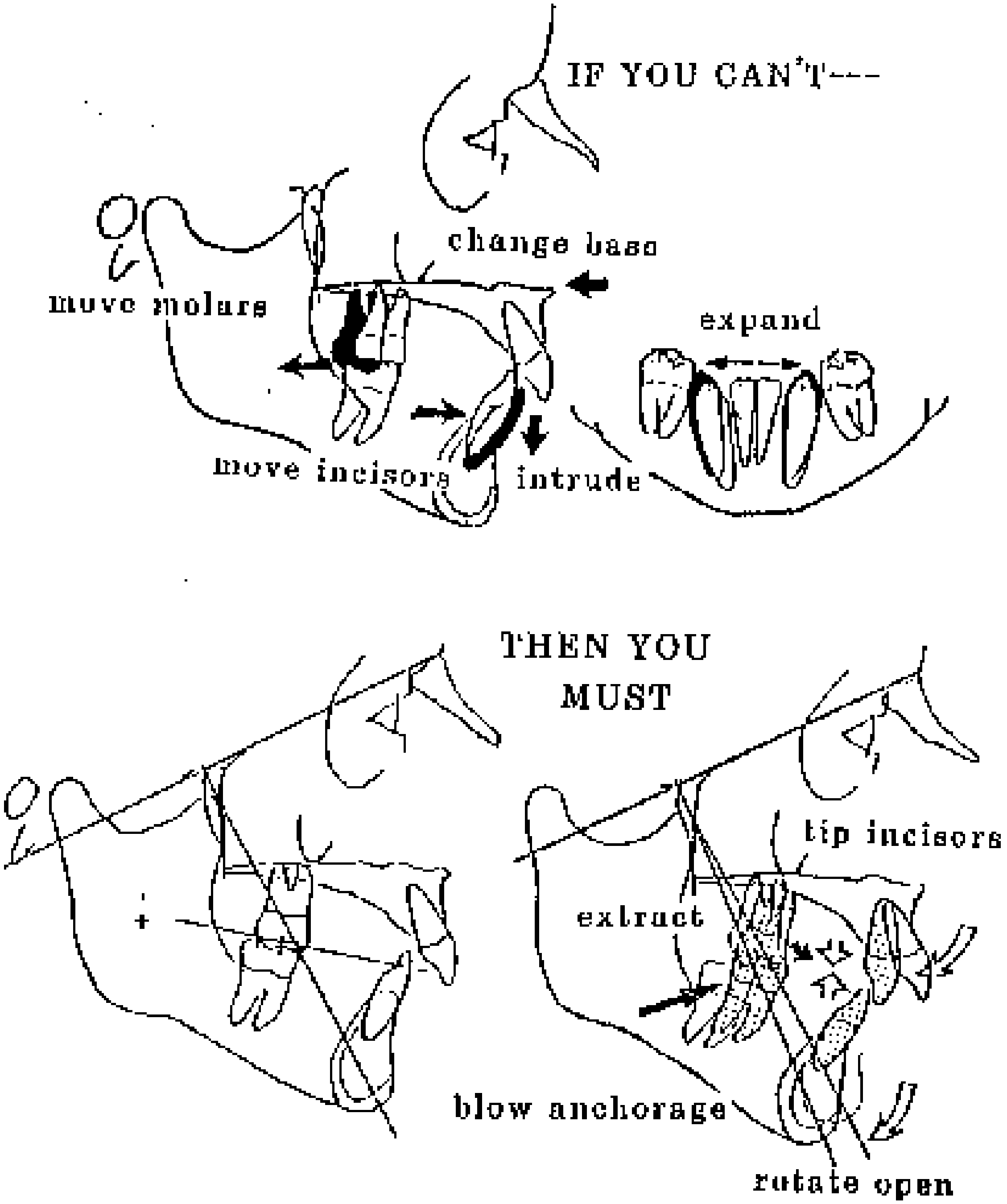


Fig. 1-1 If skeletal and certain tooth changes and prediction of the outcome are impossible, then Class II deep bite conditions demand extraction and mandibular rotation.

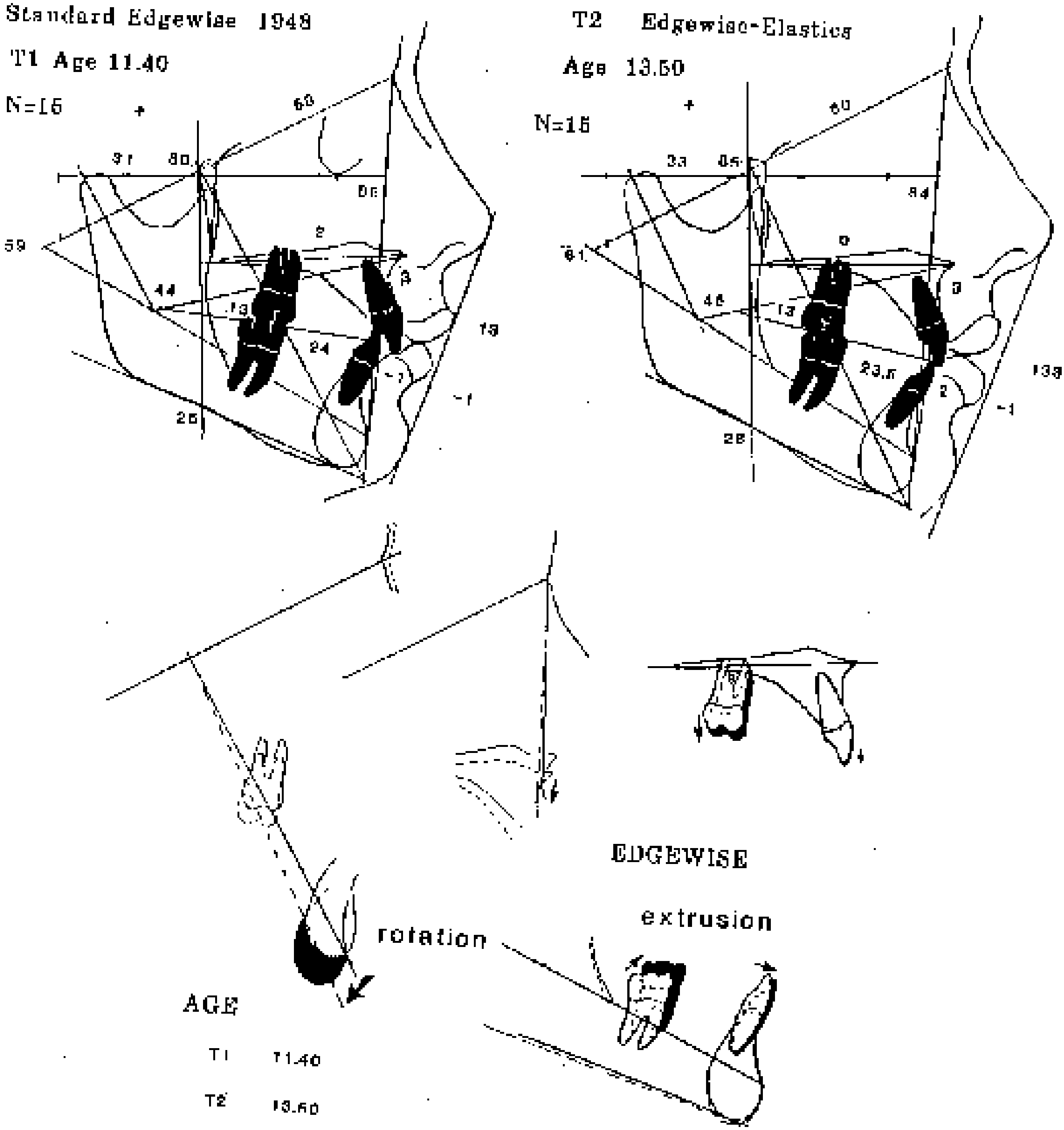


Fig. 1-2A T1 and T2 composites of 15 children treated non-extraction standard Edgewise, as practiced in 1948, on average rotated the mandible, lengthened the face, lost lower anchorage and did not reduce the maxillary component.

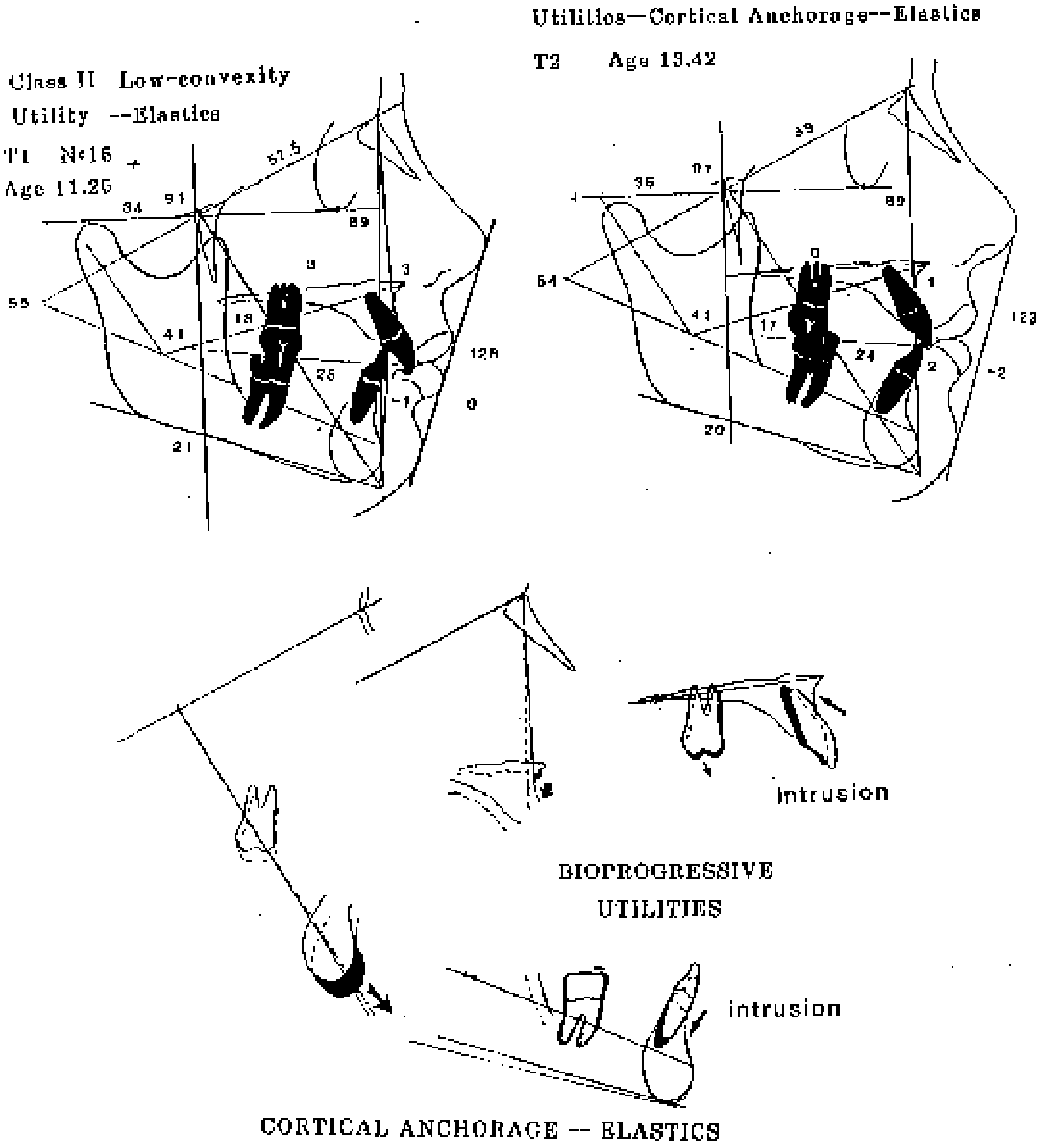


Fig. 1-2B T1 and T2 composites of N=15 Class II, Division 1, deep bite treated with Bioprogressive. Same age treated with utility arches and cortical anchorage. Note maintenance of chin, anterior intrusion and little anchorage loss. Compare to Fig. 1-2A.

Principles

Despite the variety of procedures currently available, often with a modality bearing the same label, but employed differently, there are underlying principles that need to be clarified. These principles in essence form the basis for the selection of mechanisms and serve as a guide for force or pressure application. The technique chosen may have a direct bearing on whether or not extraction is employed and the result to be achieved. Thus, a philosophy obtains -- a philosophy which is composed of an integration of more than one hundred principles pertaining both to the physical nature of appliances and the biology of reactions.

Physical and Biologic Laws

When scientists in the 1890s found the architecture of bone to be consistent with engineering principles of design it came to be believed that physical laws had essential control over morphology. Scientists made a mistake in overlooking the more basic laws which were biologic in nature because the influence of biologic factors was less evident. It was found to be fallacious to try to explain morphologic phenomena purely in terms of mechanical laws. Yet the mechanical-physical laws may serve as a starting point for understanding and communication of orthodontic mechanics. Any consideration of biomechanics will start with applied mechanics.

APPLIED MECHANICS AS A BASIS FOR TEACHING

Applied mechanics is a branch of physics. Applied mechanics is divided into "statics", which concerns resistance, and "dynamics", which deals with displacements, motion, and actions in the physical sense. Physicists seek "laws", which are derived from facts and truths, and which have no exception. Through such laws the technical world has advanced to reach the stars and send messages through the core of the earth. The physical laws do provide a basis for science.

But living tissues, such as connective tissue, muscle and epithelium produce a variable in "friction" to a motion. This changes the laws of application of applied mechanics. Mechanics is concerned with the application of physical laws which perhaps start with Newton's laws of motion, Hooke's laws of stress and strain, Boyle's laws of pressure, the physical properties of materials. Mechanics also includes the laws of friction.

It is well known that when compared to circumstances in the natural air, bodies behave differently in a vacuum, in anti-gravity fields, or when opposed by water. In addition, within the construction of a given device, such as a bridge, a body must be calculated to overcome the bearing of its own weight plus the loads it is intended to support. Therefore, even in the natural physical world, equilibrium of forces is required for stability, as a tree must support its weight plus the winds that bend it.

In order for a body to remain stable, equal and opposite forces must operate. And because two forces directly opposite are almost impossible, forces operating from various angles are necessary for equilibrium. The balancing force is called an equilibrant for mechanical stabilization to be attained (Fig. 1-3).

Homeostasis

General biochemical equilibrium, and the maintenance of that equilibrium through the body's systems, has been called "homeostasis". For want of a better term the author has called this phenomenon a mechanical or physical homeostasis in a biologic context for the stability of joints. This also applies to the stability of teeth, and the general nature of mechanical equilibrium within the body (see Fig. 1-3). When teeth remain stable they are said to reside in a "static neutral zone" relative to the muscles.

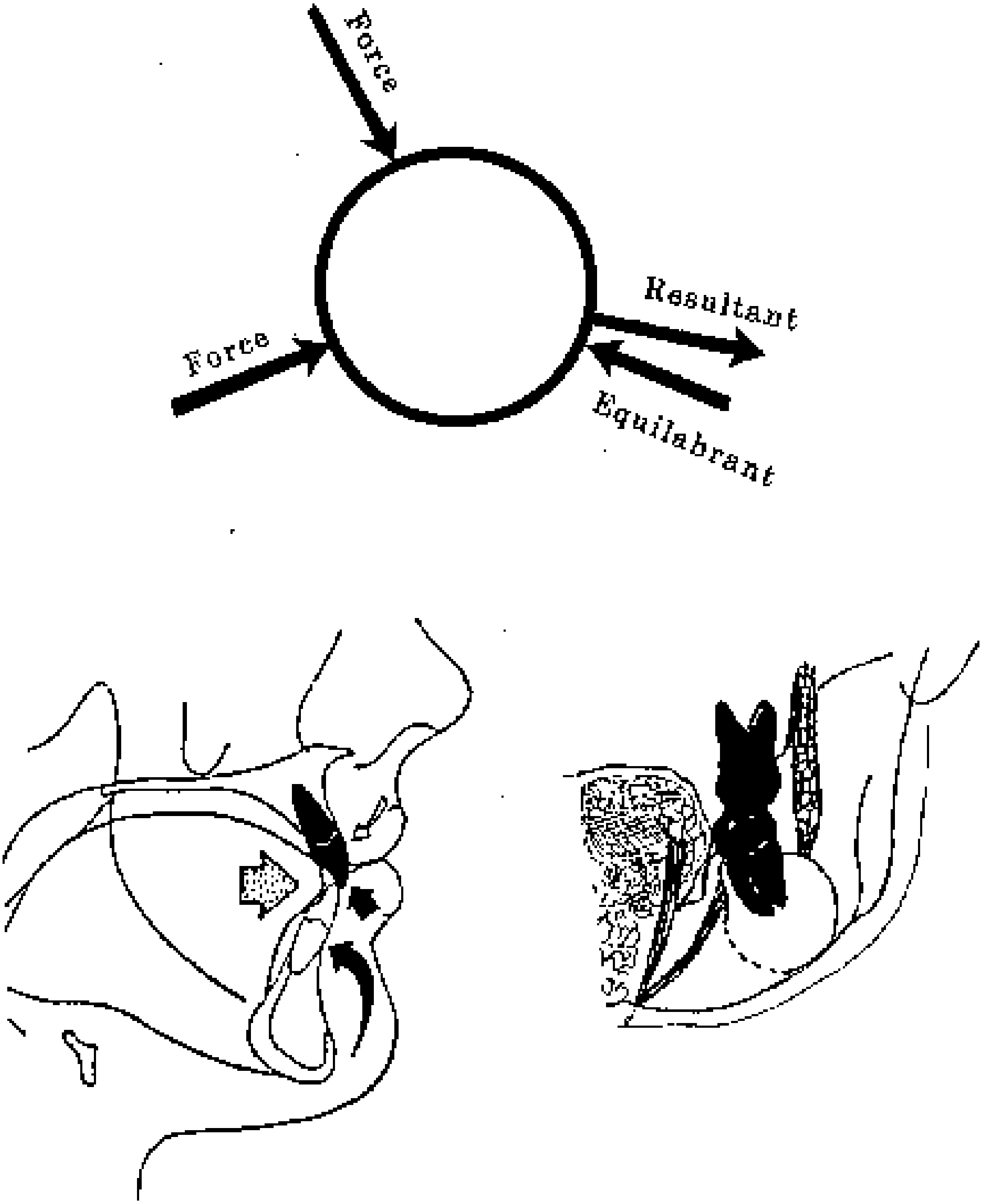


Fig. 1-3 Force analysis and three-dimensional concept of physical homeostasis of the human occlusion. Notice the lower lip contains the upper incisor perpendicular to its long axis.

PHYSIO-CHEMICAL HOMEOSTASIS AS A KEY TO ORTHODONTICS

Every joint in the body is surrounded by an equilibrium of force in order to maintain stability and health. The gomphosis, the attachment of the tooth, is a joint between bone and root. For normal movable joints, ligaments surround the joint in a capsule and the muscles are attached through tendons in such a manner that the joint's integrity is protected. The human jaw mechanism is special (Fig. 1-4).

Muscles of the tongue and lips create a balanced environment, and muscles of mastication determine height for the oral cavity. But fascial planes, connective tissues, including periosteum, and even epithelial tissues enter into the balance.

Law of Adaptation

Balance is a loose term meaning equality, but an underlying law in physiology not often recognized is the "law of adaptation" in order to attain equilibrium. To further appreciate this law it is necessary to understand the effort made by the body tissues to recover from states of imbalance or the production of a new state of balance, or homeostasis, when disturbed.

If the muscle on one side of a joint is lost a new equilibrium will be established for the joint. The connective tissue on the disturbed side of the joint may be employed to offset the stabilizing elastic resistance of the muscle on the opposite side which "takes up the slack" until a new equilibrium is reached. In fact, the orthopedist Dr. Arthur Steindler described such conditions and referred to this type of muscle behavior as a non-painful "dynamic imbalance contracture". The muscle's reaction is to establish a new point of equilibrium for the joint, if not opposing another muscle, and the muscle takes up resistance against connective tissue. This is seen clinically in orthodontics with diseases of the mandibular condyle, causing a shortening of the condyloid process and subsequent elevation of the coronoid process and ramus relative to the zygomatic arch (Fig. 1-5).

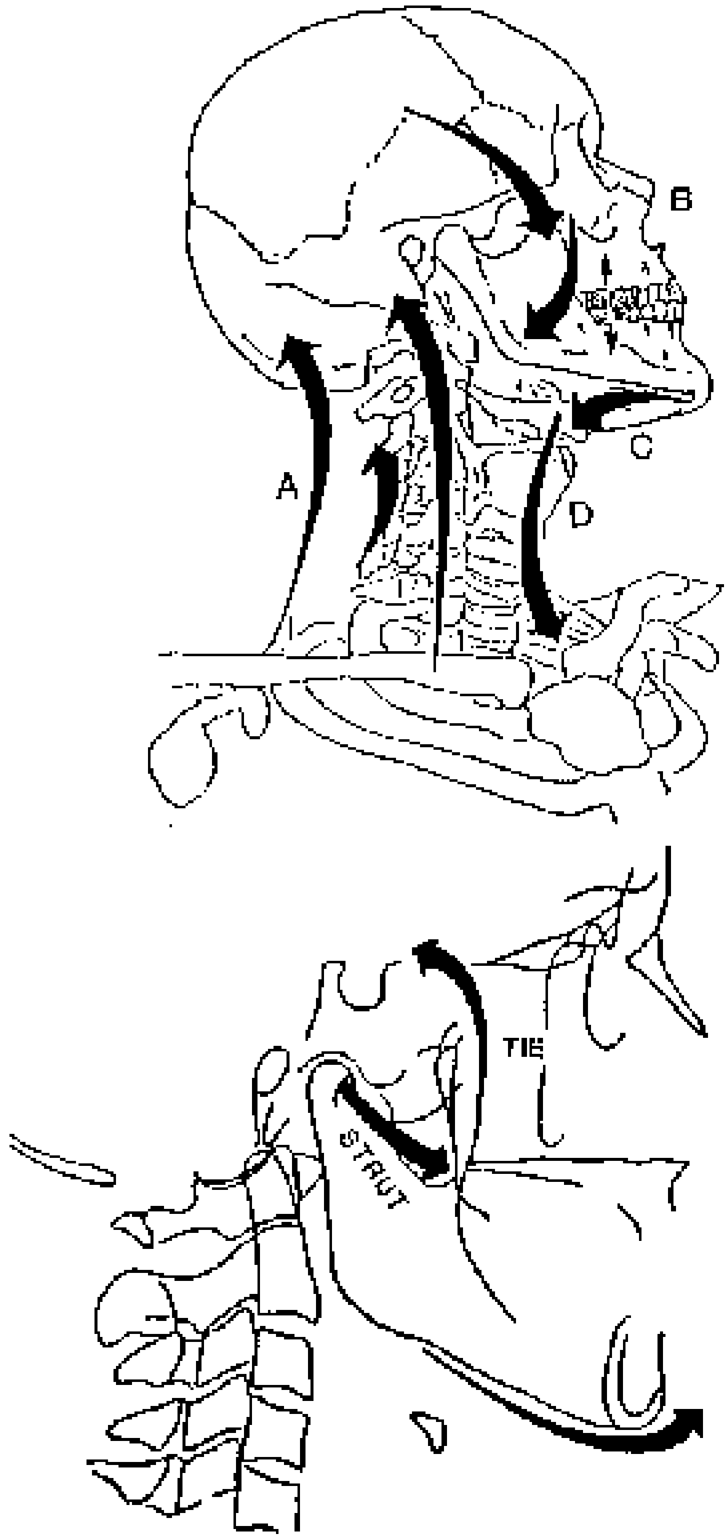


Fig. 1-4 Not only the teeth but also the mandible is sustained by muscle equilibrium.

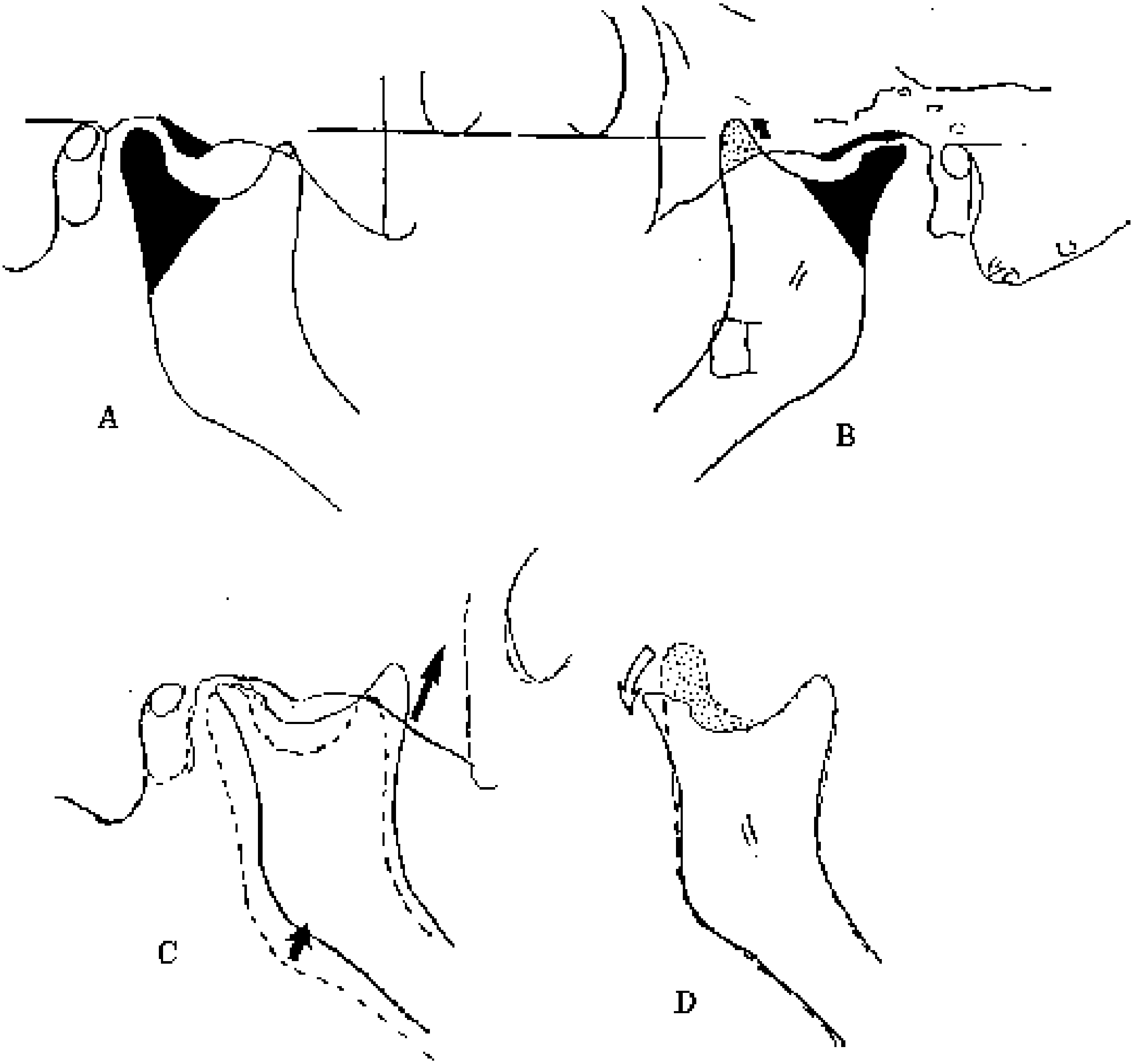


Fig. 1-5 Unilateral degenerative joint disease.
A. Left side normal. B. Right side advanced breakdown -- note alteration of size and form of condyle and fossa. C. Comparison shows displacement of ramus upward by muscles. D. Shows condyle shortening and bending.

RECOVERY FROM IMBALANCE THE KEY TO ORTHODONTICS

A more pertinent phenomenon, for the orthodontist, is represented in the attachment of the tooth to the alveolar bone. When a pressure is applied to the tooth, it is common knowledge that the ligament is stretched on the tension side, and compressed on the pressure side. Thus, the original length of the fibers and equilibrium of the periodontal membrane is disturbed.

The length of the periodontal ligaments is relatively short, being in the range from one-tenth to one-fourth of a millimeter, depending upon the given tooth, and its conditions under function. It is the general law of adaptation that comes into application for tooth movements to be successful. After the movement the membrane on each side wants to return to normal length. This is the body's attempt to restore a normal equilibrium or homeostasis both chemically and physically. The system struggles to regain the normal dynamics (Fig. 1-6).

Thus, the general physiology will attempt to maintain the reduced space on the pressure side by resorption of bone and fill in the increased space on the tension side by the apposition of bone around the stretched fibers so that they may return to a normal length. This is indeed the secret to tooth movement but it also applies to alveolar modification or bone management in general. It is also an immediate factor in growth or structural modification.

It is within this same context that other bones in the body react to normal growth, to the repair of fractures and to the adaptations to change in function. Dr. Don Enlow described the processes occurring as surface resorption and endosteal apposition, which is the mechanism for bones to drift in adaptation to different functional matrices. It may be within these biologic processes that drift of teeth occurs. It is with all these natural processes that the present teaching manual is concerned.

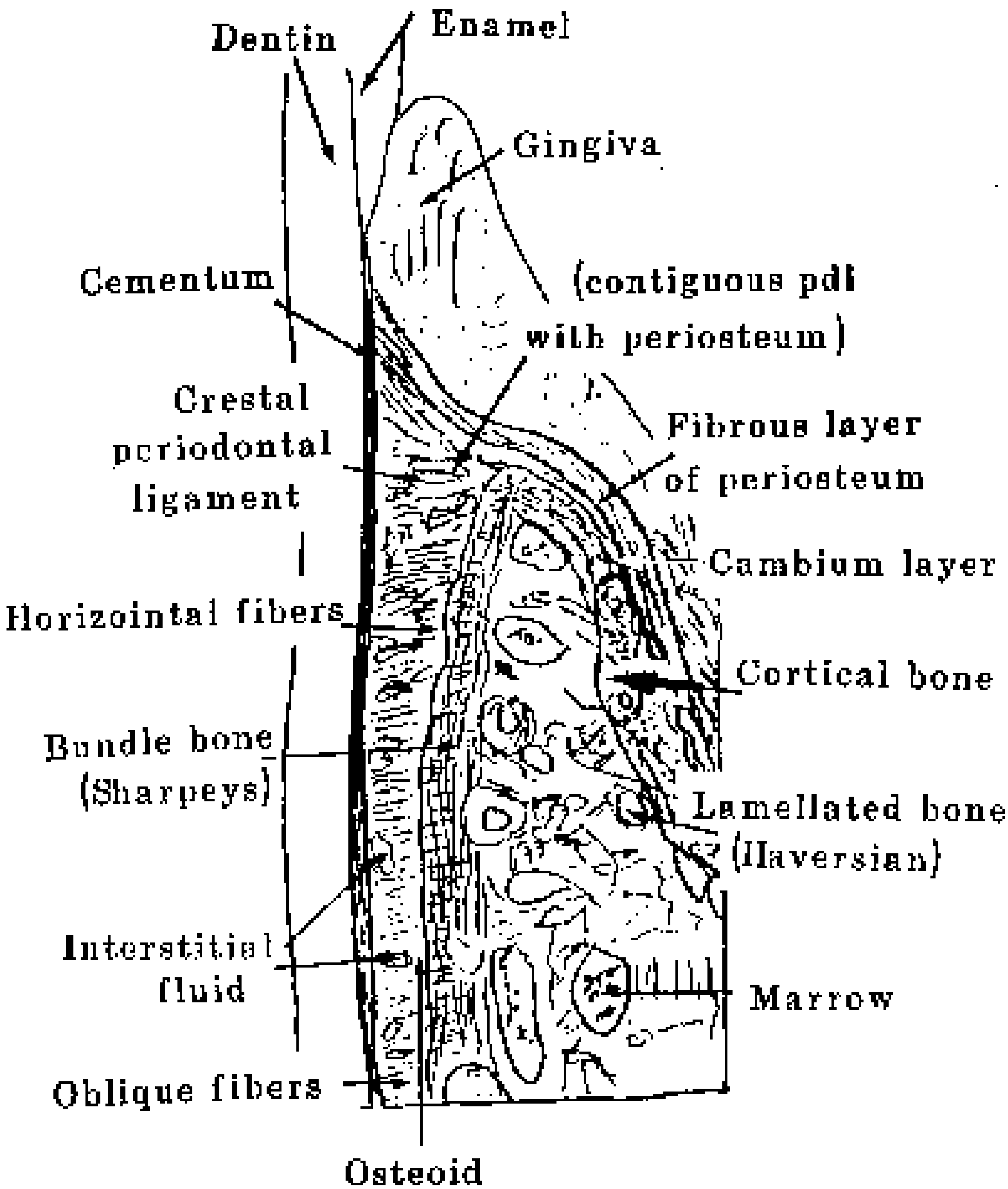


Fig. 1-6 Diagram of cross section of tooth attachment to alveolar crest. Note ligament contiguous with periosteum. Note bundle bone for periodontal fibers and cortical bone with Haversian systems on the buccal side. Note interstitial fluid spaces in the periodontal membrane.

CELLULAR NEEDS AND FLUID MEDIUMS

In order to maintain health and to maintain reproduction of cells leading to homeostasis, all the cells in the body, which are in fact tiny, living organisms on their own, have four main essential needs. These are: (1) oxygen, (2) nutrients, (3) elimination of waste, and (4) a physical-chemical balance which includes an acid base and an electrolyte equilibrium (Fig. 1-7). If any of these four is not available, the cell will struggle for survival. The internal mechanism of the cell may go through changes for the process of its individual continuation of life. In fact, the absence of this normal basic process might even be a cause for the formation of metaplasia, neoplasia, or aplasia.

In order for the individual cell to be supplied, three fluid mediums are provided by Nature. The first fluid medium is intracellular or within the cell itself. Just as the whole body cannot survive dehydration, each cell must maintain its own fluid. The intracellular fluid is absolutely necessary for the life and performance of the individual cell, it is a living organism on its own.

The individual cell, however, gets its nutrients and oxygen from its surrounding fluid. This is the interstitial (or intercellular) fluid, which has many functions. It provides the essentials for the life of a cell, but it also is a reservoir for the cell's wastes and biproducts. No cell can survive in its own excrement. Therefore, interstitial fluid becomes a key to individual cell health (Fig. 1-8). This applies to the cells and tissues of the periodontal membrane together with the bone cells and the connective tissue, muscle, and nerves as well as the base of epithelial tissue.

For maintenance of interstitial fluid, in its proper balance, there is the third fluid medium, which actually is composed of two systems. The cardiovascular system, through the arterioles and venules, serves the interstitial fluid. Oxygen is brought to the interstitial fluid, together with nutrients. In addition, progenitor cells, hormones, enzymes, and all of the products needed for cellular function are supplied

CELLULAR NEEDS

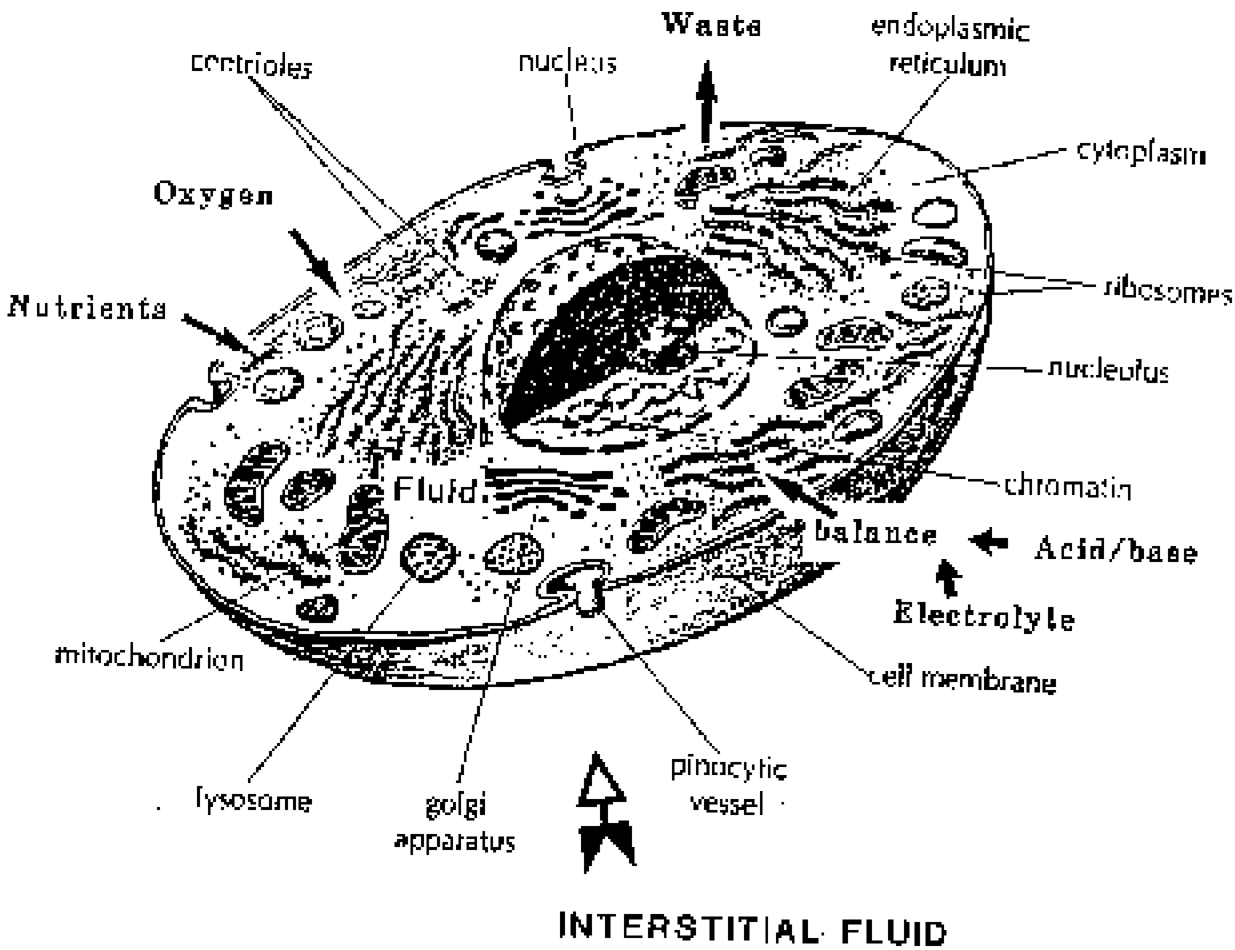
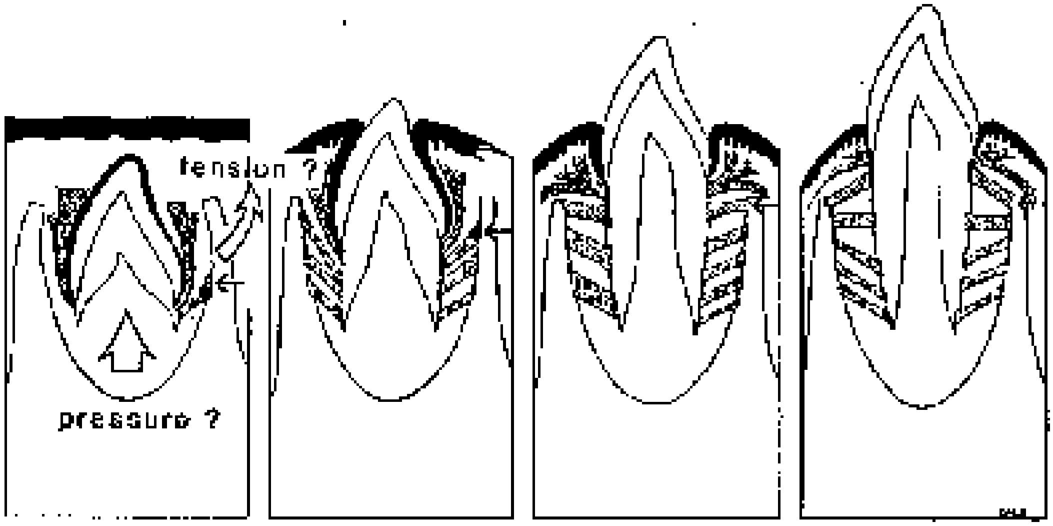
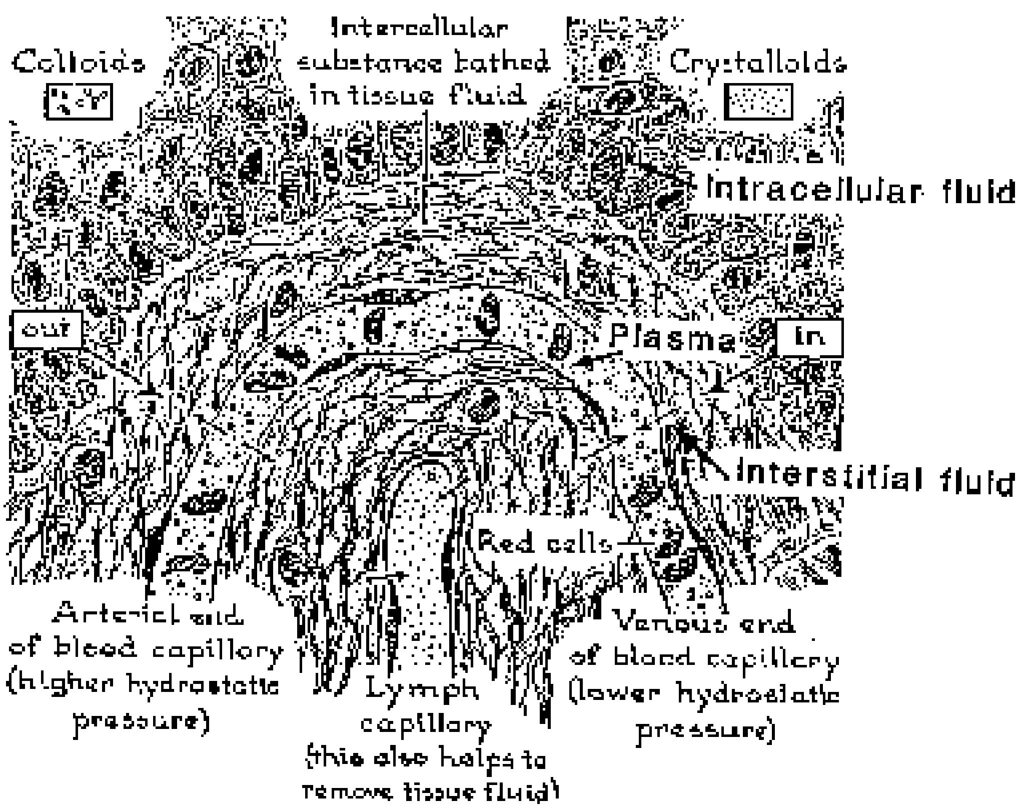


Fig. 1-7 Diagram of typical cell and contents. Needs are that oxygen and nutrients enter membrane from interstitial fluid where wastes discharge and where acid-base and electrolyte balance is maintained for homeostasis.



A

From TenCate



B

From Ham

Fig. 1-8 A. Eruption by probably a combination of pressure and tension.
B. Three fluid mediums of Ham. Fluid within the cell and from plasma is balanced by vital interstitial fluid.

through this mechanism. The cardiovascular is an "open" continuous line which collects carbon dioxide and other wastes, and returns them through the venous apparatus.

But another system, which is "closed" is the immuno-lymphatic system. Here, tiny terminal branches, again located in the connective tissue, serve as a drainage and a sewer-like sludge-line system for the gathering of wastes and toxins from within the connective tissue (see Fig. 1-8). When this system falters the tissue becomes "toxic" and perhaps induces pain via the "C" fiber. It is thought this system is excited in ultra-sound therapy because the treated area is flushed with lymphocytes.

For sophistication in orthodontics, these three fluid mediums and basic cellular needs must be understood. It is impossible to move the teeth on a skull, short of fracturing the bone. All tooth movement and all surrounding tissue behavior is biological and hence biomechanics is the issue.

BIOLOGIC LAWS

In connection with the tissue, it is essential that it be understood that the laws of physics are modified because physical forces yield to the laws of biology. "Biology" pertains to living tissue or living organisms, and is referred to as all the "life sciences". Certain biologic laws have been stated, such as Sherrington's "All or None" law, pertaining to the fiber contraction of muscle, and also his second law regarding "reciprocal inhibition" in group muscle function in kinesiology.

Additionally, there are certain constants, or at least near-constants, in the biochemical laws which can usually be expected and counted on, such as gravity. There are certain other fundamental laws which usually are referred to as the Laws of Nature, such as the body's tendency to conserve energy and to attempt to supply only the tissue necessary to perform a given function. Another law in the link between conservation of energy and tissue is a law of "profound efficiency" on the part of Nature. The law mentioned above is the law of "tissue adaptation". There are other laws of growth and form with reference to neurotrophism, which pertains to neural and blood control. The divine proportion or 1.0 to 1.618 is so commonly observed there must be some deep law pertaining to economy of proportions.

PHYSICAL FORCES AND SPEED

In the natural world, force and acceleration are usually equated. A greater force will move a larger body and, under continuous application, that force will produce an increase in rate of motion until a resistance is reached to counter that force. Thus, distance and time are linked in describing speed of motion, such as miles or kilometers per hour, down to millimeters per week, or even slower, sometimes millimeters or fractions thereof per year. Such is the nature of description of motion with mass, and the nature of rotation or translation. Rotations are described in moments of force around a given point of reference.

ORTHODONTIC "FORCES" AND PHYSIOLOGIC MOVEMENTS

Almost simultaneously in the 1870s Coffin showed continuous force (spring) and Farrar exhibited intermittent stress (jackscrew); both worked successfully Scientific biologic explanations for reactions did not begin until the 1900s. Sandstedt in 1904 was the first to describe a hyalinization-like response. Experimental work was done by Gottlieb in 1931, Stuteville in 1938, Reitan in 1940 and 1951, Bunch in 1942 and Lefkowitz in 1945. All used dogs for experiments.

Oppenheim in 1911, Johnson in 1926, Oppenheim in 1931, and Marshall in 1932 worked with monkeys. Macapanpan in 1954 and Petrovic later studied rats.

Maira in 1973 used the rabbit. Human material was used by Hersberg in 1932, Sicher in 1944, and Reitan in 1950. But Storey and Smith in 1952 were the first to focus on the analysis of pressure or to analyse the area over which force is applied. Reitan in 1957 showed root resorption following orthodontic tipping movements. Burstone in 1960 showed that 50 to 75 grams of force was adequate to successfully move upper incisors.

Others using human material were Andreasen in 1966 and 1980, Hixon in 1969 and 1970, and Hosevar in 1981. Quinn in 1988 summed up work in forces. But it remained for Dr. Brian Lee in 1995 to conduct experiments with pressure analysis in humans, where he concluded that 197 grams per square centimeter (1.97 grams per square millimeter) was ideal for bodily movement. Lee states:

> "The design of orthodontic appliances should be based on the principle of using the lightest forces possible to achieve tooth movement in the shortest possible time that is consistent with minimum tissue damage."

Ricketts added two significant variables. The first concerned the pressure required to preserve anchorage (of units desired not to be moved). The second was the pressure needed to modify the alveolar ridge as during expansion, or arch length increases beyond the original ridge.

Almost simultaneously (in the early 1950s) and without direct communication among different workers, similar observations were made regarding tooth movements although labelled differently. Various descriptions were made in order to communicate the conditions and the findings.

In 1951 Dr. Kaare Reitan in Norway reported his research entitled "The Initial Tissue Reaction". His work, in which forces were applied with removable appliances, was studied on dogs. The condition of the periodontal membrane and surrounding structures was analysed histologically. When excessive pressure was applied, he described the area of compression as likened to the homogeneous character and similar histologic picture of hyaline cartilage. He noted that when such compressional tissue was produced, motion was inhibited. Hence, **hyalinization became an adopted term.**

At the same time, investigations were being conducted in Australia by Dr. E. Storey (who was a bone biologist) and Dr. R. Smith (who was an engineer). The experiments were set up in the orthodontic clinic under the supervision of Sir Kenneth Adamson. Six patients were studied during the process of experimental canine retraction. Measurements were made from the upper arch, as well as the lower teeth, for scientific evaluation. From observations it was determined that the **laws of physics regarding friction could be reversed due to factors biologically** effected in tooth movement. **Increase of force to specific levels did not result in an increase of movement, but rather an inhibition of movement.** In order to explain this situation, Storey described **cell-free areas** in which, succinctly stated, reparative and resorptive cells were squeezed out of the tissue. Stasis rather than displacement occurred with too much force.

Meanwhile, during the same period, Ricketts made clinical observations by means of delicate measurements of tooth movement. The technique employed was laminagraphy (or body section X-ray), in which "cuts" through the alveolus were analyzed, both sagittaly and transversely. Drawing on some of the nomenclature employed in radiology, Ricketts adopted the term "**sclerosis**". For instance, in any joint loaded excessively, one of the early signs is **a thickening of the cortex** below the layer of the cartilage. This, in medical parlance, was referred to as sub-chondral sclerosis. The term "sclerosis" means hardening of tissue. On viewing detailed laminagraphic (tomographic) X-rays, magnified 20%, Ricketts observed that in certain instances **the bone in the area preceding the motion was seemingly thickened.** It appeared to be an increase of bone and hence resistance to the tooth movements that were being suggested.

Further studies by Dr. Samuel Pruzansky and Ricketts in cleft palate children led to the discovery that, from assessment of the distribution of cancellous bone within the alveolar process as seen in intraoral X-rays, heavier trabeculation was present on the non-cleft side or normal side. X-rays of the lower arch alone were employed to determine on which side a unilateral cleft palate was present. Bone without proper function was less trabeculated as compared to the normal, as explained by Wolff's Law of Functional Adaptation.

Work in the 1990s by Dr. Vincent Kokich also clearly demonstrated that loading osseointegrated implants with orthodontic forces caused heavier trabeculation (or sclerosing) of the supporting alveolar area.

It is therefore clear that alveolar bone in the absence of function becomes more "senile" in character with sparse trabeculation, and that loading of bone, or loading of a tooth or an implant in the alveolar process, may stimulate a buildup of bone in resistance to an increased load. Three questions emerge. What is the most proper force? What is its distribution? What is the most appropriate time frame? These are biologic questions associated with applied mechanics.

TOOTH ERUPTION AND DRIFT

Scholars have long conjectured regarding the mechanisms involved in eruption. Experimental studies have shown that a force of eruption does in fact exist. For clinical use, we have employed hypothetically a pressure about 0.2 grams per mm. of root cross section. This would yield about 4 grams of eruptive force for a lower incisor and up to 20 grams for the molar teeth, adding up to 70 to 80 grams for an adult lower dentition (without third molars).

Eruption Hypothesis

Experience with biologic phenomena would lead to a speculation that no single factor would suffice to explain eruption. Interpretation of the "law of adaptation" would suggest that each tooth would seek a resistance normal to its integrity. Thus when an opposing tooth is lost the tooth will seek opposition, unless sustained by the tongue or some obstacle. This idea is much the same as that of a muscle which will undergo a "dynamic imbalance contracture" when opposition is lost. When the tooth erupts the whole alveolus is involved because eruption brings with it new alveolar bone. Over time the alveolus disappears with tooth loss.

The explanation of the mechanism involved may be speculated to be in two main factors (see Fig. 1-8). First is the design of the periodontal fibers to resist vertical forces of biting and chewing. The tooth is suspended, and the "hammock-like" tension may, with shrinkage in the ligament, pull the tooth from the existing alveolus. The "walls" of the socket are stimulated to prepare the stage for increase in height. The same may be true for preparation of the buccal or labial alveolus for expansion.

The second factor would be a push (see Fig. 1-8). This may come from interstitial fluid pressure and perhaps from blood pressure. Because the socket, with its dense bone of the lamina dura, is a walled chamber the pressure does not need to be too great to produce a hydraulic action. A very subtle pressure could produce effective influences.

Drift

Drift may occur as the result of one and the same process. The added factors are the effects of the tongue, lips and cheeks, and the pattern of jaw movements in function.

The molars with few exceptions drift forward in both arches. In the absence of first molar teeth, premolars and often canines drift relatively distally or follow the line of least resistance. But for better understanding, the natural developmental principles constitute the starting point.

When the teeth are pushed by the lips in function, they may be considered to be infixed rather than drifted. This happens in the development of malocclusions as oral environmental conditions dominate the natural developmental tendencies.

Upper Teeth

The maxillary arch behavior is in general agreement among workers in growth and development. Although osseous drift occurs in the palate, the palatal plane has served as the principal reference by most workers. Viewed from this plane, with Anterior Nasal Spine registered, the upper molar teeth in eruption travel farther vertically than the incisors, in a ratio of 0.7 mm. per year for the molar, to 0.4 mm. in the incisor, or almost 2 to 1. All the teeth drift mesially 0.3 mm. per year on average essentially until growth stops and the further progress is stopped by the lower lip (Fig. 1-9).

Lower Teeth

Mandibular Plane

A great controversy in orthodontics surrounds the opinions regarding mandibular occlusal development. The interpretation of behavior of the lower arch largely depends upon the method of superimposing and registering. When viewed in the old traditional cephalometric method, from the symphysis and mandibular plane, the developmental pattern is upward and backward with the molar moving upward at a rate of about 1 mm. per year (Fig. 1-10A). This picture is shown from computer composites of 73 untreated children from age 6 to 18 years.

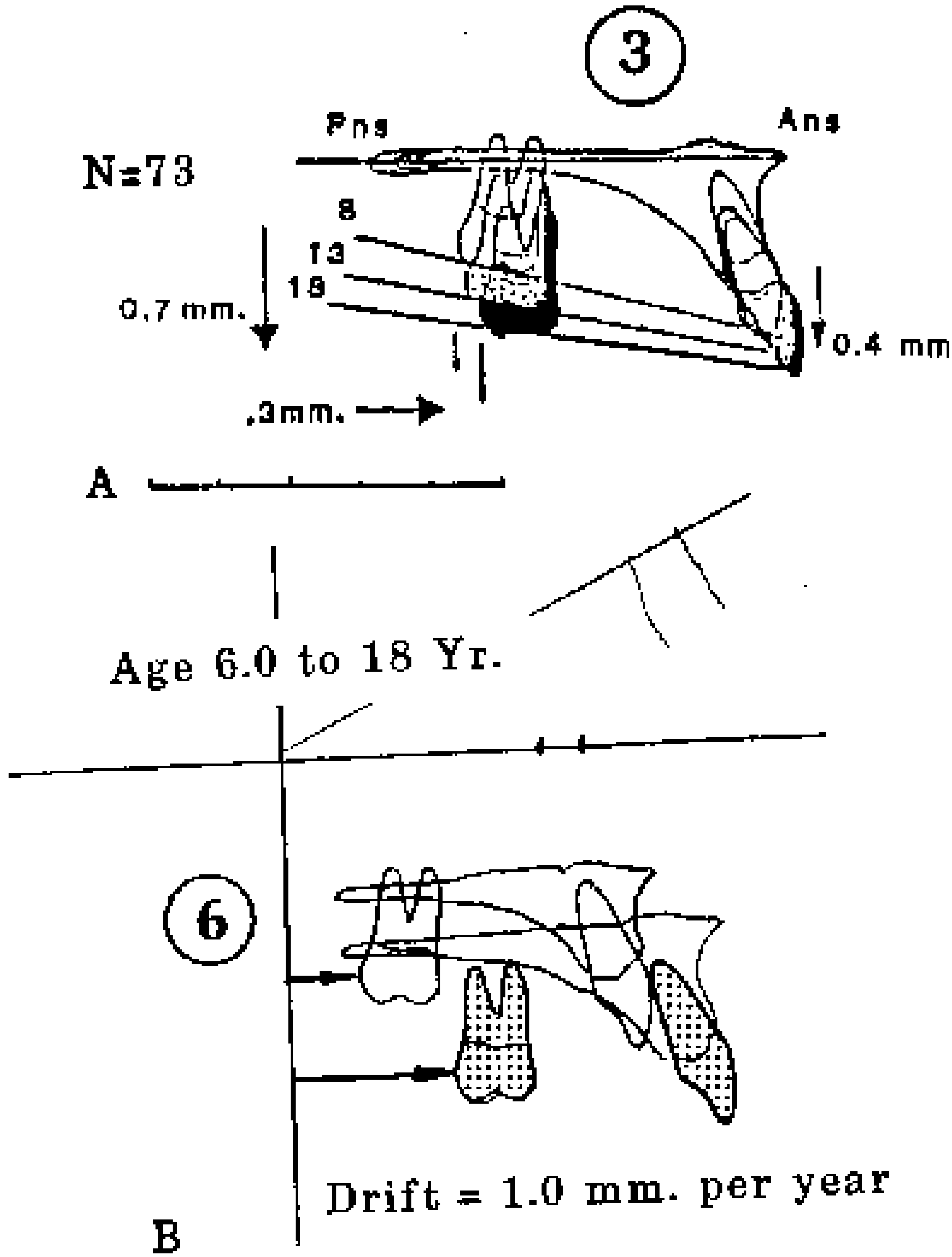


Fig. 1-9 A. Findings of the mean normal pattern of eruption of the upper teeth in 73 children are measured from the hard palate at Ans. Note forward drift. (Position #3)

B. Total forward movement of upper arch (together with change in palate) equals 1.0 mm. per year. (Position #6)

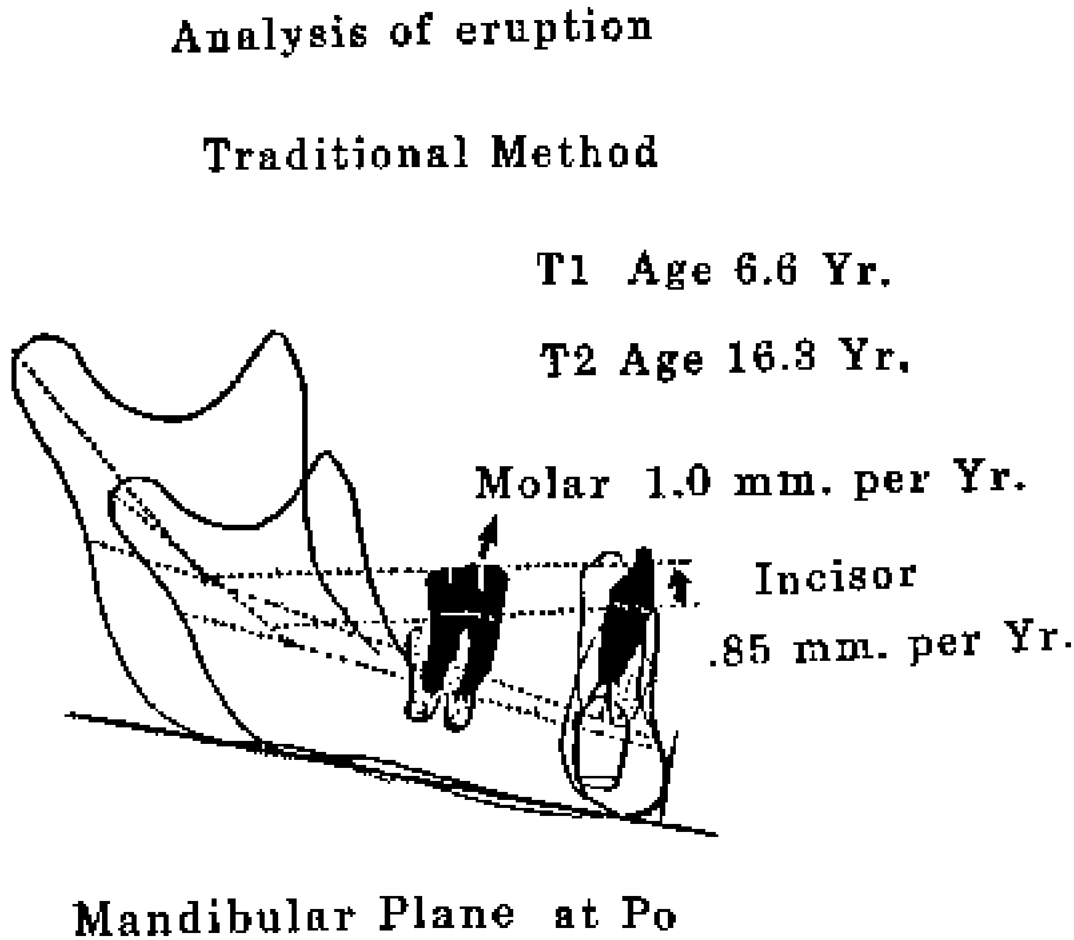


Fig. 1-10A Findings of eruption from composite of N=73 children when superimposed on mandibular plane at chin. Note molar moves upward and forward (at 1.0 mm. per year) and incisor moves upward and backward (at 0.85 mm. per year). Old Traditional Method.

Corpus Axis

Seen from the Corpus Axis at Pm, the molar moves **straight upward** about .05 mm. per year, and the incisors still appear to drift backward (Fig. 1-10B).

Arcial Growth

Viewed from the mandibular arcial growth method, with the Pm and external oblique ridges superimposed, **the whole lower arch moves upward and forward a mean of 1.4 mm. per year.** This occurs until growth ceases and the lips and upper arch contain the eruption and drift (see Fig. 1-10B).

Using Drift - Driftodontics

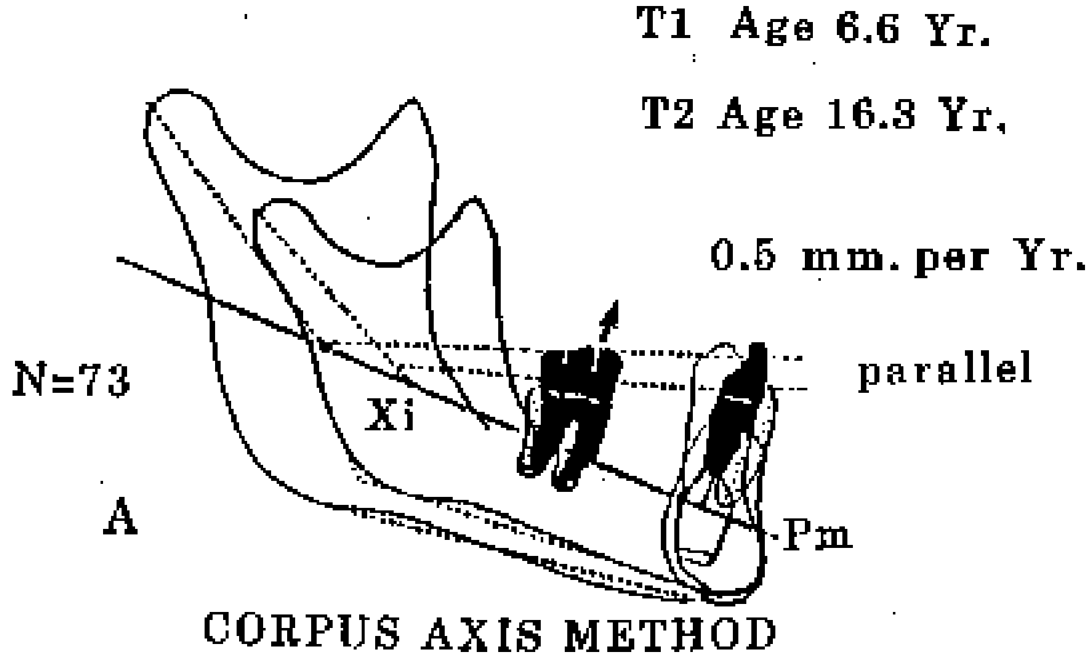
When the effects of cervical traction on the upper molars were studied by Kitterhagen in 1950 it was found that eruption and distal drift of the upper premolars and canines occurred. Studies of serial extraction revealed that canines drift distally after premolar extraction. These are developmental eruption and drift tendencies employed by clinicians.

However, **in sectional mechanics and utility arch therapy, drift even after eruption was found to be dramatic.** Premolars also **drift buccally** when an extraoral face bow is used with routine expansion and is stepped outward as a shield. Thus, with these modalities the premolars may only be engaged with fixed therapy at the later finishing stages, **if at all.**

THE NATURE OF ALVEOLAR BONE

Scholars have debated exactly the limits of alveolar bone. Some references are made to the "apical base", assumed to be the bone surrounding the apex of the roots which is deemed to be the line of separation of "alveolar bone" with "basalar bone". Other literature has suggested that alveolar bone is separated by the position of

Analysis of eruption



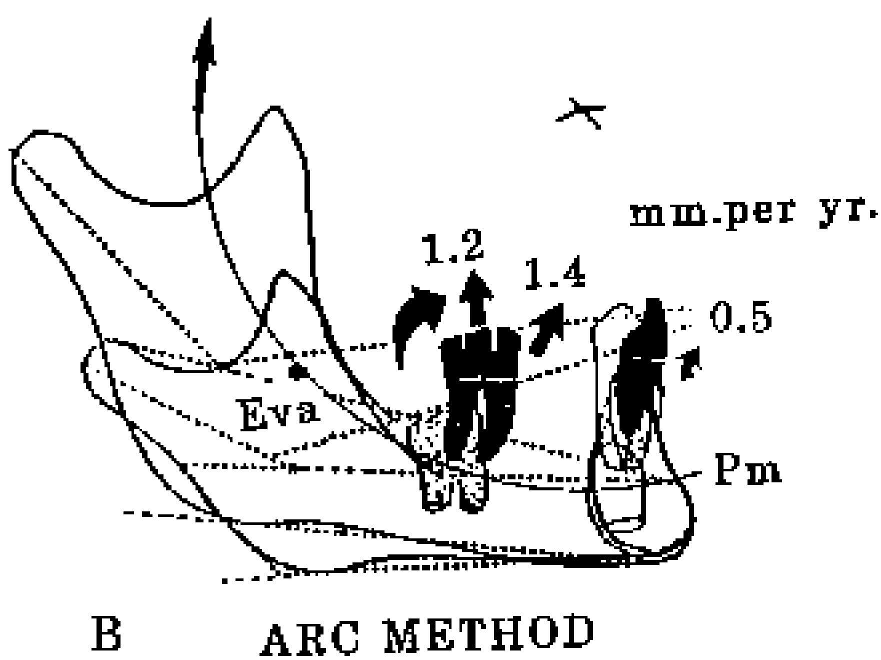


Fig. 1-10B A. Findings of same composites as seen in Fig. 10-A, but superimposed on Corpus Axis. Note that the uniform occlusal plane and perpendicular eruption of molar at 0.5 mm. make superb method for treatment analysis. Lower incisor drifts bodily backward with this view.

B. Arc method (most true biology) (Pm and external oblique ridge) shows dramatic actual eruption upward and forward at molar at 1.4 mm. per year.

muscle attachments such as the buccinator in which muscle is attached to basal bone.

In studying the infant mandible, and in turn analysing the mandible of older subjects who have been long-term edentulous, another conclusion emerged. This prompted the definition that alveolar process was first "any part of the maxilla or the mandible that was ever associated with the formation of the tooth or its eruption or function". This suggests that alveolar bone is at a much deeper level than the root apex (Fig. 1-11). The second part of the definition was that alveolar bone is "any part of the jaw structure that is associated with carrying physical stresses from the teeth to the basalar portion". This was concluded from the same studies of aged skulls and the stress lines in weathered specimens. This extends the alveolar process significantly beyond the limits usually described.

Thus the alveolar process seems to fulfill Wolff's Law of bone functional adaptation as much as any other bone in Nature.

The Cortex

The main or greatest stresses on bones either long or plated are carried by the outer cortex. The cortex is made up of many compressed trabeculae with inner prismatic calcified substances and Haversian systems. The construction of the cortex or plates is such that the main strains and stresses encountered with normal function can be withstood (Fig. 1-12). All tangential forces – compression, tension, torsion and shear -- are resisted by bone.

It has been noted that stresses run parallel to the trabeculae orientation. But main directional forces are transmitted **perpendicular to the long axis of sutures** (Fig. 1-13). How is it possible that a compression runs through a suture when the ligament tissue is designed to take tension?

The answer lies in the **serrations** of the suture. The pressure is converted to a pull on the ligament similar to the pull on the periodontal ligament as a hammock-

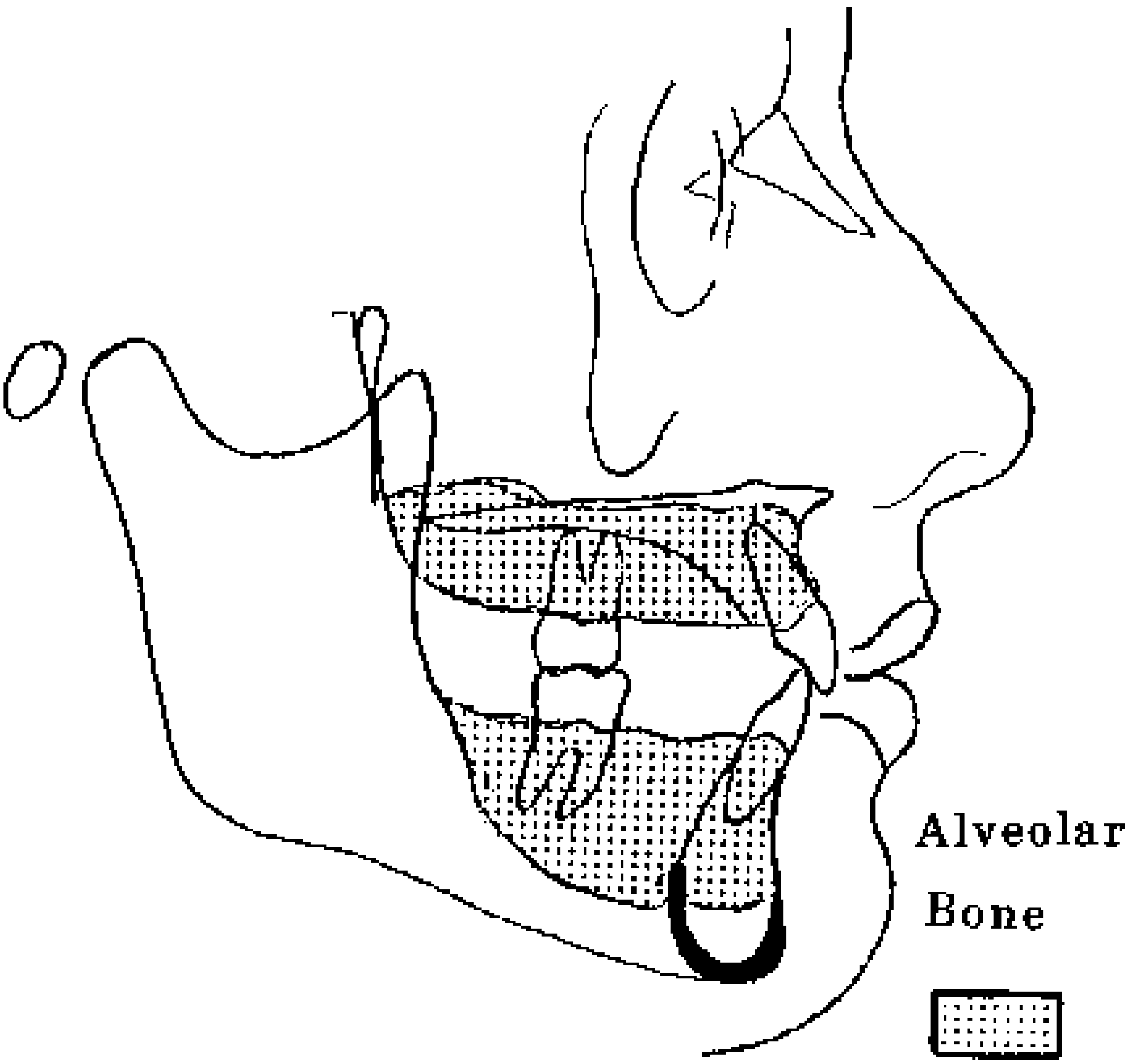


Fig. 1-11 Actual Alveolar process extends far beyond roots as evidenced by changes following loss of teeth.

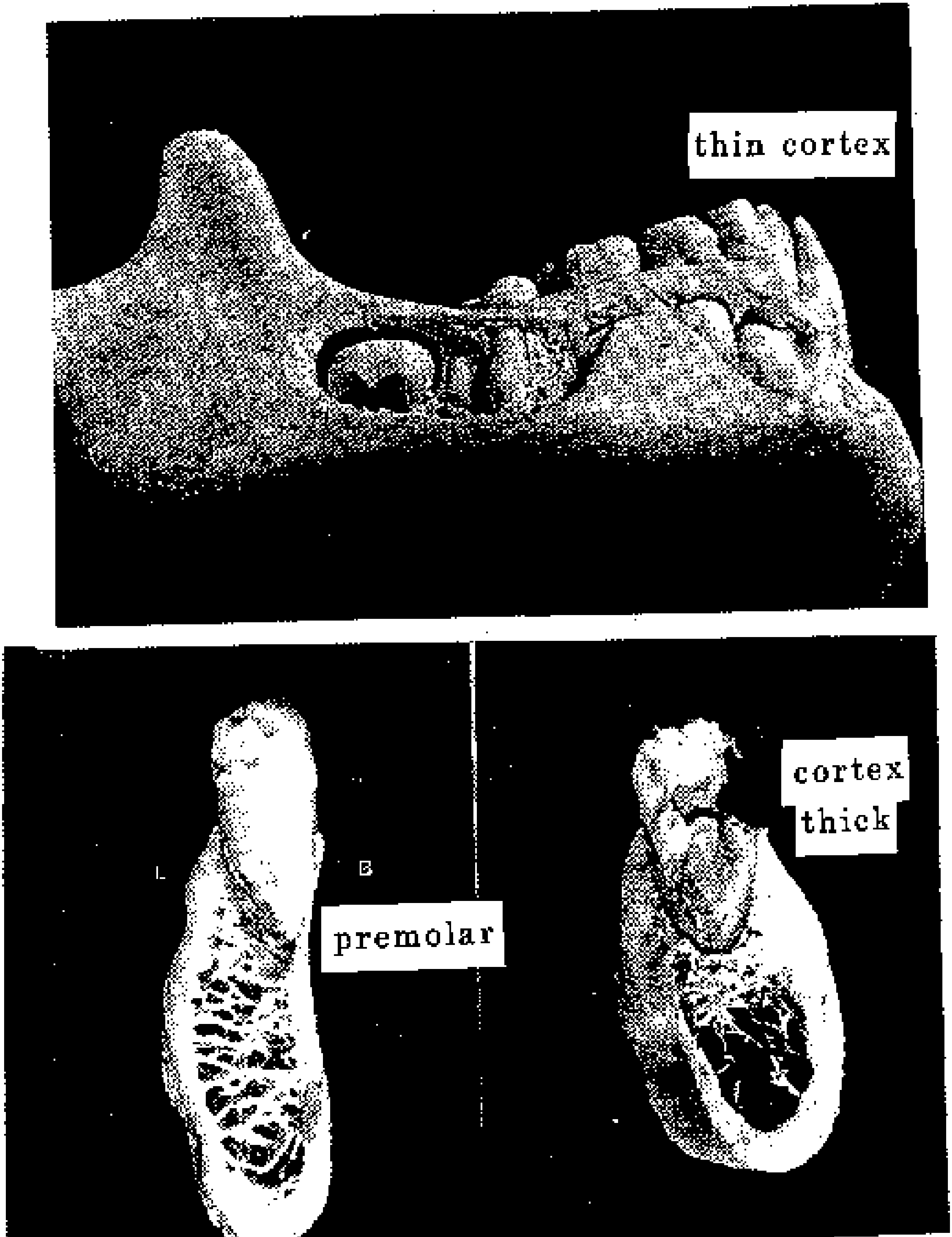
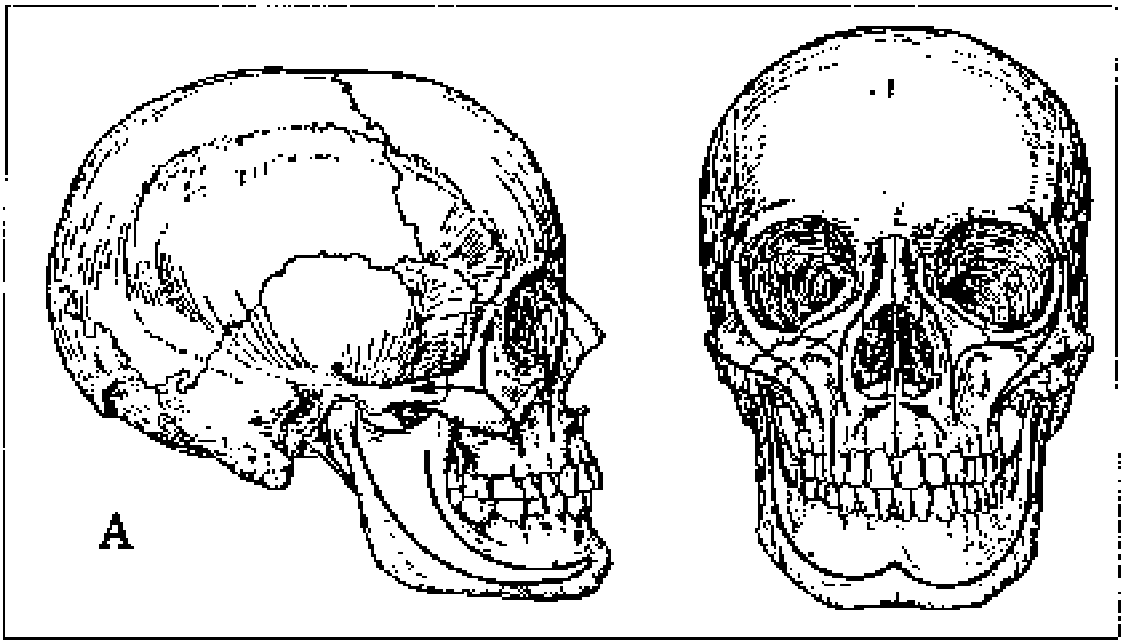
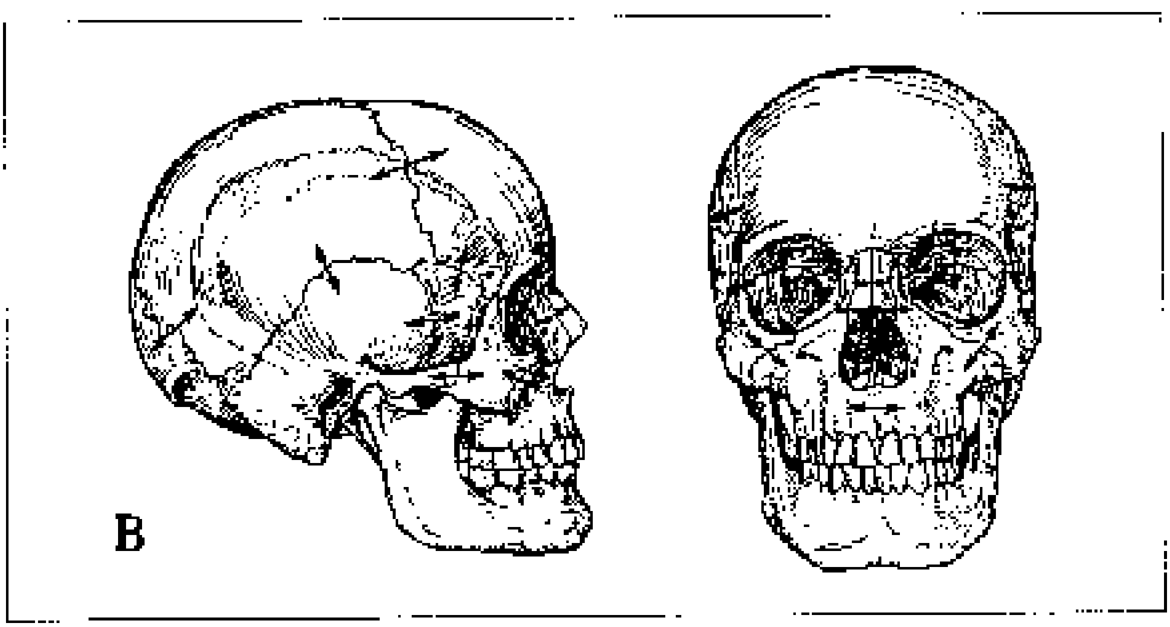


Fig. 1-12 Labial cortical plate at the lower incisors is thin. The buccal plate at the molar is thick and extends almost the length of the root. The lower first premolar sits over the moderate buccal plate.



Forces parallel to trabeculae



Forces perpendicular to sutures

Fig. 1-13 A. Forces are carried along the long axis of trabeculae.
B. Main forces of compression run perpendicular to sutures but are transmitted to tension in the serrations.

like tension when biting on a tooth. Each tiny spike is like the root of a tooth. When a continuous force overcomes the ligament the bone is compressed. Ankylosis can ensue even in the plates of the skull cap when the compression obliterates the suture, as demonstrated by the experiments of Hendrickson and seen sometimes in the human skull.

Cancellous bone is made up of many little bridges connecting the outer to the inner plates, and in fact is the original idea of the trabeculae, meaning "little bridges". Cancellous bone is also called "medullary" or "spongy bone" because it is reminiscent of the sponge, having spaces inside. It was further shown, by Dr. W. Williamson, that cancellous bone not only was composed of a different physical anatomic nature, but also had different qualities in terms of chemical analysis and mineral content. Within the cancellous area or inner trabecular arrangement is a variety of tissues. These are blood vessels, blood-forming cells, interstitial fluid, and adipose tissue.

Tooth movements entail resorption and apposition of bone. But further movement involves the atrophy and hypertrophy of other cells or the dystrophy or hyperplasia in the various tissue systems.

Periosteum

On the outside of the alveolar process, as in all bones in the body, there is the periosteum. This layer of tough connective tissue fits tightly around the bone likened, by Storey, to a panty-hose concept. The periosteum has a layer of osteogenic cells which affect the developmental behavior of the outer cortex of the alveolar process itself wherever apposition takes place. The periodontal fibers are connected to the periosteum at the crest of the alveolar processes (see Fig. 1-6). Frankel placed shields to the labial tissues which also put tension on the periosteum, resulting in bone apposition. Tooth movement and alveolar modification commonly resulted from a "pull" rather than a "push".

Cortical Bone

The cortical bone of the alveolus on the labial-buccal and the lingual-palatal sides displays a variety of thicknesses, sometimes paper-thin, as on the labial and lower incisors, to as much as several millimeters on the buccal of the lower molars (see Fig. 1-12).

In normal situations, the alveolar process terminates gingivally around the tooth as a "crest". This crest itself in cross-section can be likened to a "spine" which is extended from the outside of the alveolus (see Fig. 1-6). At the crest the cortical bone folds backward on itself to form the thin lamina lining of the socket of the tooth. The entire socket of the tooth in the adult can be likened to a very thin, compact bone, and hence is referred to as lamina dura, meaning "a hard layer".

In the younger patient, with a developing alveolus, the socket is more "cribiform" in character. It has more abundant channels, rich blood vessels, and immature bone which undergoes transition to more mature states in the attempt to maintain function while vertical growth is taking place. The lamina dura is usually twice the thickness of the periodontal membrane, again depending on the status and function of the tooth. The lamina dura is actually more compact and takes time to resorb. Hence, intrusive forces have been shown by Bunch to take 7 to 14 days before action is seen. This has also been called "lag time". Clinical experience has suggested that in adults the lag period can be as much as two months.

The question remains, "Does a pull or push on the periosteum stimulate bone formation?"

The Periodontal Membrane and Characteristics of Ligament as a Tissue

The periodontal membrane is made up of collagenous fibers and in the description of collagen itself is usually composed of the Type III, as described by Dr. H. Slavkin at the University of Southern California. Because the fibers are essentially interwoven, some investigators -- making a longitudinal cross-section -- gained the impression that the fibers were not continuous and were connected by an intermediate transition area. Other workers have concluded that a single fiber runs from the cementum of the tooth root continuously through the periodontal membrane area and into the lamina dura of the socket.

The lamina dura is adaptive and probably undergoes a continuous transition throughout life. Witness adaptation in hypercementosis with aging. The periodontal membrane is highly endowed with interstitial fluid and blood vessels, as well as nerves, being highly proprioceptive in characteristic. In patients with an absence of nerve function for proprioception a massive overclosure is witnessed. Hence, monitoring of the system is necessary for integrated control.

When a tooth is under active eruption, the blood supply is increased, and the periodontal membrane space is widened. When a tooth is in trauma, one of the cardinal signs in the X-ray is a wider-than-normal periodontal ligament space.

Ligamentous Tissue

The physical property of a ligament is estimated to sustain about 5 to 6 kgm per square millimeter of resistance before breaking. The periodontal membrane is ligamentous tissue and is almost identical to the sutural ligaments in the skull. A ligament is designed by nature to take tension, or resist a pull, not to take compression. Dr. Arthur Steindler described ligament as a **checker and restrainer against a sudden displacement**.

All ligaments in the body tend to display equilibrium at rest and are relatively tension-free. But ligament as a tissue also, unlike the tendon, **cannot withstand permanent deformation**. Ligaments surround joints and serve to limit border movements.

But under continuous tension **ligaments stretch. It is for this reason that**

intrusion is possible (Fig. 1-14). The stretched ligament within eight minutes subjects the socket to expansive pressure from the root. Thus the action of **prolonged tension results in ligament elongation and the force becomes compression** in the socket. This explains intrusion (or depression) and has been shown by Bunch in 1942 and Lefkowitz in 1945 and proven by Ricketts in 1948 up to 1960.

The mechanism permitting the stretching of a ligament is not well known. Like a rubber band, under stretch the circumference of the ligament tends to decrease. It has also been shown that under a continuous tension the ligament loses some of its liquid contents, which are elaborated outward into the interstitial space. There is the uncertainty regarding the exact mechanism of elongation and also the mechanism by which "shrinkage" occurs. At any rate, it is the stretching of the ligament that must be appreciated in order to understand the "Bioprogressive-biomechanical concept" and the **necessity for appropriate light continuous pressures** for safety in tooth movements. Even Oppenheim preferred "gentle" intermittent forces.

Conclusion

If conclusions could be dared they are: (1) that for "orthodontic" movements, fixed appliances have been too large and forces too excessive; (2) that the clinician has erroneously thought about force rather than pressure; (3) the biology of drift with a change in the environment has not been appreciated; and (4) the understanding of the mechanisms involved with intrusion are contingent on the fact that ligaments cannot withstand deformation.

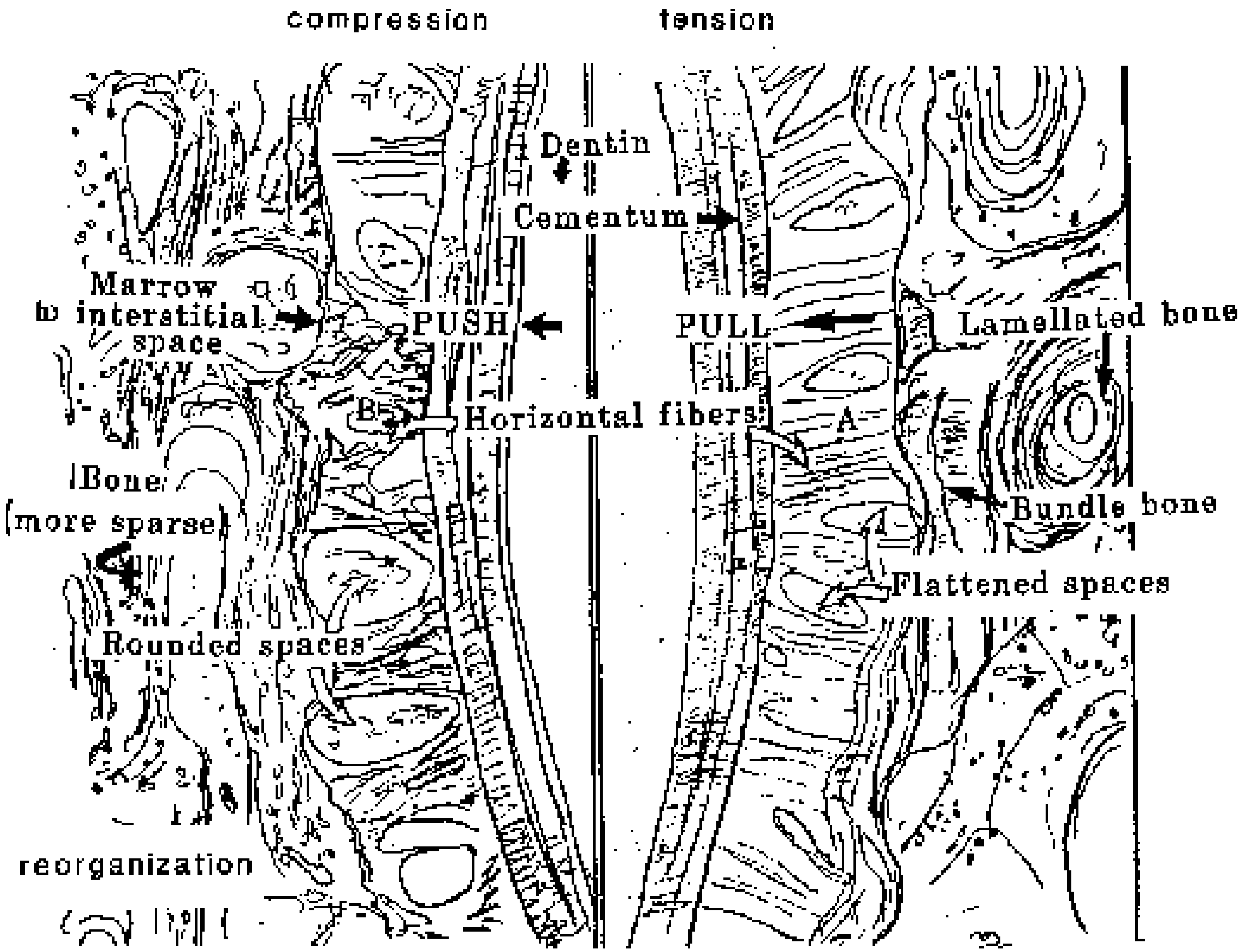


Fig. 1-14 Diagram of comparison of pressure side - B (left) and tension side - A (right) in tooth movement. Notice collapsed membrane and large rounded interstitial spaces on pressure side and resorption into narrow space. At A note oblong interstitial spaces, stretched membrane fibers and new bundle bone on tension side. Bone is being reorganized ahead of area of resorption. Note resting lines in cementum.

SUMMARY

Technical problems with full appliance mechanics were discussed. The advisability of using elastics concomitantly with full arch engagement and intermaxillary elastics for arch manipulation for non-extraction treatment was indeed questioned in the light of history.

Full engagement techniques (employed as starting appliances) have given way to a philosophy of the gradual application of selected modalities for specific goals as practiced in the light of current knowledge.

Applied mechanics as a branch of physics is a base for communication and for the application of physical laws insofar as they apply to the clinical situation. However, mechanics must always be tempered clinically with the biologic considerations.

Homeostasis, or tissue equilibrium, was shown to be a base on which concepts of mechanics were to be added. The tendency of the body to return to its original balance is a basic biologic law which we may call the "law of adaptation". Nature will try to regain normal dimensions in the periodontal space when teeth are moved with appliances. The orthodontist "cashes in" on this phenomenon because it is this biologic recovery that underlines the concept of biomechanics.

In addition, three fluid mediums and the four cellular requirements are also factors to be understood in the process of homeostasis. It is the interstitial fluid in the final analysis that is the key to cell survival. Nature must also eliminate the toxic wastes from the breakdown in an "orthodontic site".

There are indeed few physical laws that can be counted on clinically. Increased force for the movement of teeth may act contrary to the success of movements. The explanation lies in the denying of blood supply and interstitial fluids to the tissues and the production of an area in which normal vitality has been curtailed.

Of all the bone in the body there is none that displays "the Laws of

Adaptation" better than the alveolar process.

A plea is made for understanding ligamentous tissue. The stretching of the ligament permits intrusion of teeth to be successful because compression is now produced completely around the socket.

Eruption and drift are biologic factors as part of the forces of occlusion. The intelligent clinician employs these biologic processes to aid in the treatment.

The next issue is the amount of pressure necessary for safety of the root and maximum bone adaptation, to be taken up in Chapter Two.

CONCEPTS OF
MECHANICS AND BIOMECHANICS

CHAPTER TWO

BIOLOGY AND FORCE APPLICATION

INTRODUCTION

Physical laws and applied mechanics were briefly explained as framework for communication. Biologic implications and the nature of tooth eruption and tooth drift were preparatory subjects for now the deeper consideration. Brought to attention was the enormous value of the understanding of the ligament and the character of the alveolar bone.

Ossification of the bone directly to cementum produces ankylosis which acts as an implant or a bone marker. There is also some suggestion that fibrous ankylosis is possible when scar tissue instead of bone replaces the ligament. Thus, two keys to orthodontic success in mechanics convey to the clinician the facility for tooth movements to be possible. First is the presence of the thin layer of 0.10 to 0.25 mm. of ligamentous tissue between the root and the socket. Second, the cementum covering of the root is more mineralized and more avascular, and therefore is less likely to be resorbed than the bone.

Bone resorption on one side and bone apposition on the other are the classic mechanisms which characterize tooth movements. The question arises concerning an optimal kind of force to be exerted in order to excite both apposition and resorption of the bone of the socket without crestal destruction in the end, and without root resorption yet still, at the same time, preserving anchorage when desired.

Types of Force

There has never been an argument that teeth are movable. Observation of eruption and drift of teeth is identified in gradual crowding, together with tooth shifts leading to spacing that occur under tooth loss and periodontal disease. Both supply sufficient evidence of a migration phenomenon even to the layman.

Orthodontics under Kingsley in 1860 for Class II correction was characterized by "bite jumping" with plates estimated now to require about 300 grams of force when in place. He also liberally used rubber elastic bands and employed finger springs of unknown strength which supplied continuous action (Fig. 2-1). Thus intermittent and continuous forces were both employed.

Circa 1880, Coffin in England with a palatal spring made in a "W" shape, together with Jackson with a wire "crib" appliance, and Matteson in the U.S. employed helix loops as all these workers advocated continuous force application (Fig. 2-2).

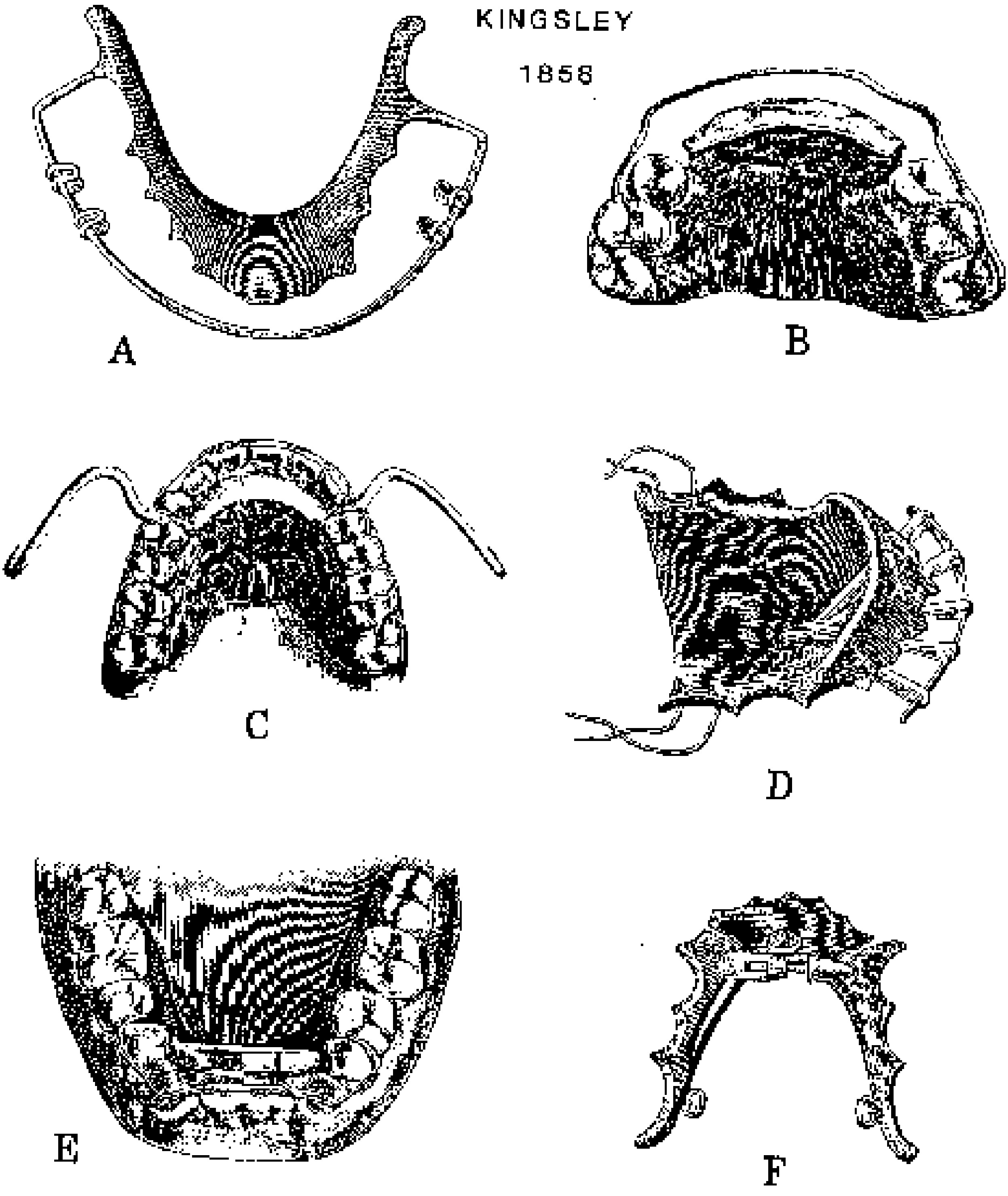


Fig. 2-1 Norman Kingsley - 1858-1892

Kingsley employed both intermittent and continuous forces and the set principles of orthodontics.

A and B: Bumper or Shielding principles and rubber bands for necks of teeth

C and D: Bite-jumping appliances with extra-oral traction and ligated plates

E and F: Finger springs, elastics and jackscrew

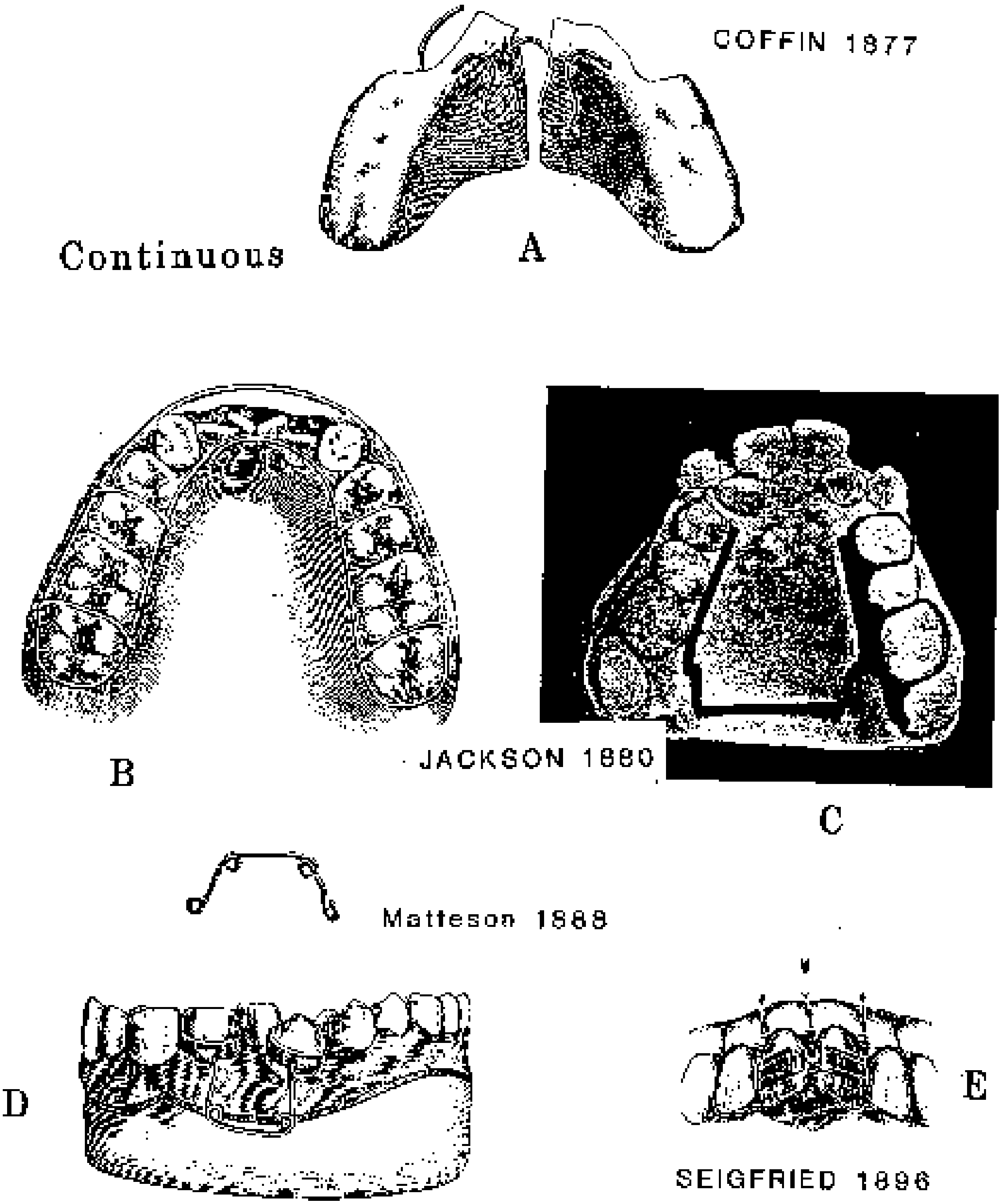


Fig. 2-2 Examples of early continuous force appliances
A. Coffin spring, B. Jackson crib, C. Unilateral expansion, D. Helix loops,
E. Compound Helix spring.

The continuous idea was opposed by advocates of intermittent forces, such as Farrar, to be introduced by screws and nuts on threads in the nature of 240 threads per inch (Fig. 2-3). Continuous vs. intermittent force has been debated for the last century and obviously both can be applied.

By 1893 Goddard in essence split palates, intruded and extruded teeth, and employed a labio-lingual brad (Fig. 2-4).

Amount of Force

But the amount of force, heavy or light, did not seem to be an issue other than the amount a patient could tolerate. The "force" employed clinically in other words, was based on pain rather than the best interests of physiology. "Pressure" was not the consideration, apparently, but the type of bone in the line of movement was recognized by Guilford in 1898.

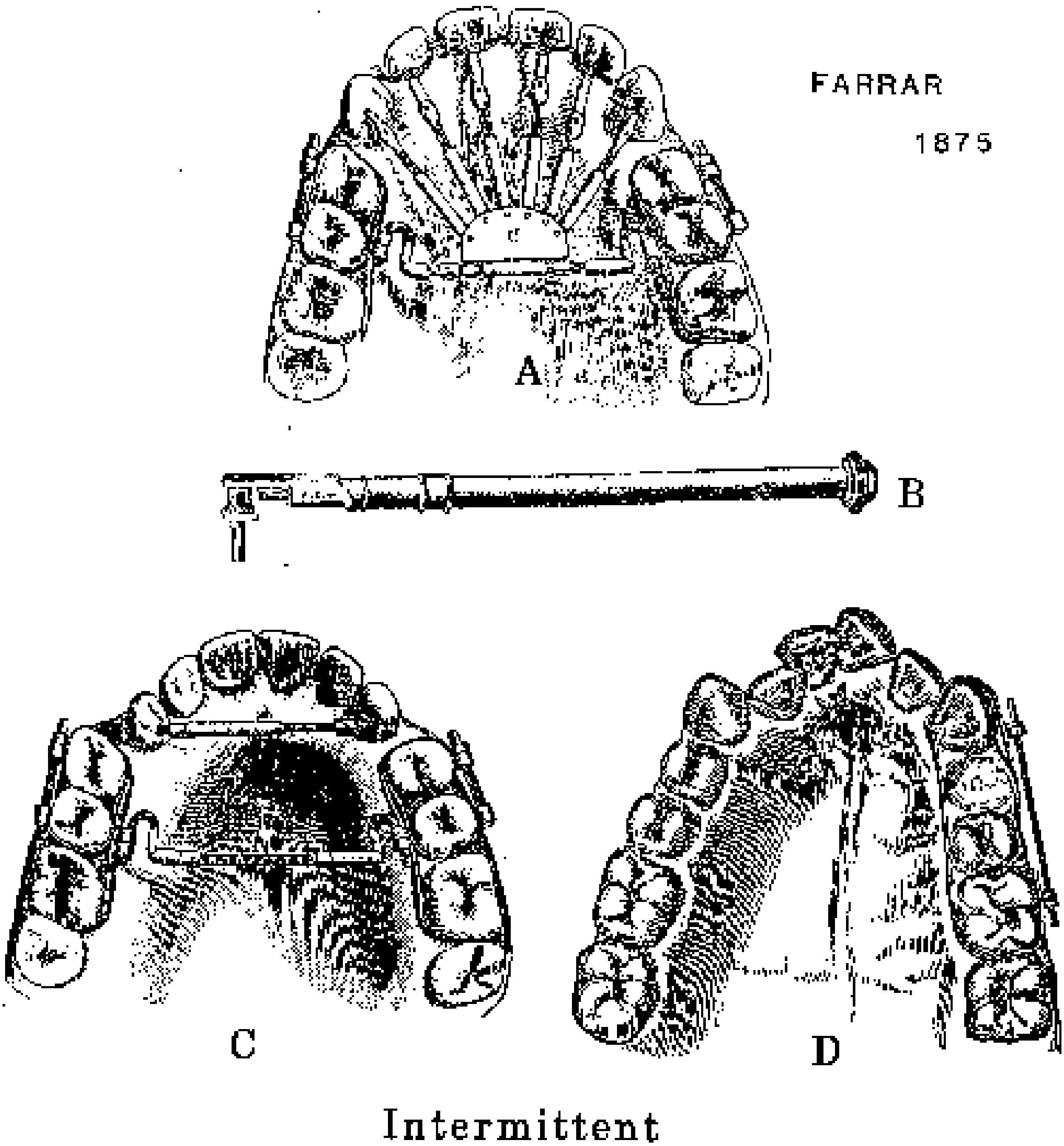


Fig. 2-3 John Farrar's first appliances with use of intermittent force by means of threaded wires and screws.

A. Note incisors ligated, holes drilled in canines, and premolars clamped together.
B. Tool for activating screws.
C. Screw for expansion of premolars and canines.
D. Note Canine Retraction Section for extraction case.

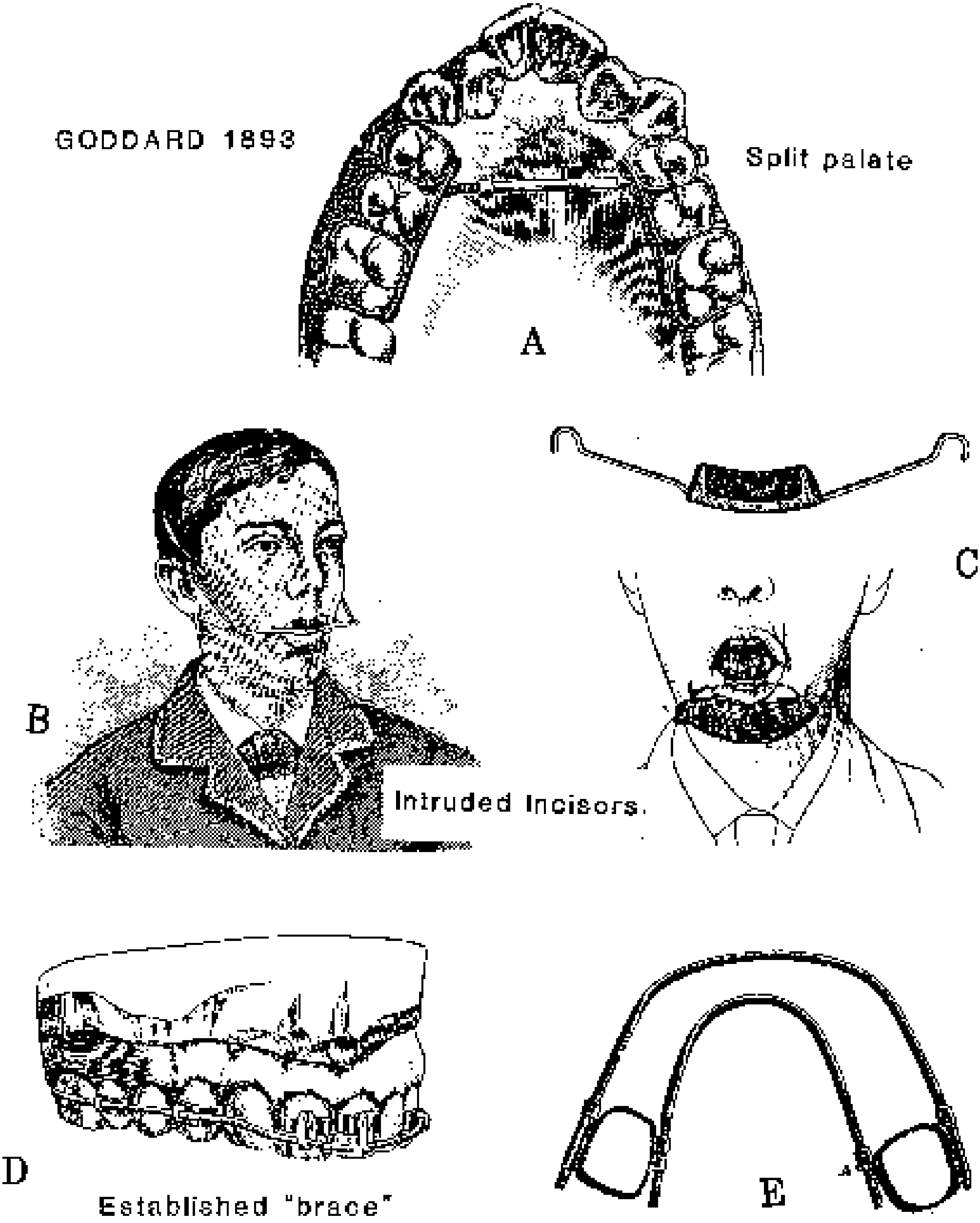


Fig. 2-4 C.L. Goddard in 1893:
A. Already split palates with a screw,
B and C. intruded both upper and lower incisors with continuous force, and perhaps
D and E. started the idea of "braces".

E. H. Angle, starting in about 1885, was precision-conscious. He became attracted to a threaded appliance. The "screw principle" was used in the design of the appliances that were made more delicate when compared to the large and crude custom-made devices previously used. The E arch, a threaded .045" labial arch wire, to be activated with a nut, was designed. The amount of force was to be guided by a prescription for a half, or a full turn of the nut, or until a "snug feeling" was experienced by the patient. The .045" wire is still retained for the inner portion of the face bow for extraoral traction and for "bumpers" (Fig. 2-5A). The "jackscrew" is still used in both fixed and removable appliances.

Angle's appliances, to include the Edgewise in 1930, were recommended to be practiced with intermittent force application. The ends of the arch wire were constructed to be received into a "buccal sheath". Tiny wrenches were given to the patient for self-force administration. This was used for the pin and tube appliance on a .030" wire. That wire was flattened and oriented vertically in order to be used with the "Ribbon" bracket for torque control by 1912 (Fig. 2-5B).

The "screw principle" was eliminated in 1924 with the development of a "Tiny Ribbon" for deciduous and mixed dentitions, as a "power jack" was used to take its place for expansion. In essence each adjustment with the intermittent idea seemed to be based on the amount of stretch of the ligament or bending of bones.

With the development of the Edgewise system (turning the Ribbon on its edge), a soldered stop was placed against a smaller rectangular tube, and the washer principle was employed (Fig. 2-6A). The larger wire size (.022" X .036") was reduced to a rectangular .022" X .028" which was technically (1) to be adapted to the malocclusion, (2) to be stopped at the molar, (3) then very slowly straightened for an increase in arch length, and (4) to receive washers added onto the wire for space creation between the stop and the tube for less than half a millimeter of arch length increase at each adjustment. Intervals were increased from one week to two weeks

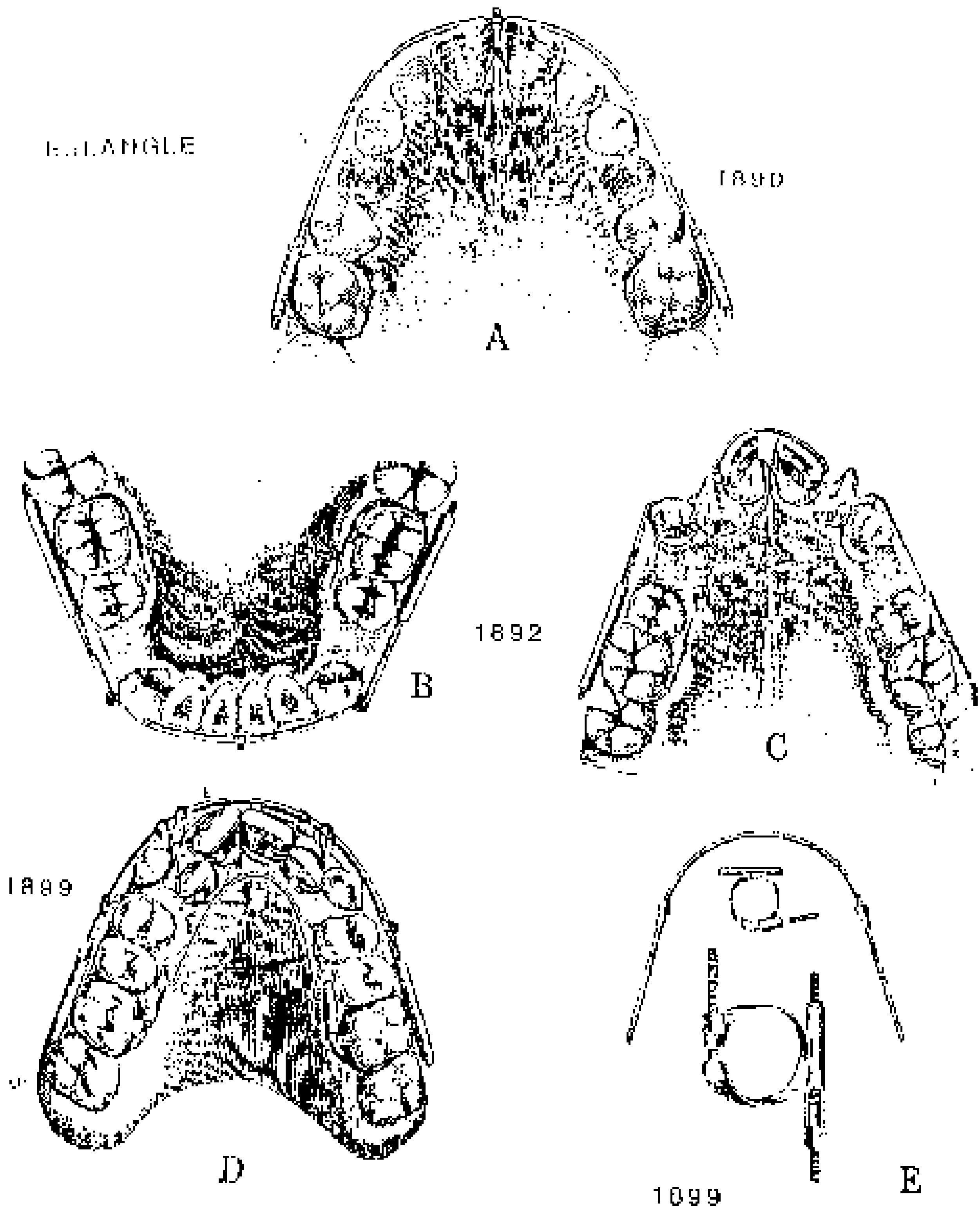


Fig. 2-5A Edward H. Angle's Early Contributions (Intermittent)

A. E Arch to receive headgear. Note extractions (1890-1892)
B. Retraction section in lower.
C. Retraction section in upper
D. Ligations to E Arch
E. Threaded components.

[When elastics were shown to correct arches Angle rejected extraction.]

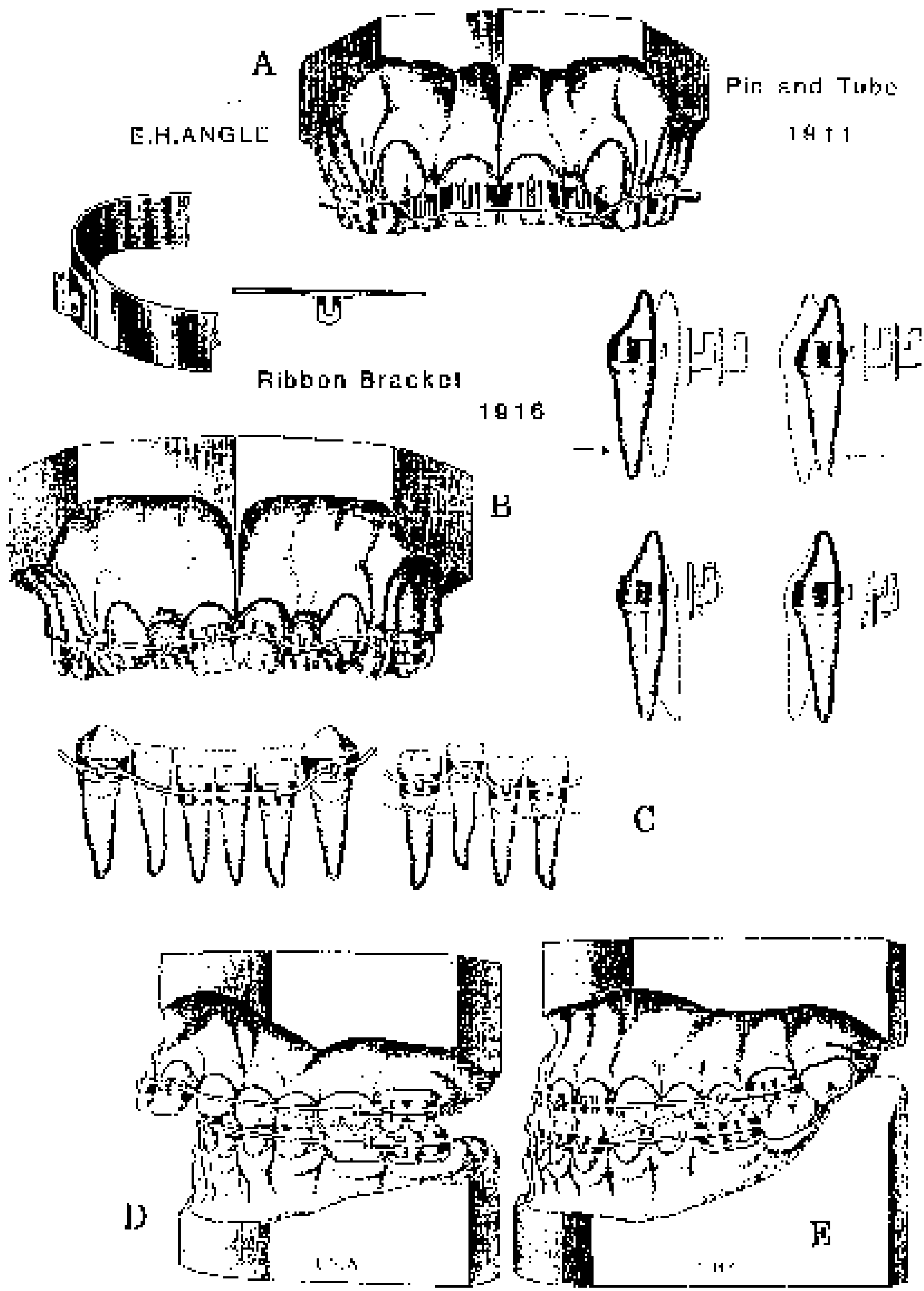


Fig 2-5B **Angle's Intermediate developments**

A. Pin and tube (1911)

B. Ribbon technique which permitted torque and bodily movement.

C. Showed "depression" of teeth.

D. For Class II, used elastics for 2 X 2 upper and 2 X 4 lower.

E. For Class III; used elastics 2 X 4 upper, 2 X 6 lower.

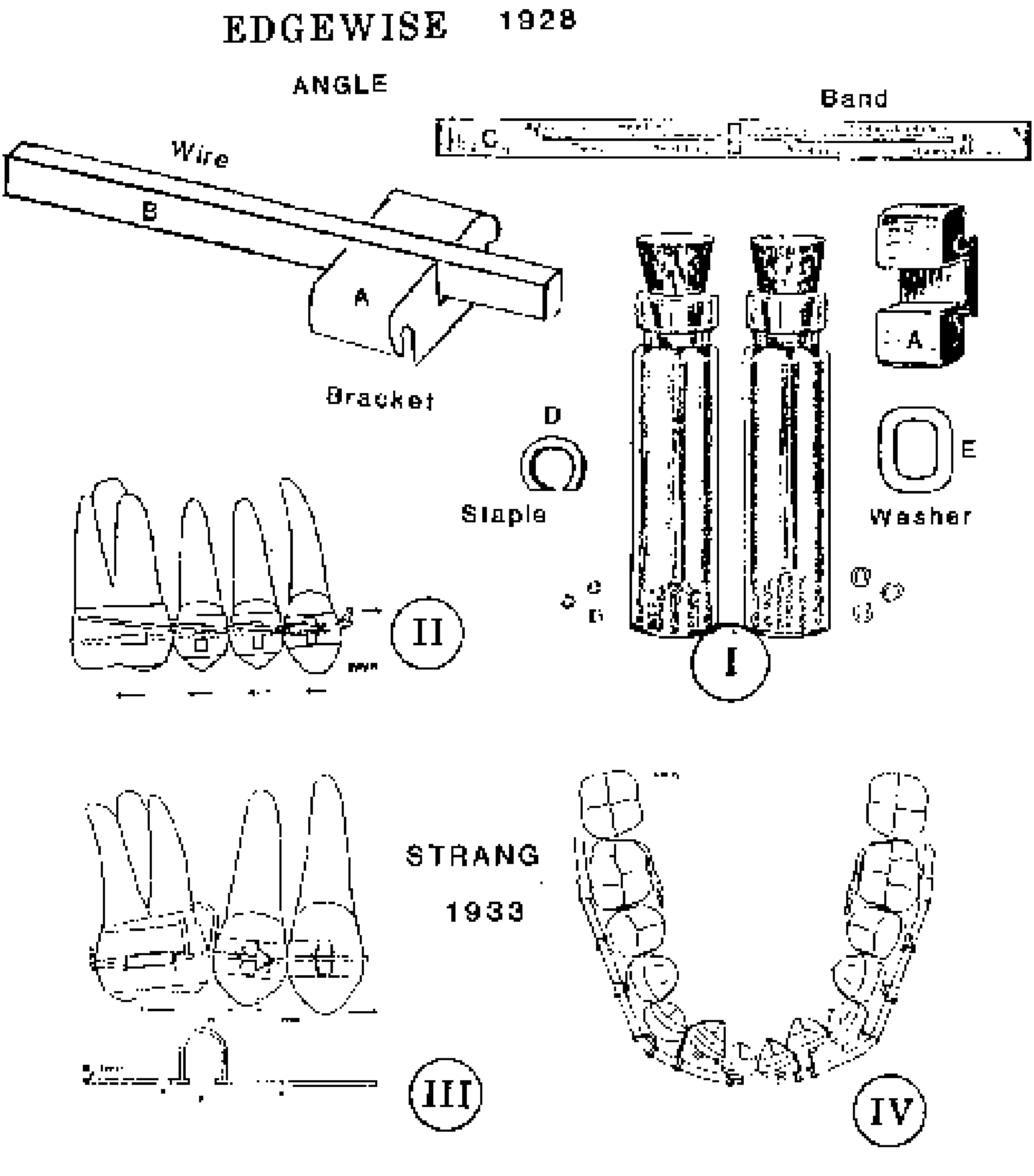


Fig. 2- 6A Angle's later inventions.
I. Edgewise bracket, rectangular wire, staples and washers.
II. After Strang - second order bends.
III. Soldered loop of .025" wire for continuous action.
IV. Teeth ligated to .022" X .028" wire

with the Edgewise method (see Fig. 2-6A).

Thus, intermittent force was advised with the Edgewise method and even practiced with a firm ligature-tying plier and full arch engagement in the brackets as soon as possible. These were, in general, the practice procedures with "Primary Edgewise" as originally conceived by Angle and taught by Brodie. Ironically, Angle's last development, according to Strang, was a theorized square .022" X .022" wire to be used.

Calvin Case was a contemporary of Edward Angle, publishing his work in 1921. For extruding and intruding he banded teeth and attached cleats, not brackets. For deep bites he used a round wire size .025" which produced "strong extrusive force" upon the premolars and intrusive force on the incisors. His narrow arch form was very similar to that employed by Tweed 15 years later. Case preferred upper first premolar extraction in many Class II conditions. He also employed sliding hooks and yokes with elastics. He leaned toward continuous action by "bypassing" teeth, and made use of a high labial wire and "sectional" ideas (Fig. 2-6B).

Meanwhile, other fixed techniques were being used clinically. The Labio-lingual technique employed lighter finger springs. Removable appliances were used with finger springs, or added bars and wires (Fig. 2-7). Consequently, the issue of intermittent vs. continuous force raged on.

Oppenheim

Oppenheim's experimental work, often referred to, was conducted on apes. He tried to deal with the issue of intermittent vs. continuous force, but still **did not seem to be concerned with the exact amount of force per tooth** being employed in the experiments. His conclusions on the original work, conducted in 1911, were in retrospect questionable. Were his continuous forces "heavy" by the present standards? The question now arises, "Were his intermittent forces light or heavy?"

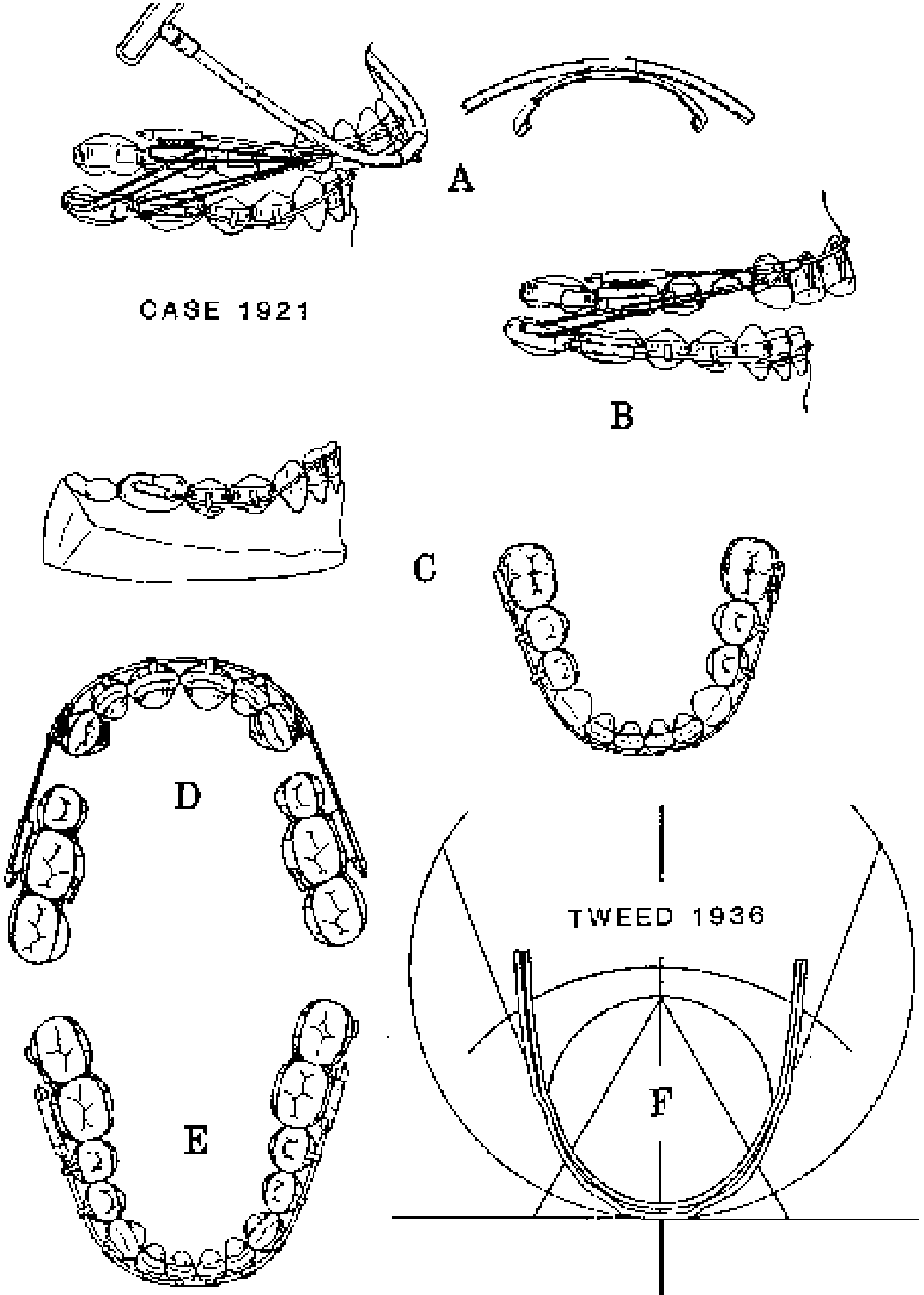


Fig. 2 - 6B **Calvin** Case was the first to fully band teeth:

A. Employment of extraction and high-pull traction,
B. Sliding hooks,
C. Bypassing the canine,
D. Extraction of upper premolars.
E and F. Similar arch form employed by Tweed.

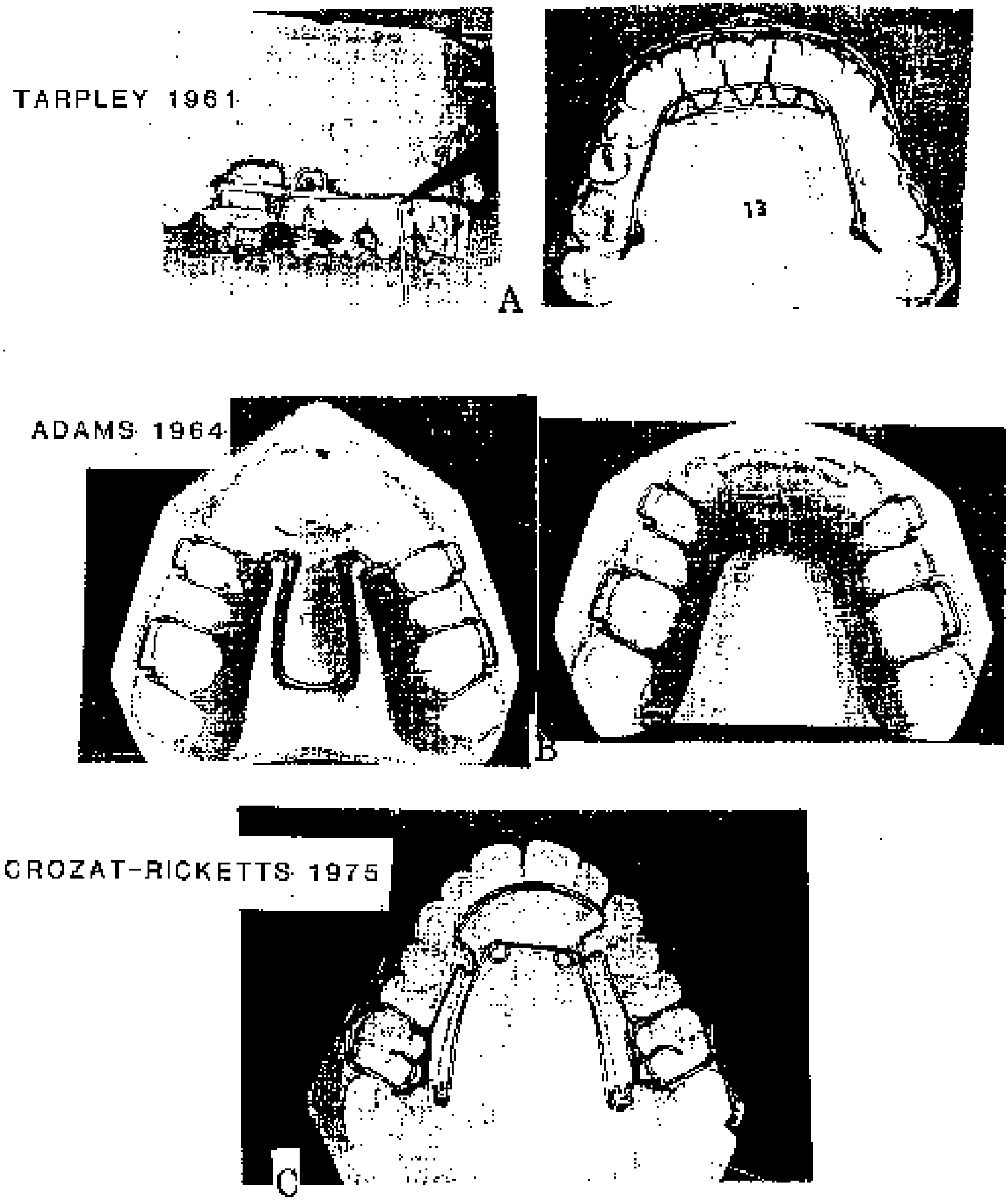


Fig. 2 - 7

A. Labio-lingual technique. Note loop for activating molar. Note fixed Oliver guide plane for bite jumping. Components were removeable.
B. Adams arrowhead clasps and plates. (Continuous and Intermittent Forces)
C. Ricketts modification of Crozat with quad-helix.

Restating his case in 1916, and seemingly falling more under the influence of Angle, Oppenheim employed his work to further verify the theory of intermittent application. Thus, the work of Oppenheim reported later in 1934 on humans was used as a brief for application of the Edgewise mechanism.

The "Light" Advocates

With observations of better efficiency clinically the arguments for lighter, more continuous forces continued. This was manifested in 1928 by Dr. Spencer Atkinson, who patented the "Universal" bracket to be employed initially with a light round wire, by Dr. Joseph Johnson in the 1940s with the light twin round wires, by Dr. Raymond Begg in the 1950s who used round wires with numerous loops for his technique, and by Dr. Joseph Jarabak in the 1960s. All took exception to the intermittent practices with the traditional edgewise system (Fig. 2-8)!

Bunch, in 1942, working experimentally, showed depression and described delayed action of one to two weeks for movement to be initiated. In 1945 Lefkowitz and Waugh published work done experimentally on dogs. **Their conclusions have a bearing on the most optimal types of force to be used.** Therefore, interest was increased, not only to continuous and intermittent but also to the idea of "light" and "heavy" forces. Light wire techniques became of wide interest in the profession.

But what was light and what was heavy? What was actually meant by continuous or intermittent? In contrast to the Angle concept, the findings and conclusions of Lefkowitz favored the application of continuous forces much lighter in character than previously employed (3 oz. or 90 grams per tooth). But still the idea of "pressure" or **force per unit area** was not entertained. Lefkowitz referred to the stimulation of the blood supply and Nature's capacity for restoring the normal periodontal space from which we formulated the "law of adaptation".

In 1952, Anthony Storey, together with an engineer named Smith, set up a

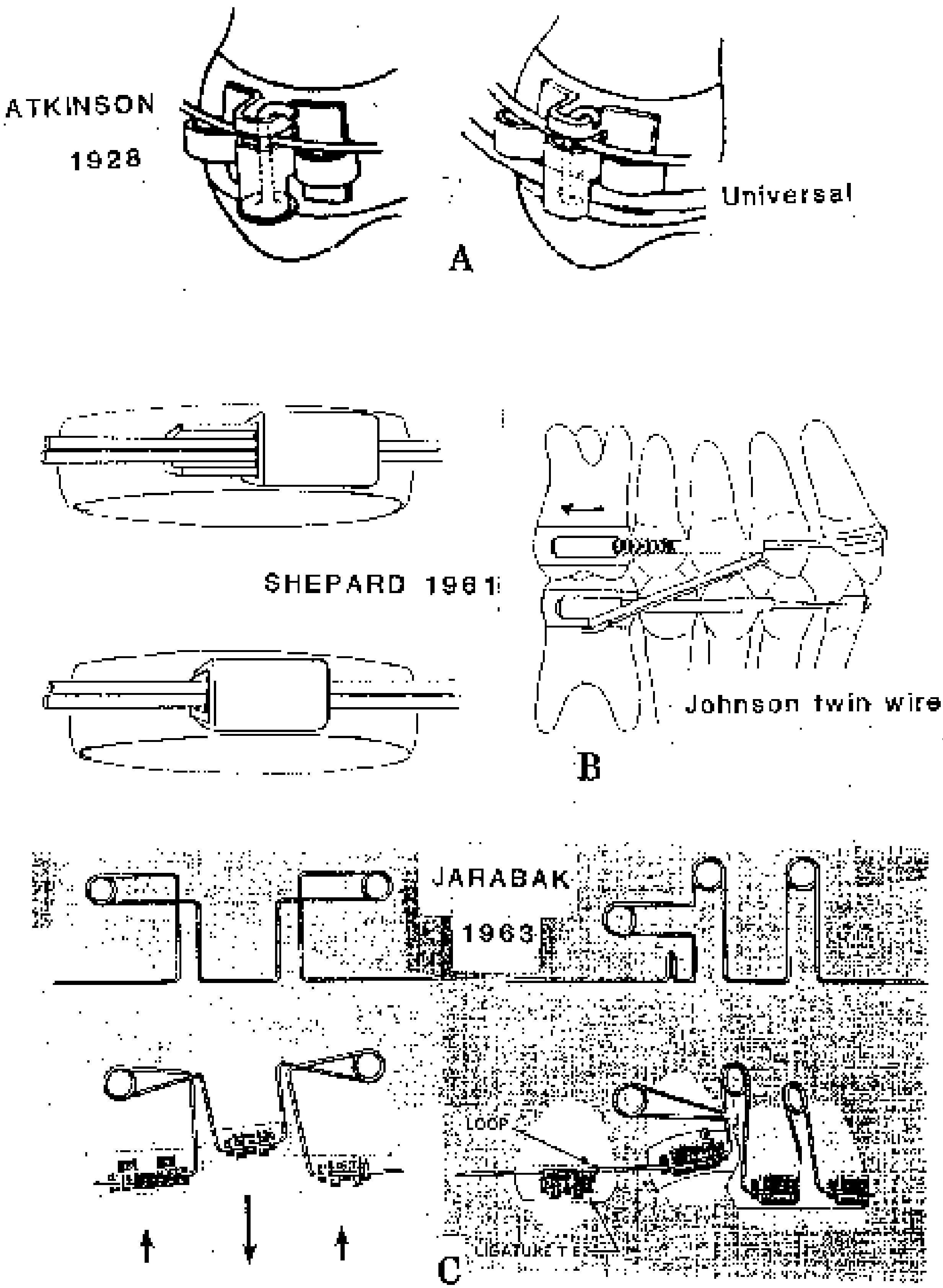


Fig. 2 - 8 A. Atkinson's Universal bracket.
B. Johnson's Twin-wire appliance.
C. Jarabak loops in round wires for long continuous action.

clinical experiment in extraction situations (Fig. 2-9). Their findings revealed that forces greater than 300 grams sclerosed the canine and produced greater mesial movement of the posterior segment. Forces lower, down to 150 grams, showed better canine retraction and more preservation of anchorage. Their experimental model contained frictional factors, however.

Dr. Raymond Begg demonstrated a rapid movement of teeth, but his technique involved severe tipping and later uprighting of teeth in the effort to promote efficiency for a five-month correction. But many proclaimed this therapy to be damaging, as premature aging of the crests was thought to be produced (see Fig. 2-9).

In the 1950s and 1960s orthodontics found itself in a dilemma, which was further heightened by a dearth of nomenclature and ability to communicate. Anchorage and the sources of resistance to tooth movements were still not agreed upon.

Constant and Interrupted Force

In the late 1960s, two concepts were added to describe force. "Continuous" was expanded to the idea of a "constant force" by Burstone. Load deflection rates in wires came under analysis. In addition, extraoral therapy with "heavy forces" of up to 1000 grams came to be advised for full time use by some clinicians. Others, such as the author, advised 12 to 14 hours of use, or even wear for sleeping only, and the use of 300 grams in the deciduous and 500 grams in the mixed dentition condition. The term "interrupted" was added by Reitan in 1958, in addition to the concept of "constancy".

The idea of "rest periods" had been added in the previous half-century by many clinicians using the fixed techniques. Resting lines or layers of bone and cementum are seen histologically. Thus, not only was the nature of forces a significant dilemma, but even rest periods, and the rationale for their practice, became other subjects of

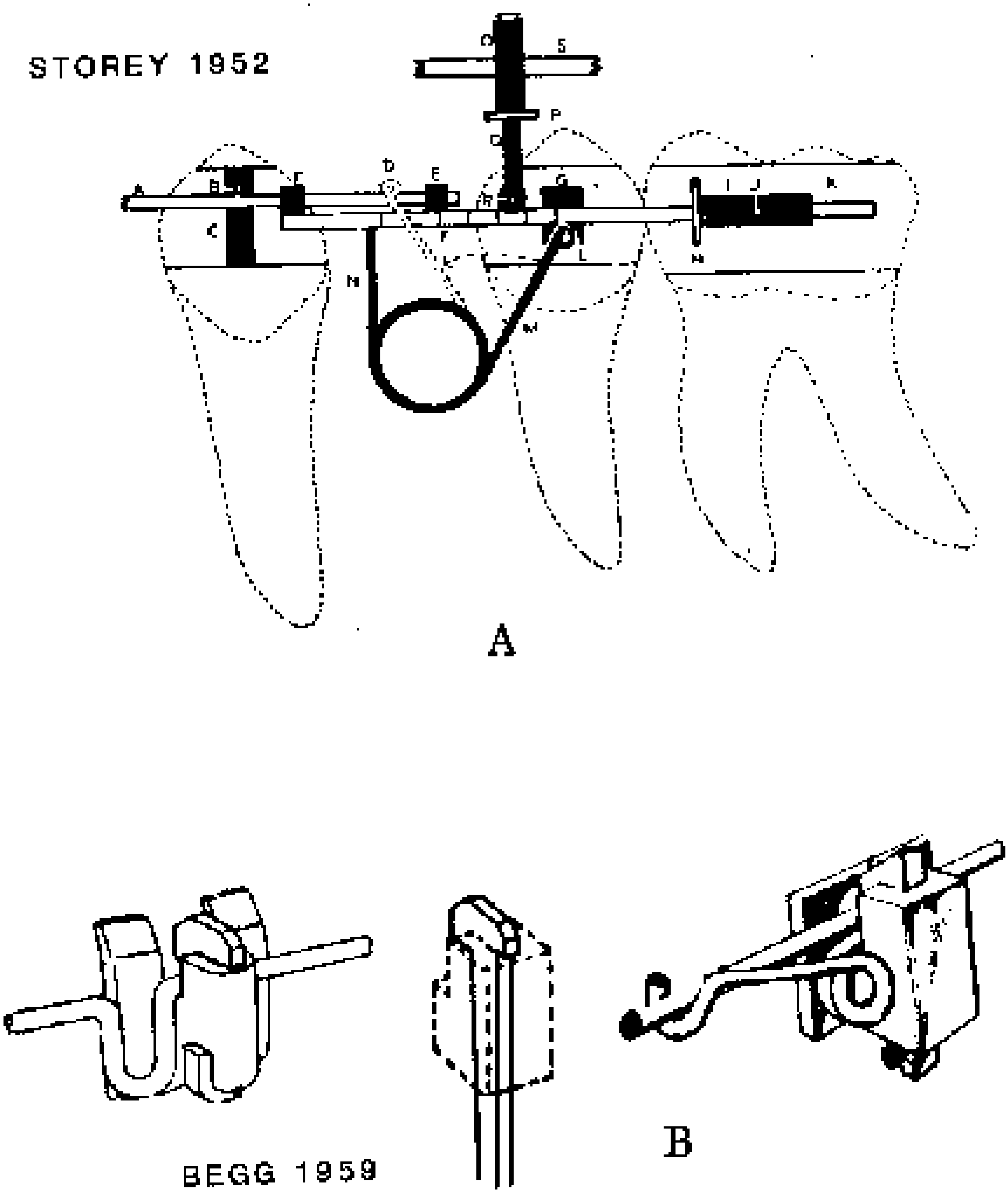


Fig 2 - 9 A Storey experimental method for measuring anchorage (note "clock" spring) to slide sections. Note friction possibility.
B. The Ribbon bracket was inverted and round wires were employed by Begg.

controversy.

During these years also the contribution of growth to treatment mechanics still remained a mystery. Muscle was talked about but was difficult to assess.

In the 1960s Ricketts collaborated with both Reitan and Storey for a working hypothesis with reference to forces, in order to at least help organize the profession (Chart I).

PRESSURE ANALYSIS

The work of Burstone and his co-workers measured application in terms of moments of force because force applied at the crowns produced rotational effects which were to be measured in moments as in applied mechanics. Their publications indicated that 2000 gr./mm. of moment was sufficient to move a molar, and 1500 gr./mm. of moment was adequate to move a canine. Therefore, more exact amounts of force became the interest clinically.

Starting with the .021" X .021" gold wire, experiments over a ten-year period led Ricketts to employ commonly the .016" X .016" blue Elgiloy wire. This size and composition was found to have the ideal 2000 gr./mm. capacity. Therefore **no larger wire is needed** to accomplish tooth movement or orthodontic manipulation (Fig. 2-10) (except for movement of a number of teeth as a unit).

If orthopedic forces are desired, auxiliary appliances -- extraoral or intraoral -- are needed to produce 300 to 1000 grams of force. As a result of the ideas of several investigators, lighter forces were gradually more accepted. Appliances were designed for continuous forces to be produced. Many advocates came to profess to be "light-wire users".

CHART 1

CLASSIFICATION OF FORCE

Relationship of Grams to Ounces

Ounces		Grams	Force
0.5		14.17	Very light
1		28.3495	
2		56.6	Light
3		84.9	
4		113.2	
5		141.5	
6		169.8	Intermediate
7		198.1	
8		226.4	
9		254.7	
10		283.0	
11		311.3	Heavy
12		339.6	
13		367.9	
14		396.2	
15		424.5	
16	(1 lb.)	453.6	Very Heavy
32	(2 lbs.)	907.2	
48	(3 lbs.)	1,360.8	

For rounding out for clinical use, one ounce is considered roughly 30 grams. Thus, three ounces for intermaxillary traction, for example, is nearly 100 grams, and five ounces is considered about 150 grams. Rounding out in this manner makes it easier to calculate.

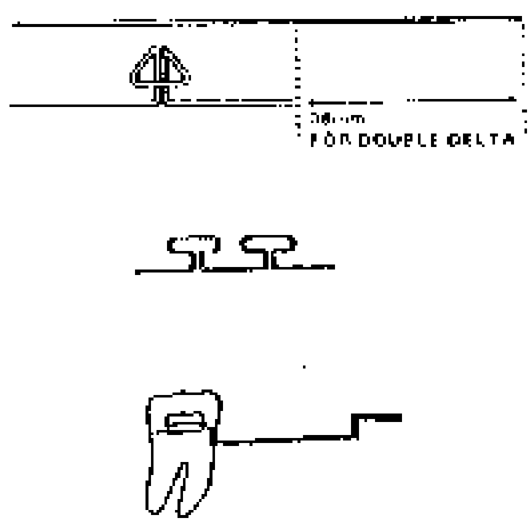
CAPACITY OF

.016" X .016"

BLUE ELGILOY WIRE

Conclusion about 2000 gram mm. of moment

LENGTH	FORCE OF BENDING
@ 40mm	+ 50 grams
@ 35mm	+ 60 grams
@ 30mm	+ 70 grams
@ 25mm	+ 80 grams
@ 20mm	+ 100 grams
@ 10mm	+ 200 grams
@ 5mm	+ 400 grams
@ 4mm	+ 500 grams
@ 3mm	+ 600 grams



Values rounded off for clinical use

Fig. 2-10 Load deflection rates with 16 mm^2 blue Elgiloy – no larger wire is needed.

Bonding and Force Reduction

One other technical factor that played a role toward lighter application of forces in the mid-1970s was the development of bonding of brackets. Clinicians could not apply the forces previously used with bands for fear of breaking off the bonded bracket. The discovery of equal or better clinical results did much to stimulate interest in lighter and more continuous wire use.

Force to Pressure

Dr. Brian Lee, of Australia, was among the first to investigate reducing the concept of "force" to "pressure" (force per unit area). Dr. M. Stoner had related to the "4 D's" in force application: direction, duration, distribution and degree. But Lee, working with the Begg concept, became concerned with the amount of bone, enface, in the direction of movement as a guide for the measure of resistance. Based upon Lee's work, and in communication with Lee, Ricketts produced a root rating scale to be used as a starting point for force application, particularly when plotting anchorage.

The Root Rating Scale

Pressure is force per unit area. That being the case, the size of the root became the question in movement and anchorage. In his work Lee had drawn the hypothesis that 200 grams per square centimeter (or 2 grams per square millimeter) was the pressure of choice in the movement of teeth, (which he essentially confirmed in 1995). This became the basis of Ricketts' experiments in the 1960s in which clinically measured forces were applied. Intraoral photographs were made for analysis, and cephalometric and laminagraphic X-rays were also taken for study. Not only tooth movement but anchorage preservation was the focus.

The 2 grams per square millimeter force per unit area was found to be excessive for movement of teeth within the alveolus when preservation of anchorage was an issue. Pressures were measured and reduced experimentally to 150, and finally to 100 grams per square centimeter (or 1 gram per square millimeter). This amount of pressure has been maintained essentially now for 30 years, and was confirmed by the laboratory work of Muira (Fig. 2-11A).

Modifications for Ridge Change and Anchorage

The force of 1 gram per square mm. is specifically prescribed for moving teeth along the arch within the alveolar channel or medullary bone. Arch wire sizes and loop designs were selected with this data in mind. However, when labiolingual or buccolingual movements are to be made (or the cortical plates are to be modified) the pressures are reduced 50% to 0.5 grams per mm.^{2}. **This idea of unit values led in turn to the sectional arch principle.** Instead of pitting all the teeth in the lower arch against all the teeth in the upper arch, only the upper buccal section was engaged. Later the utility section, with modifications, was employed to great advantage. The whole sectioning concept warrants a manual unto itself (Fig. 2-11B).

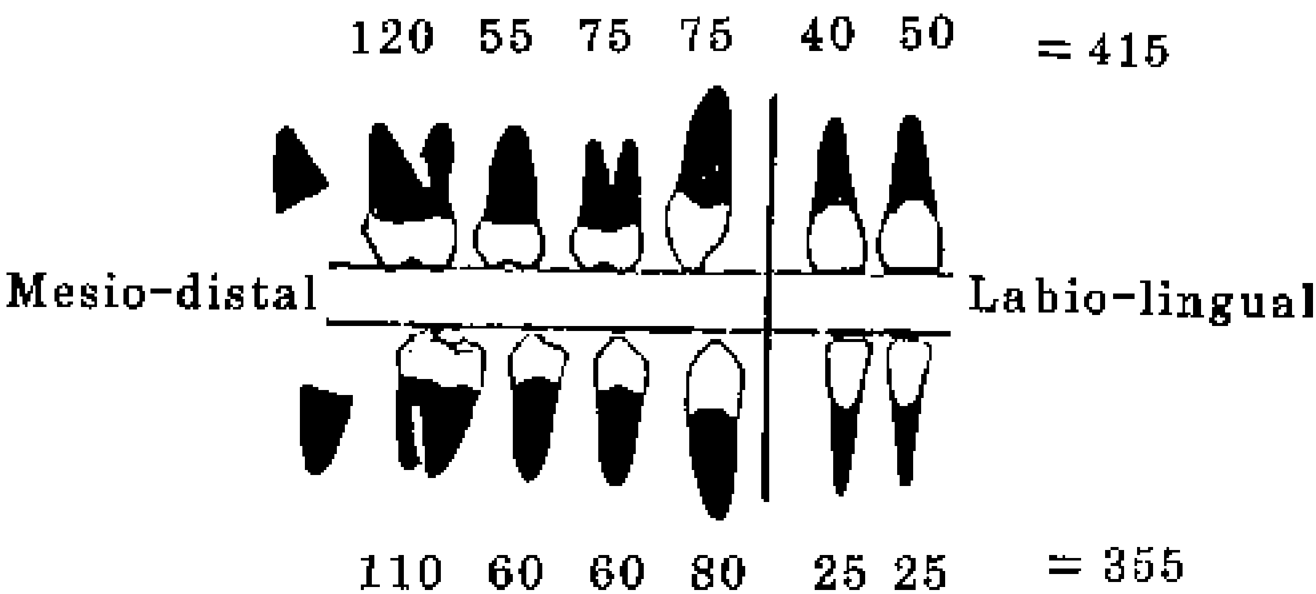
Mesio-distal Translatory Tooth Movements and Arch Sectioning

The hypothesis of a tooth pressure of 1.0 grams per square millimeter in the direction of movement was tested and retested clinically. Force was measured and results were appraised. **Tipping actions in which force is directed only on the crest would develop much higher local pressures at the crest,** as shown by Thurow.

Further work by F. Muira, published in 1973 [*Proceedings of the European Transactions in London*] showed that by using very tiny pressure gauges in the periodontal membrane, 0.83 grams per square millimeter resulted in tooth movements. In personal communication with Muira, he confirmed that the use of 1.0 grams per square millimeter was perhaps best. With the foregoing findings, these values were applied as a guide for all local movements and hence apppliance choice

ROOT RATING SCALE

ONE (1) GRAM PER SQUARE MM.



ANCHORAGE

For Sclerosis × 2 or × 3

For cortical modification 1/2 gram

Fig. 2 - 11A Root Ratings in sagittal plane direction. Distal movement of molar with sectional mechanics requires (bodily) 120 grams.
Cortical anchorage of lower molar (buccally) X 3 = 330 grams
Labial movement of lower incisor X 0.5 = 12.5 grams.

RATINGS

Prescribed force per square millimeter of ROOT-BONE engagement

(1) For ordinary Cancellous bone
1.0 gram per $mm.^2$

(2) For ridge modification
0.5 gram per $mm.^2$

(3) For cortical anchorage or sclerosis
2.0 to 4.0 grams per $mm.^2$

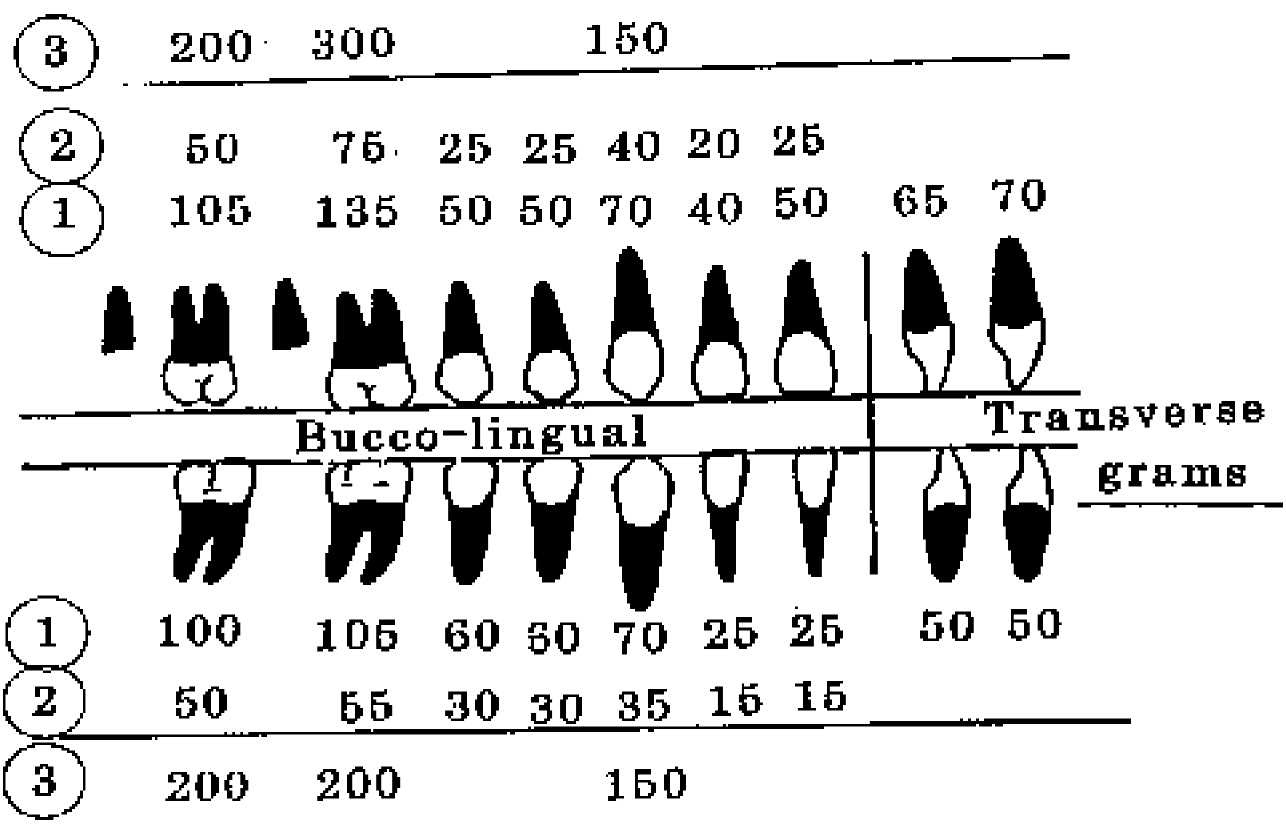


Fig. 2 - 11B Root Ratings in Transverse directions.
1 – Ordinary movement,
2 -- For ridge change,
3 -- For anchorage.

and design, which included breaking up the straight wire.

TOOTH INTRUSION

Dr. F. Muira in Japan demonstrated conclusively, with experiments in the rabbit, that intrusion was a possibility. Using one central incisor in the rabbit as a control, and applying measured intrusive forces on the adjacent incisor, a force of 3 grams was seen to slow down its eruption. A force of 5 grams was seen to arrest eruption, and a force of 7 grams was seen to actually intrude the incisor in the opposite direction along its arcial path of eruption. Therefore, **intrusion has been proven** both clinically and experimentally in the laboratory. The time has come to put the argument aside. It is not just a "relative" condition, but true intrusion directly along the root long axis.

Force of Eruption

Based on these experiments, and clinically employed with the guide of the rating scales, a working hypothesis was made regarding the force of eruption. It was estimated to be approximately 0.2 gram per square millimeter of root cross-section. Thus, any continuous pressure around 0.2 grams per sq. mm. would theoretically counter the eruptive force. Any force, say double that amount, or 0.4 to 0.5 grams per sq. mm. would be great enough to intrude the tooth as well as overcoming the eruptive force. Calculated in this manner for a lower third molar, a force of only 20 grams would be sufficient to overcome the force of eruption, and a force of only 40 grams, **as long as it was continuous**, would intrude it. This is in contrast to experiments for intrusion of molars in open bite by some investigators in which 800-1000 grams were used. Based on the present hypothesis, 40 grams or 1/20 of that force would be sufficient, if applied continuously (Fig. 2-11-C).

ROOT RATING SCALE

ONE (1) GRAM PER SQUARE MM.

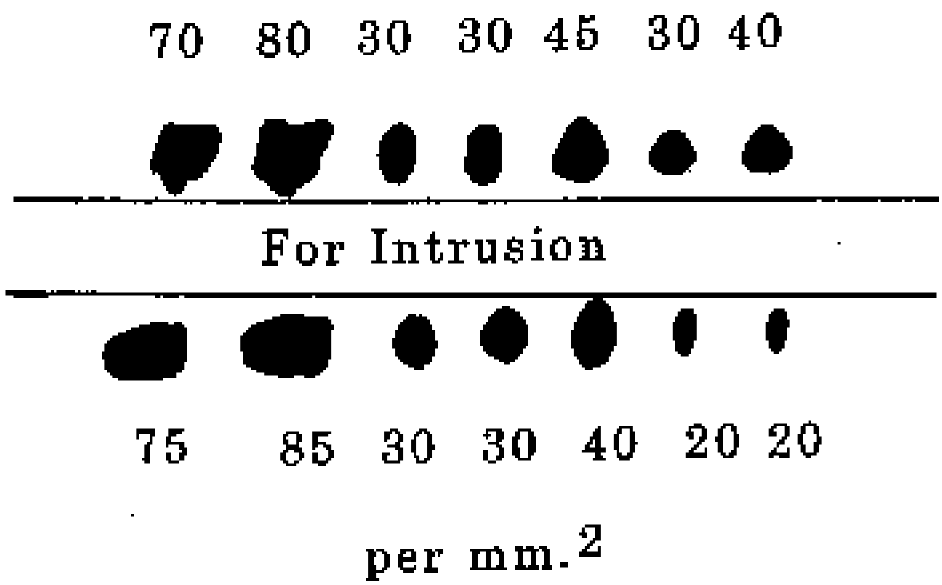


Fig 2 11C Theoretical intrusive force for different teeth at one gram per mm.^{2} of root cross-section. Actual may be less

Cephalometric Evidence of Intrusion

The first cephalometric evidence of intrusion, as seen by the author, was in 1948. It was in a female Class II, Division 2 mixed dentition case treated with "Ribbon Philosophy". A size .022" X .028" gold wire was used. The deciduous molars and canines were bypassed as with the original Ribbon technique (Fig. 2-12). Not only were teeth intruded but it seemed to affect the behavior of the mandible as well.

Progressive Engagement and Findings

Placing separators for opening spaces for banding was time-consuming, tissue-damaging, and was painful. Chrome alloy molar bands alone could usually be placed without separation in young patients. **Progressive banding** and **progressive control** was consequently developed. In the beginning, lower molars were tipped backward to create buccal space with straight wire by using the canines as anchorage. A straight .016" round wire was employed as the first step in this procedure. It was evident that **canines would intrude** as a result of tip-backs placed in the wire if the tipback was not too vigorous. This was the **second clinical evidence of intrusion possibility** and was recognized in 1954.

The third clinical suggestion of intrusion was seen in extraction cases in the lower arch in the second premolar. During too vigorous space closure, the molar was seen to tip forward and the lower second premolar appeared to be depressed relative to the other teeth. Forty-five degree cephalometric films were obtained in order to accurately measure the tooth changes from the lower mandibular border. With the forces used, as the first molar tipped forward, the second premolar was actually intruded. The canine, also moved with excessive pressure, tended to extrude.

Thus, by now, premolars, canines, and lower incisors had been noted to be "depressed". But in some patients the lower incisors had been moved obliquely, rather than directly along their long axis.

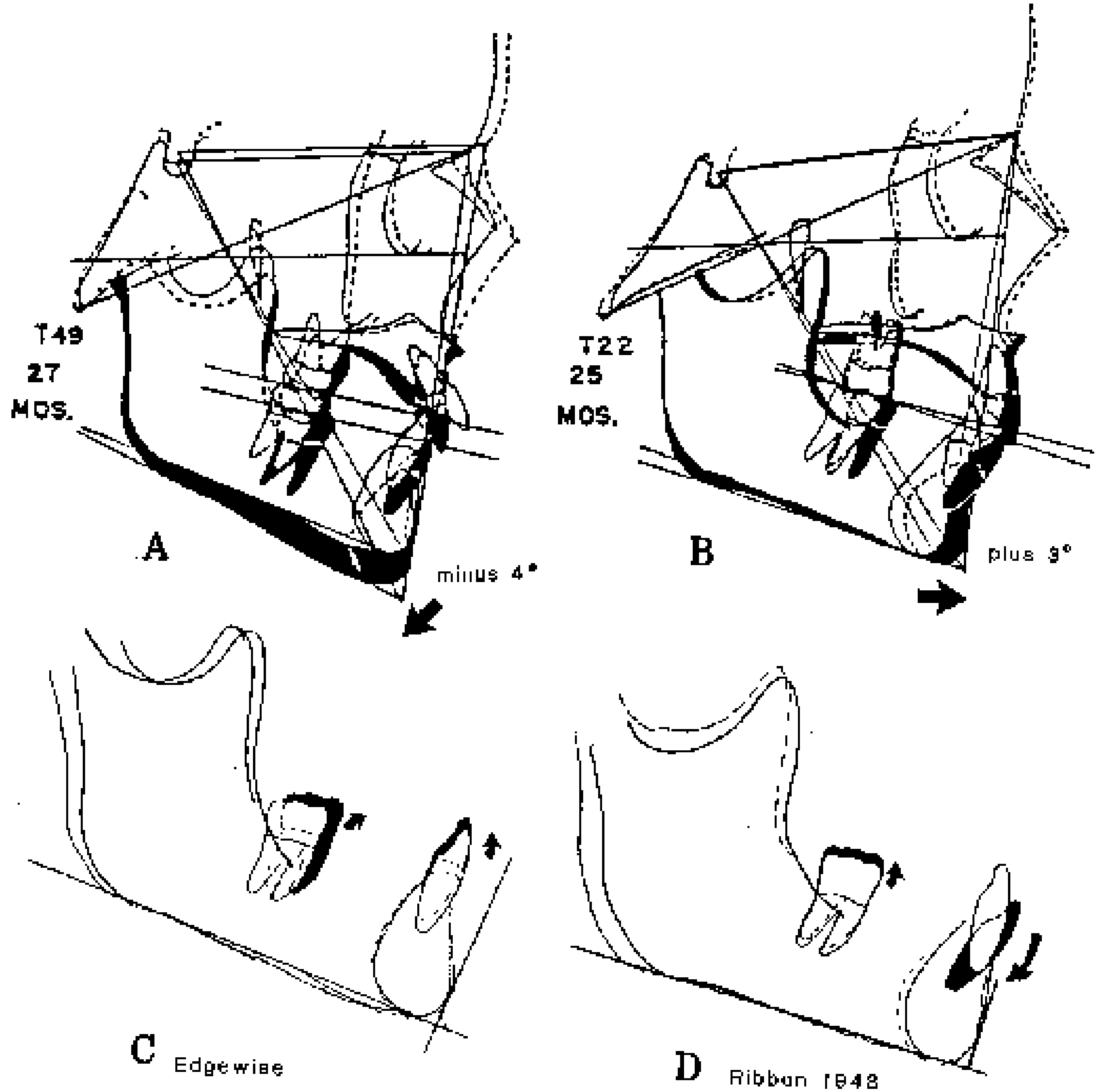


Fig. 2 - 12 Two patients treated in 1948. Patient T49 corrected with primary Edgewise and T22 with Ribbon philosophy. In A note opening rotation of XY axis of 4°. In B note closing rotation of 3°. Note differences in occlusal plane. In C note extrusion of lower arch. In D note dramatic intrusion of lower incisors when related to mandibular plane.

The Birth of the Utility Arch

In experiments with extraction cases a second wire (a round .014") was anchored from the molars and bypassed the premolar and canine. Cephalometric comparison revealed findings of incisor intrusion directly into the sockets. Prior to this time, direct intrusion of teeth had been deemed impossible. It was assumed clinically to be a false impression or an illusion caused by rapid eruption of the adjacent untreated teeth. Such was certainly not the case, particularly in adults where no height increase occurred (Fig. 2-13).

Upper incisor intrusion and torquing have been gained even against the palatal shelf when light continuous pressure was applied (see Fig. 2-13). By 1960 there was no longer any doubt about true intrusions. It was obvious that it required light pressure, that the application needed to be continuous, and that pressure on cortical bone needed to be avoided.

This prompted the development of the "utility arch" and double lower molar tubes. By 1961 remarkable efficiency was demonstrated with the utility arch for intrusion of anterior teeth with .016" X .016" blue Elgiloy wire (Fig. 2-14).

Developments in Brackets and Tubes

In the pursuit of lighter pressures Ricketts selected smaller wires while attempting to maintain "three-plane control". From the .022" X .028" it was reduced successfully to a .021" X .021" gold, which was employed during the years 1950 to 1954. This size was further reduced to .019" X .019" in the blue Elgiloy (chrome-cobalt) wire, still employed within the .022" edgewise bracket for application until 1956. The forces as measured, however, were still too excessive!

Siamese brackets were adopted in 1953 to eliminate the inefficient staple. The need for a smaller bracket box was obvious from the study of results. The dual

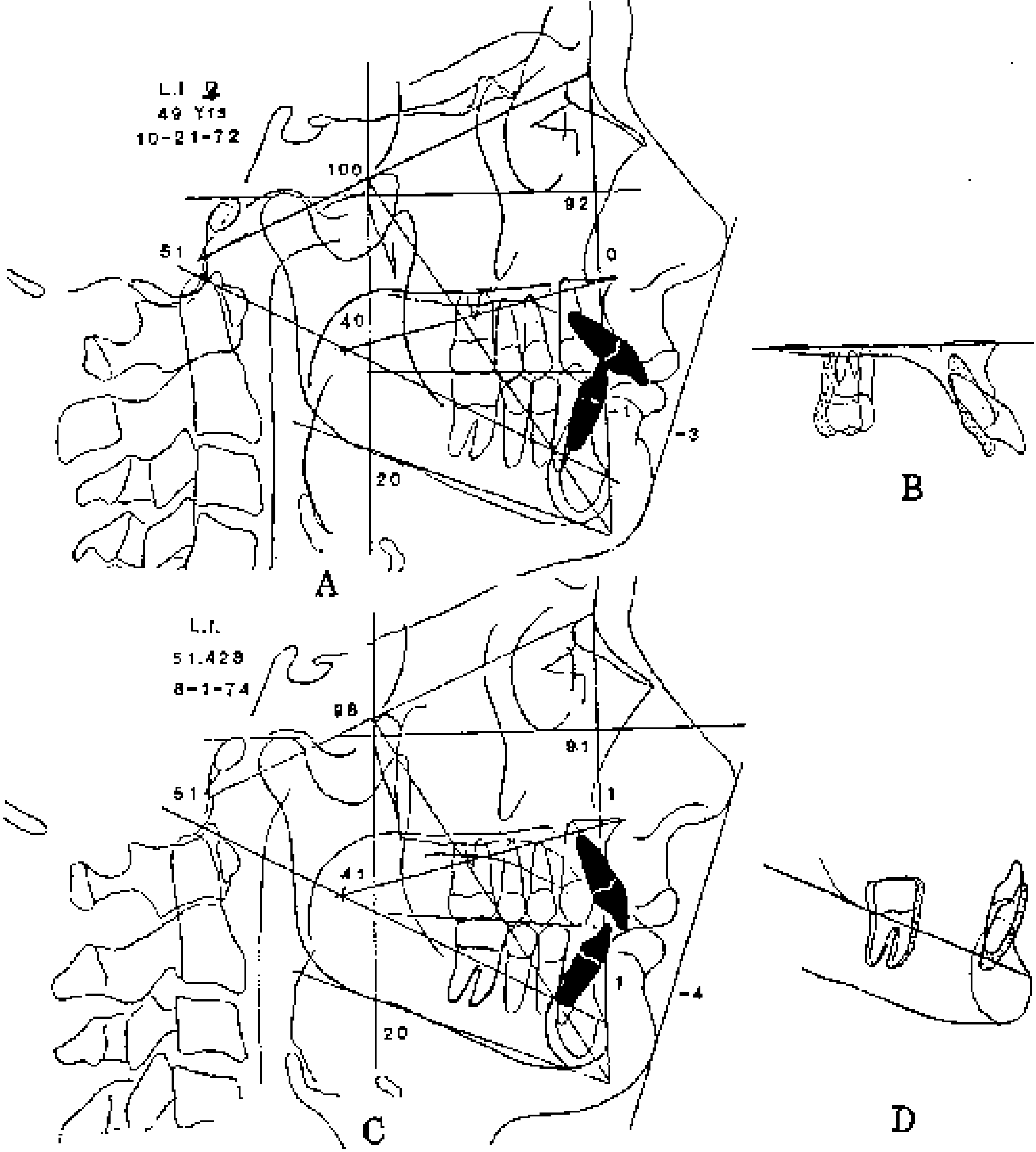


Fig. 2.13 A. Adult female, age 49 years (Class II, Division 1). Complete closed bite, supra erupted lower incisors and protrusive upper anteriors. B. Correction of molar to Class I and intrusion retraction of upper incisor. C. Condition after 20 months of treatment. Note lip change. D. Correction of lower molar to Class I and intrusion and emplacement of lower incisor to APo plane

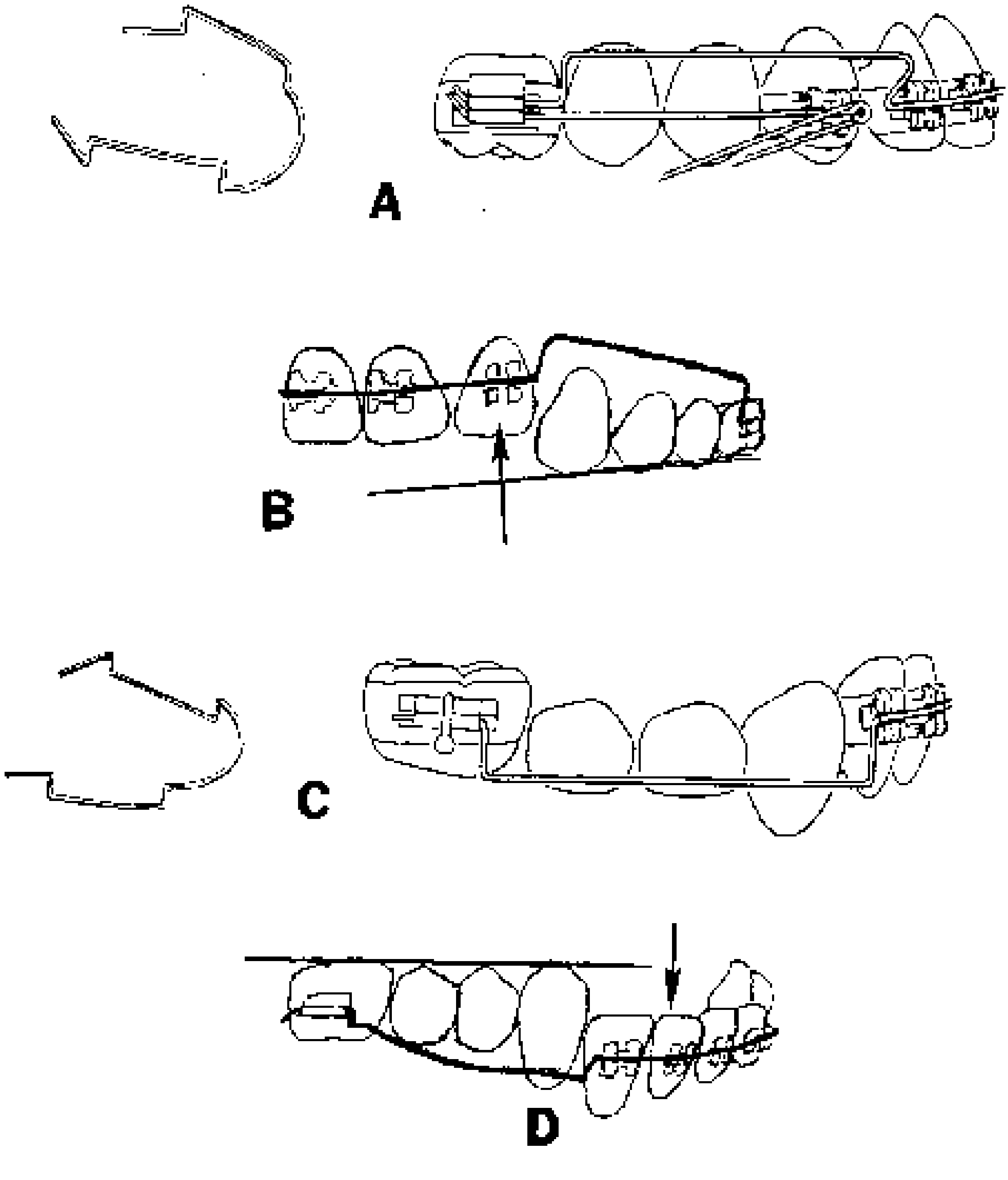


Fig. 2-14 A. Diagram of classic upper Utility arch with "Z" shape for elastics and opening or closing action. B. Rough tracing of photo showing intrusion of upper anterior section from occlusal plane. C. Classic lower Utility. D. Dramatic lower incisor intrusion shown in tracing of photograph.

brackets increased leverage and increased the effective force of the wire due to shortening of the lever arm. This occurred at the same time lighter and more continuous pressures were thought to be indicated. Preformed bands were designed and the brackets and tubes were "preadjusted".

After three years of experiments the .018" bracket was settled on in 1958 in collaboration with Dr. C. Steiner and Dr. H. Lang (Fig. 2-15). Measurements of forces and clinical results led to a reduction from .018" X .022", to .017" X .022", to .016" X .022", and finally to .016" X .016". (Lighter wires were sought to be used with the smaller bracket). In 1980 about 10% of orthodontists used the .018" slot. By 1997 its use had grown to 50%, and will probably continue to become more popular, as it comes to be taught in graduate schools.

BIOLOGIC STIMULATION

All connective tissue cells have one remarkable characteristic in common: each cell is a manufacturing plant. It receives from the interstitial fluid the necessary building materials, produces collagen, and elaborates through its membrane a ground substance. This material in turn, according to Dr. Simon Rodbard in 1973, is acted upon by the environmental tensorial forces to produce the specific connective tissue, one of which is bone.

Orthopedics

Skeletal alteration is a biologic process involving sutures, cartilage and bone remodelling. Interest in skeletal maxillo-mandibular relationship as well as arch relationship has become a major concern in clinical work. Bone and soft tissue development, and their alteration by orthodontic means, together with behavior of all connective tissues, including the integumental profile, are also of major concern. The

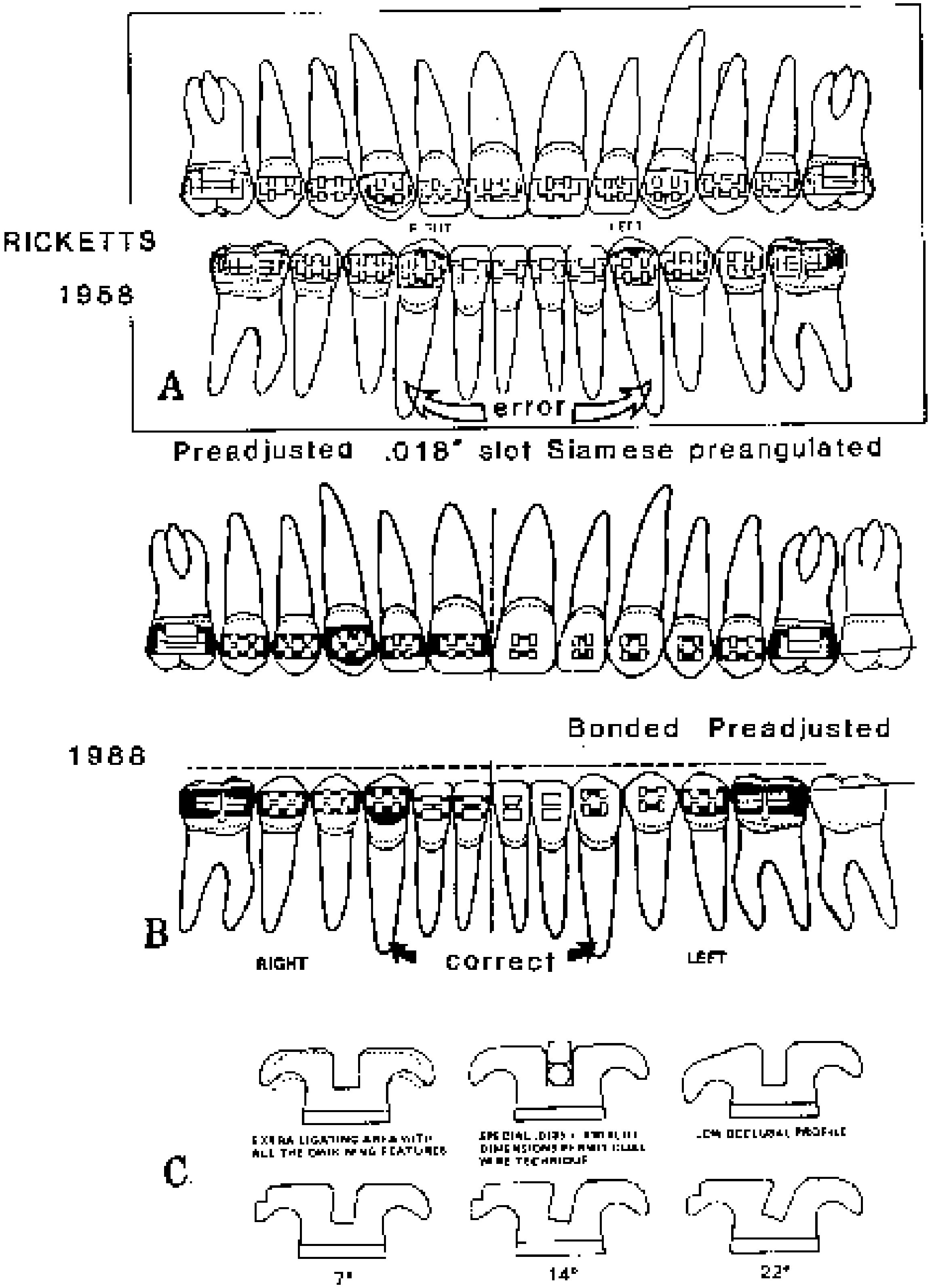


Fig. 2-15 A. First attempt to "preadjust" in 1958 with .018" slot in full preformed bands (the lower canines were tipped forward in error). B. By 1988 lower canines were corrected! Bonding was started in 1976. C. Torque brackets with "quick wing" design in 1965.

controversies rest with permanency in alteration of the mandible, but scientific findings show that maxillary skeletal change can be permanent.

Histology

Research at the cellular level conducted by Dr. Eugene Roberts showed mechanisms which affected bone formation and bone behavior under physical stress. Bone cells are initiated from progenitor mesenchymal cells. Bone is formed, beginning as Type I collagen elaborated from the cells.

The osteoblast is the final immediate producer of bone which becomes an osteocyte as it is surrounded by calcified material. For the production of an osteoblast, progenitor cells are required which go through a series of about six changes in character and function. The arresting idea is that for the production of new bone a biologic process is required going through osteoid first before being calcified

Osteoclasts remove bone and giant cells, together with macrophaging cells, do the cleanup. If none of these cells for the biologic process are admitted to an area, then stasis is produced. This is what Storey meant when he described a "cell-free area". Cells are needed for osteolysis to occur. This process is paramount in the movement of teeth. The bone becomes an anchor source when it cannot be resorbed.

In addition, the application of force on almost any material will produce electrical responses. These may be so low and subtle in nature that they are discounted, but Dr. Roberto Justis showed that loading a bone produced an effect on the calcium ion. Thus, another of the physical effects of force that must be considered is the stimulation caused by electrical potentials within the alveolar apparatus. This, together with the whole concept of interstitial fluid, which needs acid-base and electrolyte balance, is not a concept commonly appreciated by the clinician. Practitioners tend to follow the habit of thinking applied mechanics. They enjoy the idea that it is their mechanics doing the moving of teeth rather than Nature.

One finding is abundantly evident from every investigator reviewed thus far. **All found that excessive force caused hyalinization** which was followed by backward or undermining resorption, also sometimes called reverse action. The question, not often addressed by those involved in histologic investigations, persists: "How can undermining occur in compact bone?" (Fig. 2-16).

THE SWITCH TO MANAGEMENT OF CORTICAL BONE (RIDGE)

Many authors, including Oppenheim from 1911 to 1940, described the undermining resorption as a natural happenstance. When too heavy an orthodontic force is applied the blood supply (which actually feeds interstitial fluid) is squeezed out. If the pressure is great enough to affect the area, instead of osteoclastic cells working in a "frontal attack" on the bone, the tissue in that area is "pinned down". Nature then makes a "flanking attack", or a surrounding "rearward attack" on the bone. **Thus resorption occurs in the area anterior to the tooth socket** or lamina dura rather than the socket surface under pressure. Such areas are also thought to undergo **necrosis**. In such instances, particularly in heavy continuous forces, the area of bone necrosis may also be combined with areas of root resorption. Cementum also does not appreciate hyperemia and must be resorbed for deciduous tooth loss by the aneuretic effect of the pulsating blood supply of the crypt.

As shown by Rohan, all necrosis, **all necrosis**, is characterized by anoxia in its first stages. In other words an absence of oxygen always leads to cell death. This is true not only of the whole body, but also the individual cells within the body. **Tissue or cellular vitality is an underlying consideration for all orthodontists if they want to maintain complete tissue integrity.**

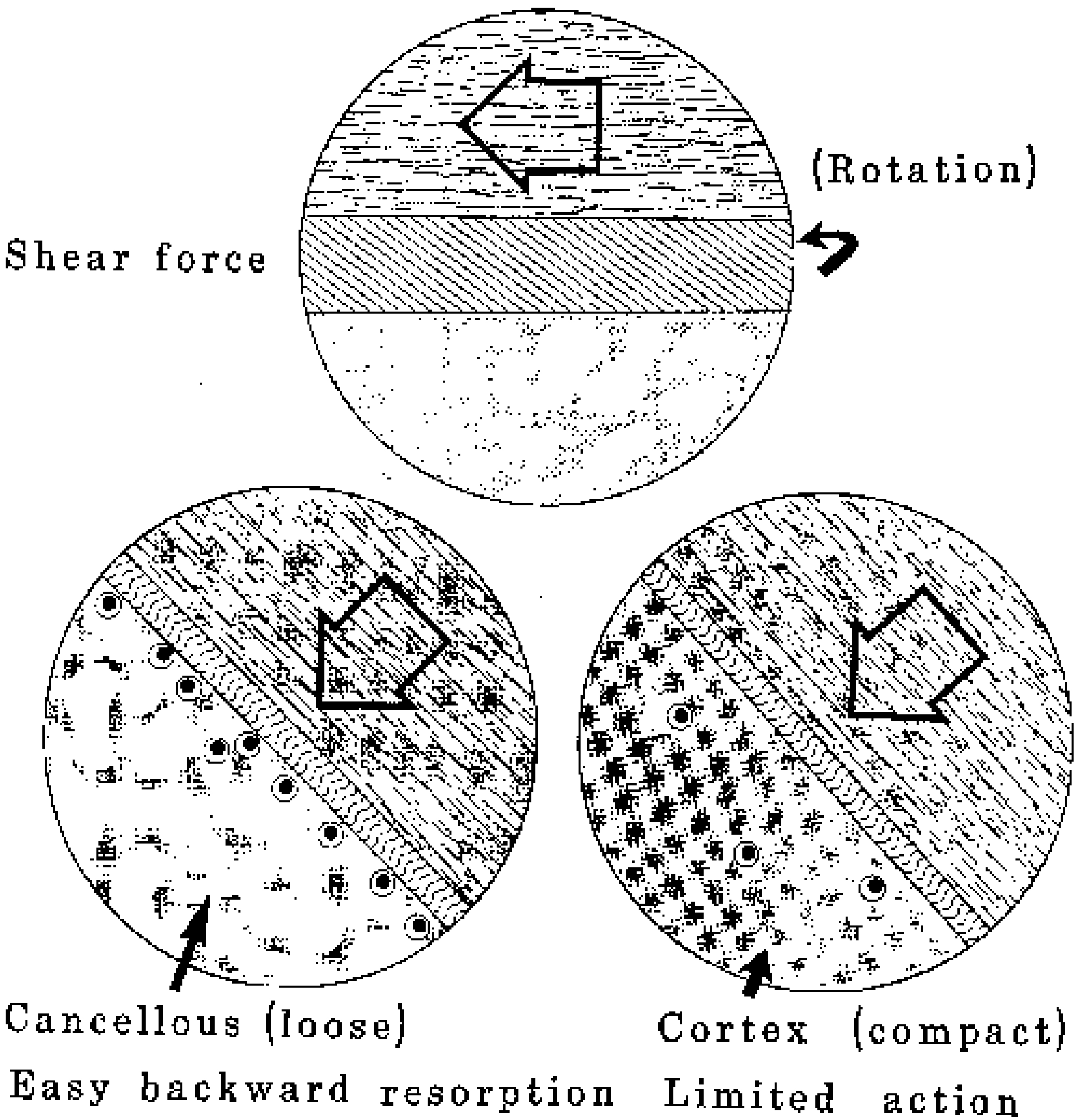


Fig. 2-16 Above: After Thurow (Edgewise Orthodontics). Translation of the root directly is made in rotation requiring a stretching of ligament estimated to be about 0.4 gram per mm.^{2} of rooted surface. Left: Movement against cancellous bone has spaces loaded with cells. Right: Against cortical bone, cells (and interstitial fluid) are more limited, and hence an anchorage source.

Cortical Anchorage

As mentioned before (see Fig. 2-16), the question arises concerning the processes of lateral or backward resorption when cortical bone is encountered. When roots engage cortical plates the action will become static when the pressure is excessive. Many examples of this are demonstrated clinically (Fig. 2-17, A). A tooth root becomes a point of resistance. Hence it becomes an anchor for an undetermined period of time. Perhaps pressure ultimately removes the cortical bone and hence dehiscence of bone. Atrophy of the gingiva can ensue, which is also thought to be due to lip pressure (i.e., pressure eschemia).

Ridge Modification

But if modification of the ridge (alveolar process) is sought, the orthodontic pressure must be quite different. First, the pressure must be very light, maybe one-half the usual 1.0 gram amount, or 0.5 grams or less per millimeter of root surface. In this event, rapidity of movement should not be an objective. Brodie taught students to use only one washer on one side for expansion at each two-week interval and even to alternate treatment of the individual arch which would mean one washer each four weeks.

Rotational Forces

The rotation of a tooth means a stretching of the fibers and reattachment which suggests a tension-type or appositional phenomenon for embedding of fibers. In order to stretch fibers it is estimated that 0.4 grams per mm.^{2} is required.

However, the analysis is not that simple. If a round root, or nearly round root, is to be rotated the force would be applied to all the fibers. Taking this into account, the lower premolars and upper incisors, perhaps, would be about 100 mm.^{2} This would mean a seed for 40 grams of force. Thus a lever arm of 10 mm. would need to have a 400 gram/mm./moment.

If the root of the lower incisor, which is oblong in shape, is to be moved the situation is different. The labial half of the root would be pressure, and the lingual half of the root would be tension -- or vice versa. This would reduce the stretching of the ligament and yield an analysis about equal to a mesio-distal movement (50 grams). The same would apply to upper molars (120 grams).

As another factor, biologically the bone development needs to be stimulated to prepare the area where the tooth is intended to be placed or is directed. This means, further, an alteration of the periosteum if movement be toward the outer plates. This is the possible secret, at least theoretically, to successful expansion of arches without ridge destruction (Fig. 2-17, B).

Thus, expansion of premolars buccally, in both arches, should take about 30 grams. For molars (with two roots) only about 60 grams is needed, according to this theory (see Fig. 2-11, A,B,C).

A quad helix in .038" Elgiloy can deliver 600 grams. This will sclerose the bone around the area of the root. But if alveolar modification for rotation and/or expansion is desired it needs to be 60 to 75 grams for an upper molar. Have orthodontists been too impatient? Does the typical operator enjoy this tissue sense?

SOFT TISSUE MODIFICATION -- ATROPHY -- DYSTROPHY

The word "atrophy" may have several descriptions, one of which is a "wasting away". Perhaps this term is a poor one for the concept of soft-tissue modification in orthodontics. Atrophy is also said to be due to a lack of nourishment leading to a reduction in size of the cell, or the diminuition of tissue. Part of the body and tissues can atrophy from either physiologic or pathologic factors.

Dystrophy is degeneration. It is often due to prolonged defective nourishment which means oxygen and nutrients or absence of the acid-base or electrolyte requirements for cellular survival. **Perhaps orthodontists should think in terms of dystrophy instead of atrophy.**

Soft-tissue modification, referred to in this context, is in the gingiva, the keratinized gum, the mucosa, the connective tissue, or even the periosteum. In fact, it probably pertains to all the tissues, both connective and epidermal in type or all tissues other than bone modification. It has been shown that swelling of the soft tissue producing a "cuff" around the neck of the tooth can actually be a factor in tooth migration, tooth movement, or a cause of relapse.

Every experienced orthodontist has seen extraction cases in which the soft tissue is "piled up" in an extraction site during the treatment process. In other words, in these particular cases bone modification has been a faster process than soft tissue atrophy -- dystrophy or adaptation. Therefore, attention to soft tissue is unavoidable.

When teeth are moved the soft tissue adapts to the tooth movement. Continued pressure on soft tissue anywhere in the body will produce atrophy. Usually such soft-tissue atrophy is preceded by **pressure eschemia**, which undoubtedly is also associated with interstitial fluid expression leading to anoxia and necrosis and **hence dystrophy**. Thus, abnormal pressure, particularly of a sufficient duration, theoretically leads to death and loss of tissue. Therefore, in orthodontics, the concern is not only with alveolar bone but also with **preservation of the connective tissue**, and with pressure ischemia of soft tissue, particularly on the labial of the lower anterior teeth so often frightening to the clinician.

One dramatic evidence of the pressure ischemia phenomenon is the reversal of atrophy to hypertrophy of gingiva with "bumper" therapy. This is also the occasion for loops to be placed in arches in order to protect the gingiva from lip pressure. Another proof of the pressure theory is the loss of lower incisor labial soft tissue from a chin cup that is improperly fitted.

SUMMARY

There has been an ongoing argument for more than a century regarding types of forces for optimal clinical use. A number of factors are of concern, such as (1) light or heavy, (2) continuous or intermittent, (3) constant or interrupted, (4) tipping or bodily movements together with (5) resting periods. Orthodontists speak of physiologic movements but seem to be guided more by pain tolerance than by anything else clinically. The Bioprogressive thesis is that light **pressures** be applied as continuously as possible for tooth movements, but that "anchorage" requires heavier pressure and, in addition, cortical bone.

The idea of pressure, or force per unit area, is the concern in the final analysis. The amount of continuous pressure needed to "stretch" the ligament in order to overcome eruption forces is a primary consideration. With the ligament yielding, pressure is placed against the socket which is designed to take tension. As soon as the lamina dura is resorbed intrusive movements are amazingly rapid.

From that approach, Root Rating Scales were devised as a basic starting point for reference. (We advocate the memorization of these data -- see Fig. 2-11.) The original scales were to apply to movements within the alveolus. Intrusion values seem to follow that rule of one gram per square millimeter of enface root surface (or cross-section of root area). When cortical plates (labio-lingual or bucco-lingual) are to be modified the force is to be **reduced** one-half. When anchorage is desired the pressure is double or more.

Tooth movements, in the sense of biology, are instigated by mechanical signals. Too much pressure produces sclerotic changes and will inhibit movement. This same phenomenon is employed as a process for anchorage production. This idea is particularly appropriate for "cortical anchorage". When ridge modification is desired the **ridge needs to be prepared by very small signals** so that lateral alveolar process development or "ridge modification" can be attained.

Soft tissue atrophy and dystrophy are further conditions of interest in biomechanics. Maintenance of the covering of the alveolar bone is as much a goal as correction of tooth relations.

The effects of muscle tension are a further consideration, and release of muscle tension is a separate issue.

The ultimate objective is to provide the patient with an occlusion that will serve him/her for 100 years.

CONCEPTS OF
MECHANICS AND BIOMECHANICS

CHAPTER THREE
MECHANICS FOR ANCHORAGE

INTRODUCTION

Orthodontics, in the end, is a game of mechanical anchorage! Anchorage is involved in moving the teeth within the same arch by using resistance of teeth against each other or by added muscular and soft-tissue resistance. Anchorage of one arch of teeth against the other is employed for maxillo-mandibular correction. Extraoral forces are added as a further source of anchorage. Growth and growth modification enter into the anchorage equation. Scar tissue becomes a profound factor when present, particularly in post-operative cleft conditions. Thus "mechanics" and "anchorage" are involved in correction of essentially all malocclusions.

Technically, "biomechanics" deals with forces as they react under living conditions, not on the typodont. Biomechanics, in truth, becomes the framework for concepts of "clinical anchorage". Always with any physical mechanism, action and reaction are the same. However, differential results of action will vary with the amount of force and the distribution of that force against different types of bone, soft tissues, muscle or scar tissue. Consequently, a classification, and a hierarchy, needs to be established for resistances to be calculated.

Anchorage is described as resistance to a drag. In addition, all resistances may need to be considered in order to predetermine or estimate the dental changes desired, change for alveolar process, or intended change in skeletal structure together with the modification of muscular factors.

The Bioprogressive philosophy may be summarized as "**The application of biomechanical principles in a progressive sequence, executed to produce -- with minimum effort -- the maximum benefit with the least tissue damage**".

BIOLOGIC ANCHORAGE

Anchorage is also considered clinically to be a means of achieving stability as it is "set up" with certain provisions. The objective is to hold fast, to check motion, or to firmly fix if possible (such as an implant). It has also been declared that an undisturbed tooth is the best anchor!

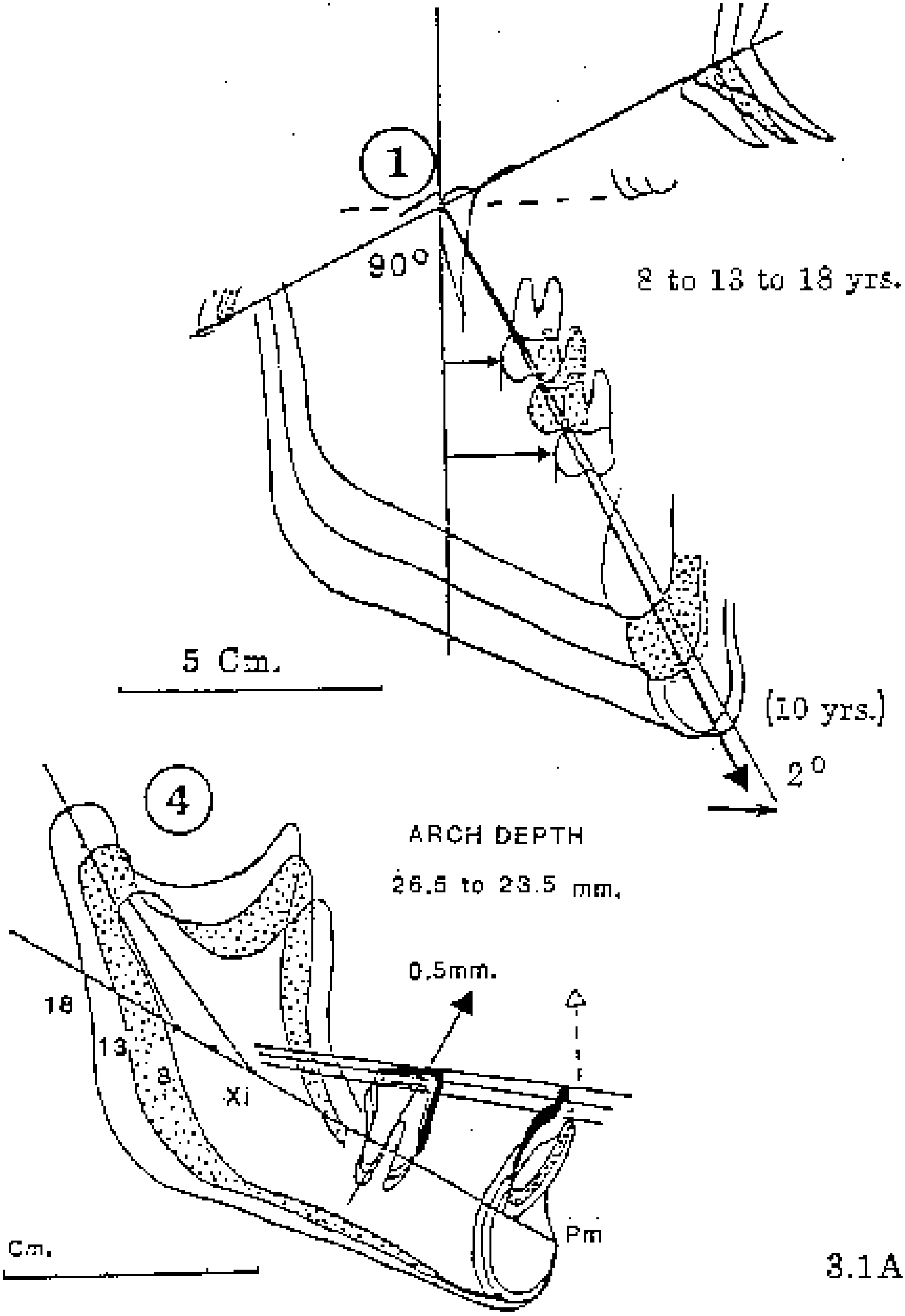
For purposes of communication we may refer candidly to three types of anchorage in orthodontics. The first may be thought of as "local". It is restricted and pertains to **individual teeth** (ankylosis or implants are a local source). The second may be considered "regional". This refers to a more profound anchorage **by groups of teeth** employed for intermaxillary traction or for orthopedic maxillo-mandibular change. The third type comes from the "muscle matrix". This is primarily resistance offered by the **lips and tongue**, which can be recruited for advantage.

Evaluation of Anchorage

In applied mechanics "stability" means holding still as opposed to "displacement" from one position to another. Relative "stabilizing" may be the proper context because displacements or movements can only be relative to some point of reference. **It is for these reasons that the Ricketts-Bench-Gugino four-position analysis serves as the best basis for clinical reference** (Fig. 3-1). Any dramatic departure from that **normal** during treatment is most often the result of the technique, particularly in short term.

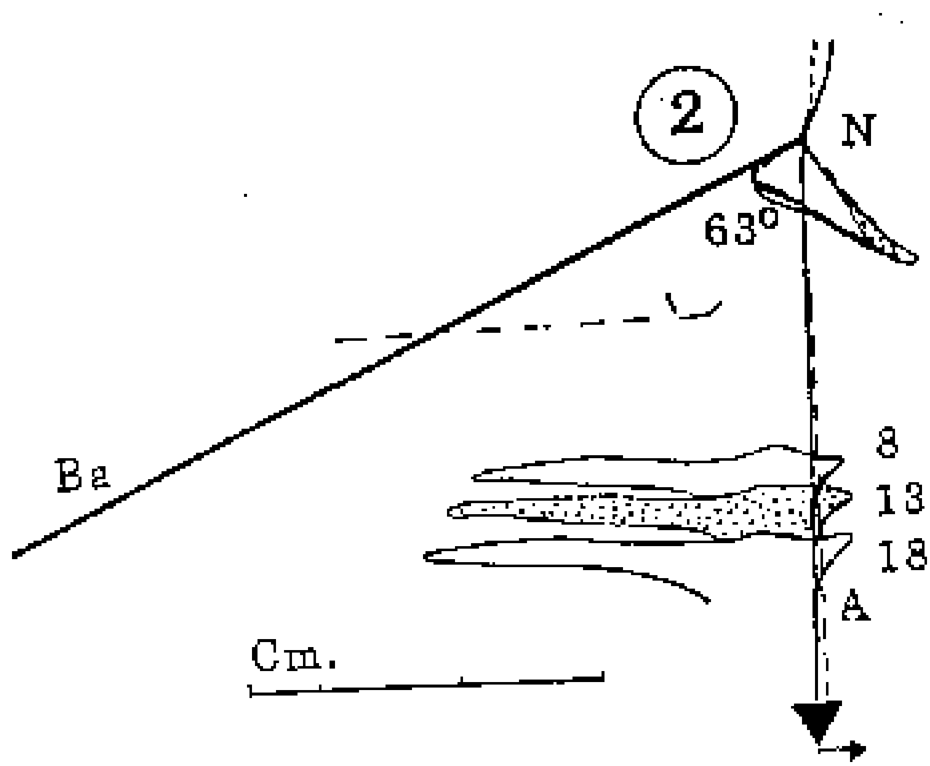
Force is likened to weight. Equilibrium is attained when opposing forces cancel

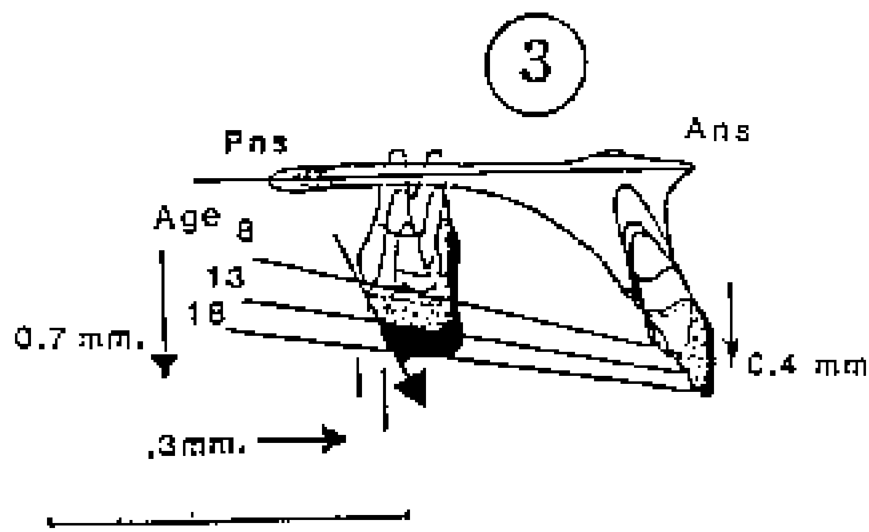
FOUR POSITION SUMMARY GROWTH ANALYSIS



3.1A

Fig. 3-1A Position 1 shows Facial Axis data for chin behavior grows 2.5 mm. per year and closes 1° at 7 years. Note molar on Axis. Position 4 shows lower teeth from Corpus Axis at Pm. Note 0.5 mm for molar and distal behavior of incisor.





3.1B

Fig. 3-1B Position 2 shows essential constancy of Point A. The dotted line suggests a very slight forward tendency. Position 3: traditional change of occlusal plane downward (0.7 mm.) and forward (0.3 mm.) per year for molar.

out. Direct forces are obvious because they are due to direct contact by pressure, friction or thrust. In orthodontics direct forces are exerted by appliances, chewing, and pressures from the lip or tongue. More indirect forces are those of eruption and the effects of skeletal growth. Remote forces may be from gravity or electromagnetic influences, but are most often ignored from a clinical standpoint.

For the greater part, orthodontists become concerned with the stress and strain within the appliances employed. The physical properties of the wire materials and the capacity of loop configurations need to be known for planning of the techniques to be chosen. This makes orthodontics a physical science, so to speak. Unfortunately, however, the **biologic laws, although less obvious, override the physical laws.**

Anchorage Sources

There are five main factors in the classification of anchorage:

1. Intraoral (bone, connective tissue, implants) (pull of elastics)
2. Musculature
3. Extraoral
4. Posturing (Mandible)
5. Growth (Negative Feedback Factor)

Hierarchy of Resistances - A Further Classification

In Biomechanics we may further rate "resistances" in a biologic hierarchy. This is for purposes of better understanding. **Anchorage is the withstanding of an opposing force.** One resistance is pitted against another resistance. For a cogent appraisal this classification includes eight levels:

1. **Pressure** on interstitial fluids in connective tissue
2. **Tension** on ligaments, gingival soft tissue and periosteum

3. Pressure on bone of **lamina dura** and surrounding connective tissue
4. Pressure on **cancellous bone**
5. Engagement against "**cortical**" **bone**
6. Pressure against labio-lingual **muscles**
7. Effects of muscles in the **circumferential chain**
8. Effects of **growth**.

(Ankylosis, implants and scar tissue are separate issues.)

Discussion of the Hierarchy

Interstitial Pressure

The periodontal membrane is richly endowed with interstitial fluids in order to supply oxygen and nutrients to the cells. Because fluids are not reducible in volume, pressure on a tooth first pushes the periodontal fluids toward adjacent areas. This is nature's first line of resistance or signalling. A pull on the tension side sends signals by compression of fibers against each other and produces fluid alteration (Fig. 3-2).

Ligament -- Tension

Ligament, as a tissue, serves to stabilize and prevent dislocation of joints. Ligament can withstand intermittent stresses such as are experienced in chewing (a hammock-like function). Ligament is a poor anchor, however, because it **cannot withstand permanent deformation** -- it stretches and elongates. **The ligament supplies only eight (8) minutes worth of anchorage.**

Periosteum is attached to a tooth contiguous with gingival fibers. The amount of resistance offered by periosteum is probably somewhere between that of the ligament and the fascia.

Pressure -- Bone (Lamina Dura)

A thin layer of compact bone lines the socket. This is laminated (bundle bone) for attachment of the ligament. After the ligament is stretched by tension and the

TIPPING ACTION

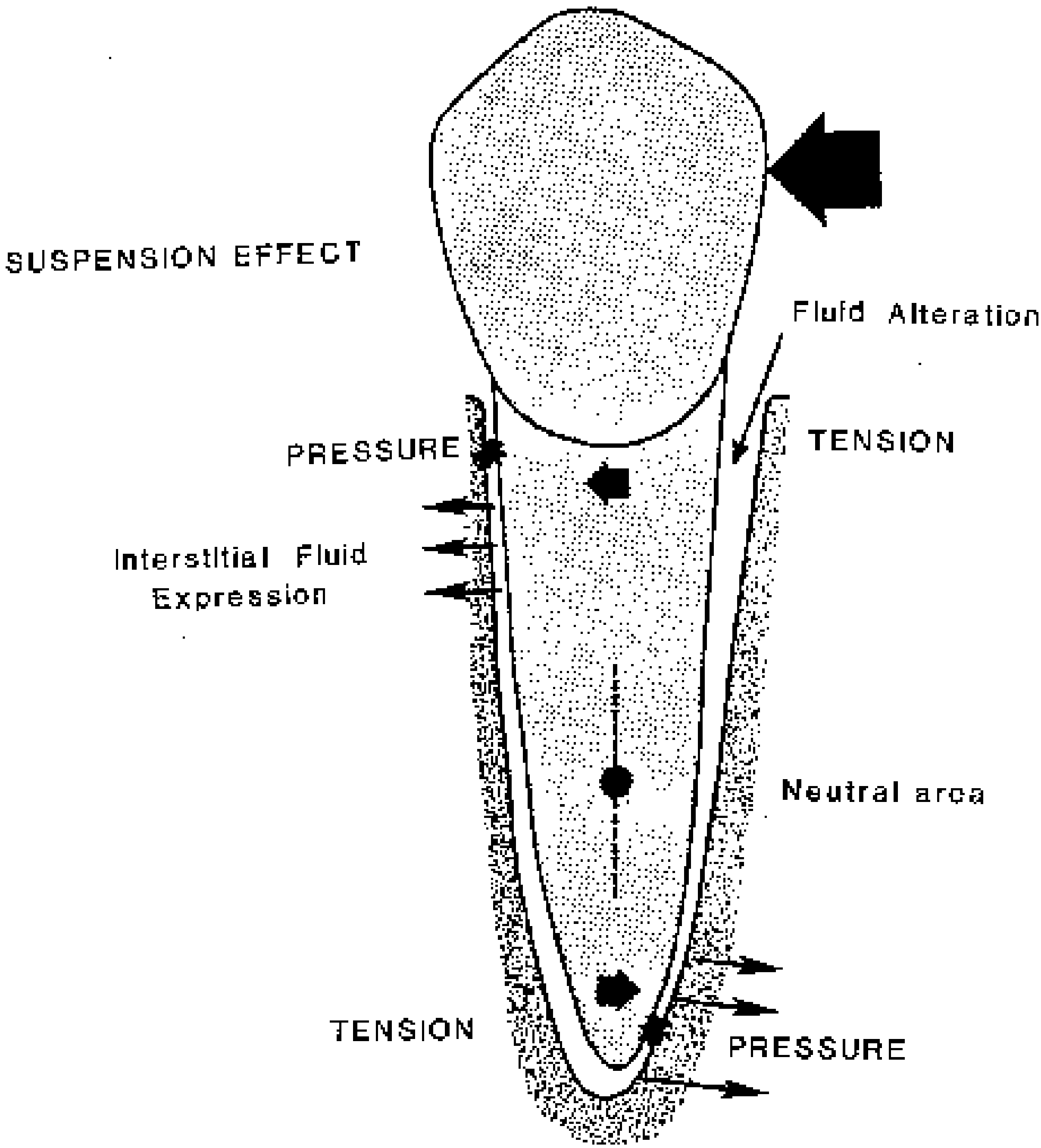


Fig 3.2 Interstitial fluid is affected and stretch of membrane permits pressure at crest and apex.

pressure side is compressed, the lamina dural bone forms the most profound "first line" resistance against orthodontic movements (Fig. 3-3).

Pressure -- Bone (Cancellous)

This "lacy" or medullary bone contains a generous blood supply and fluids. Also, the smaller trabeculae may resorb rapidly as they are affected by a surrounding pressure. Movement of teeth within cancellous bone requires less anchorage than when the outer plates are encountered. A marrow space may become an interstitial space in the ligamentous area (see Fig. 3-3).

Pressure -- Cortical Bone

Cortical bone, lacking generous blood vessels and being highly compacted, serves as a significant anchorage source. Backward resorption is more difficult. It will therefore be discussed as a separate entity (see Fig. 3-3).

Pressure -- Oral Musculature

Pressure, from the sublabial area (in the lower), or resistance has been demonstrated to be resistant enough to stabilize the entire denture, causing flat mouths to exist. This can be recruited as an effective source of resistance, as with the "shield" or "bumper" or "T" loops (Fig. 3-4).

Pressure -- Postural Musculature

The muscles of mastication and facial muscles maintain denture height. Pain can cause a disruption of normal resistance in the chain which encircles the head. With release or prevention of tension in closing muscles, teeth are permitted to extrude and anchorage is lost in the process. Also, uncorrected breathing problems lead to continued mouth opening. These are more important factor than at first realized. Unchecked, they lead to relapse (Fig. 3-5).

Growth -- Orthopedics

Growth is a feedback factor to a change in jaw relationship. Inhibition of growth in either jaw changes the requirements for anchorage. Activation of growth

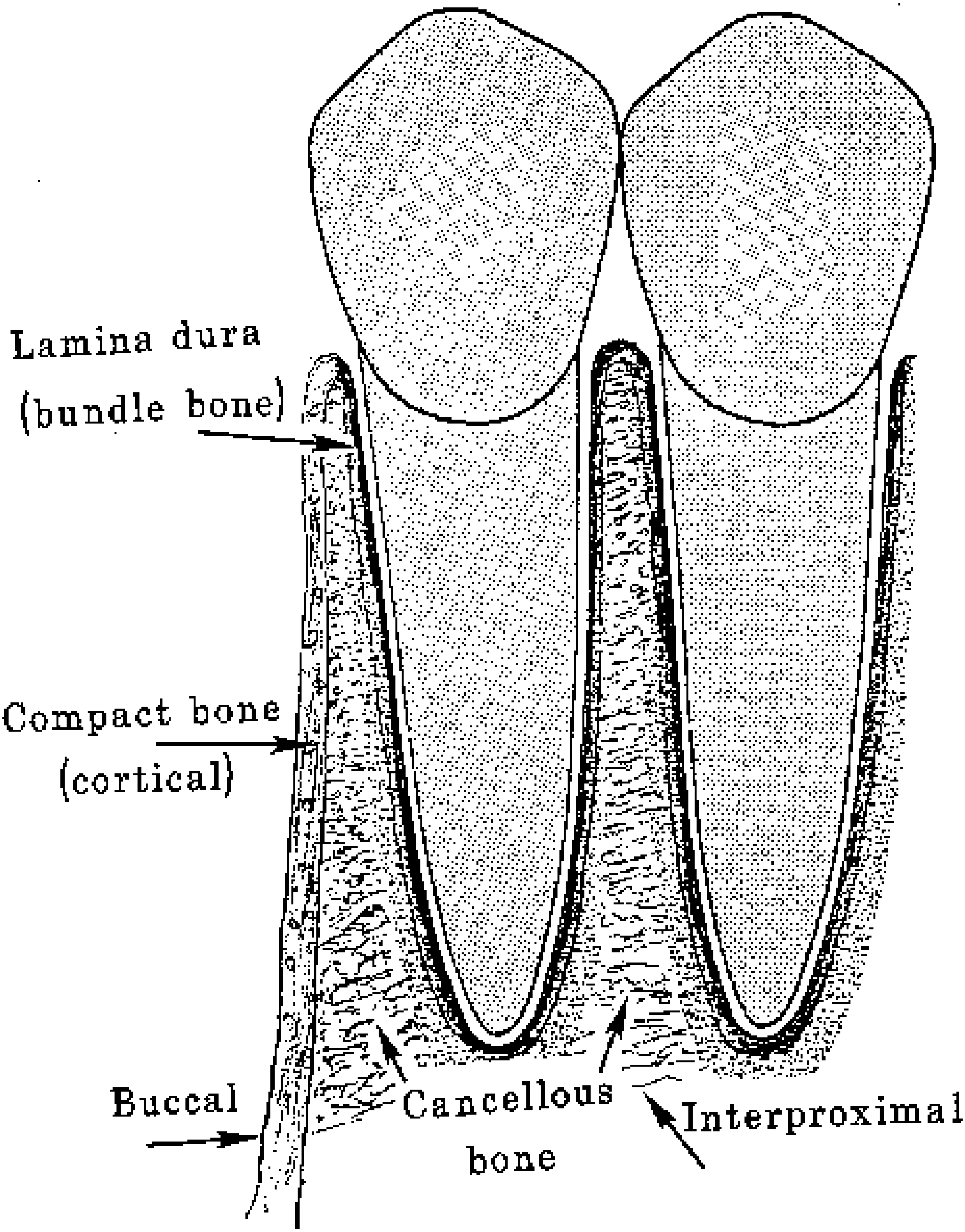


Fig. 3.3

Around the socket is the lamina dura (thin cortex) as the first bony encounter, then cancellous and finally external cortical plate.

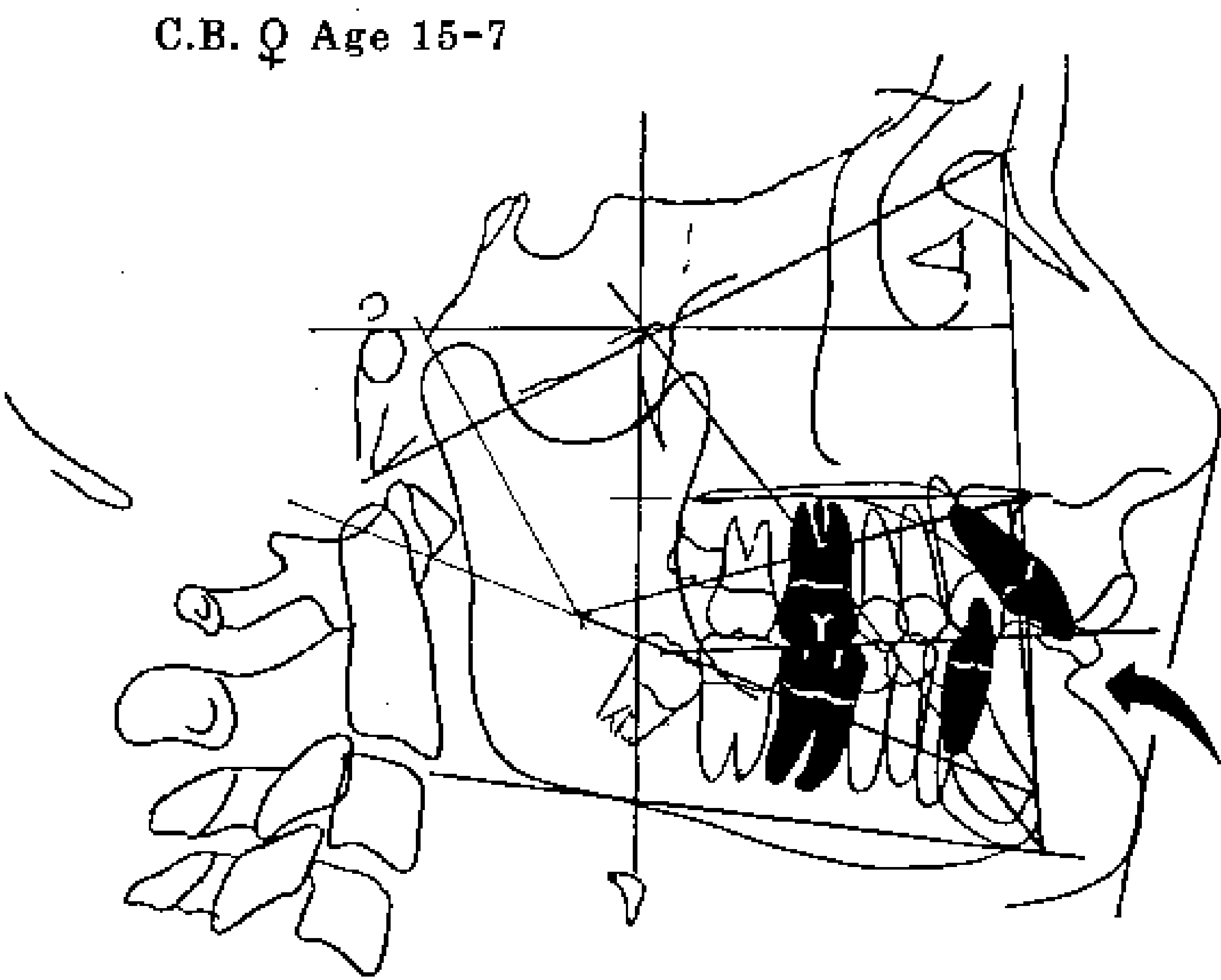


Fig. 3-4 Fifteen-year-old female requiring forward movement of lower arch and lip therapy which was done.

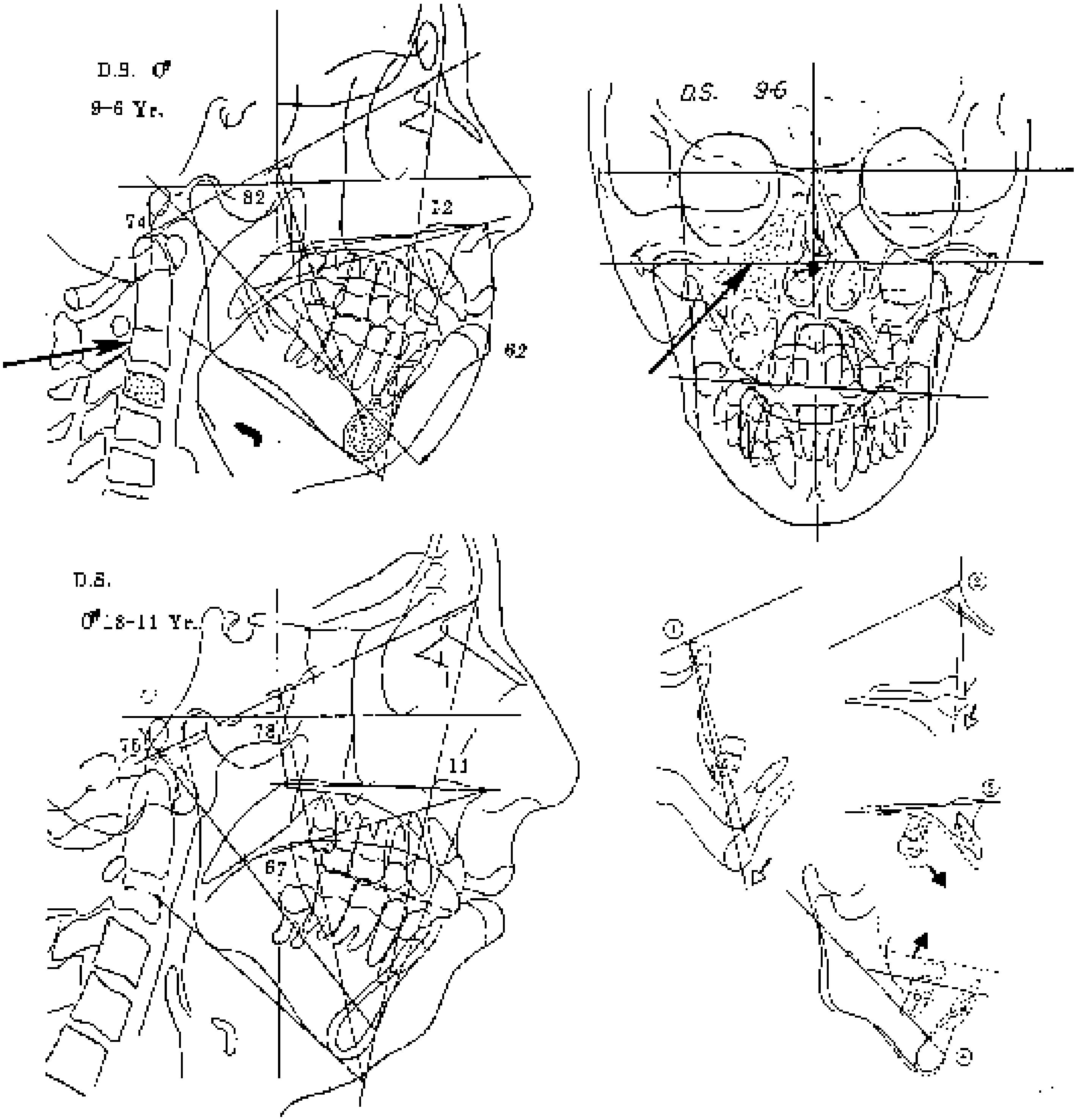


Fig. 3-5 Male patient D.S. was treated successfully but was relapsed totally 10 years later. Note the vertical growth with chronic sinusitis on left (at arrow) and septal deviation to the right. Also note the fused C2 and C3.

serves in the opposite capacity and also changes anchorage demands (Fig. 3-6). Growth inhibition likewise can change a treatment regime. Rapid growth with generous vertical increases can be a detrimental factor to anchorage but beneficial to movements also. Stabilizing of the lower arch by cortical anchorage is understood by the sophisticated clinician.

SPECIFIC PHENOMENA

Intrusion

The question in orthodontics is no longer whether intrusion is possible, but rather actually **how** intrusion is accomplished and when to stop it. This was discussed in Chapter Two. Intrusion, as considered in a histologic and anatomical context in the 1940s, was based on the presumption that bone resorption could not take place under tension. When occlusal force is placed on a tooth it is pushed further into the socket, but the resistance to that force comes from the **tension on the periodontal ligament** as the tooth is suspended in the socket. Thus, the force on the wall of the alveolus is to hold the ligament outward against the pull inward. Hence, the socket design is like a double suspension bridge, holding the socket outward (Fig. 3-7). Ordinary force of mastication and swallowing and normal biologic forces therefore **pull the socket inward** due to the suspension which is intermittent during chewing and swallowing and even bruxism.

That concept would be an entirely plausible restriction for intrusion were it not for **one fact which is not well appreciated, i.e., the periodontal ligament stretches under continuous tension.** Research has shown that within a period of eight minutes a tooth under continuous pressure rests against the socket anywhere it is placed. Thus, when the ligament is overcome by **continuous force**, the concept of tension resistance must be changed to the recognition of pressure or compression

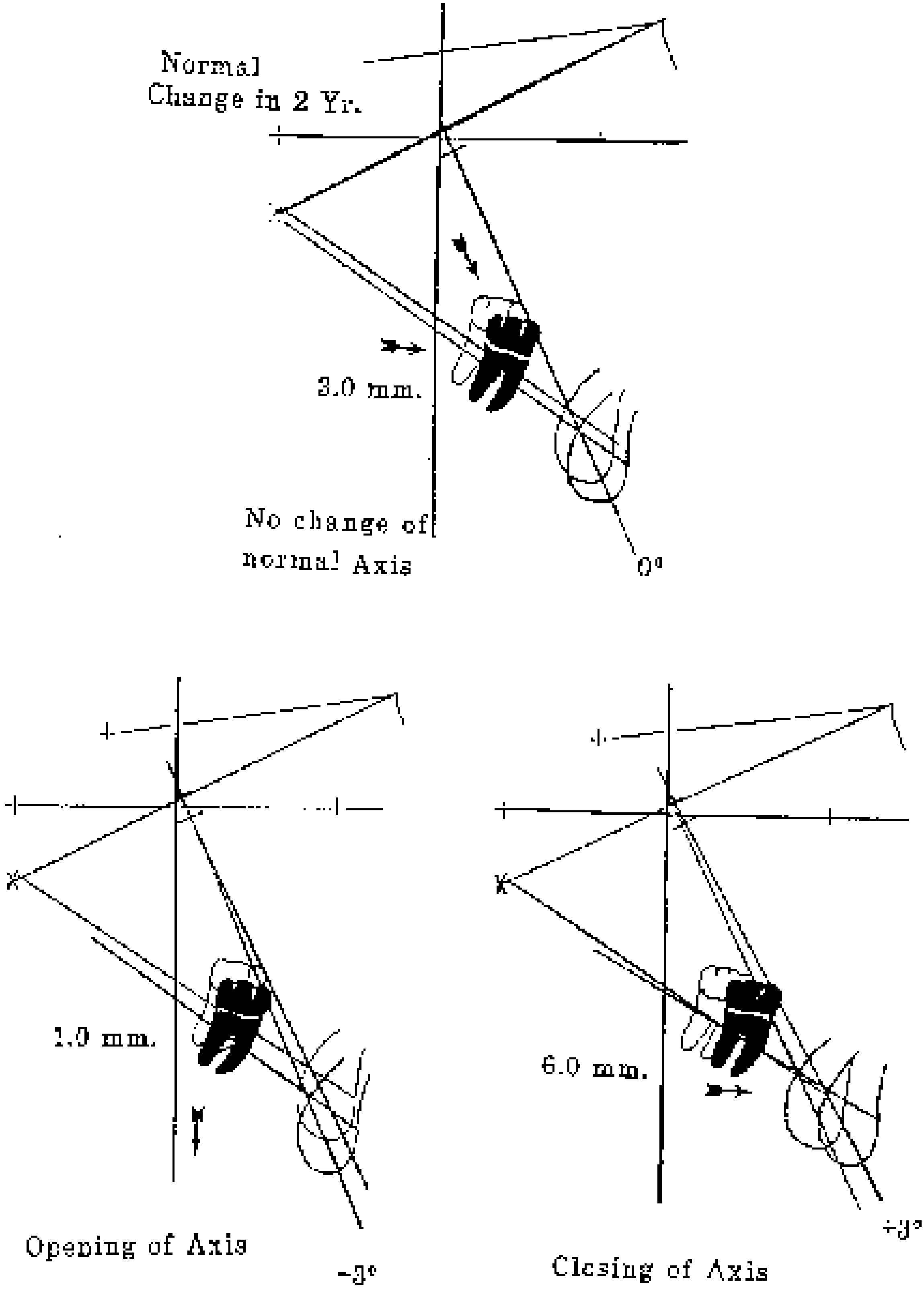


Fig. 3-6 Normal growth on a 90° facial axis can witness 3.0 mm. of forward development of lower molar (together with eruption on the arc). When opened only 3° it is reduced to 1 mm., but if closed 3° the benefits are doubled.

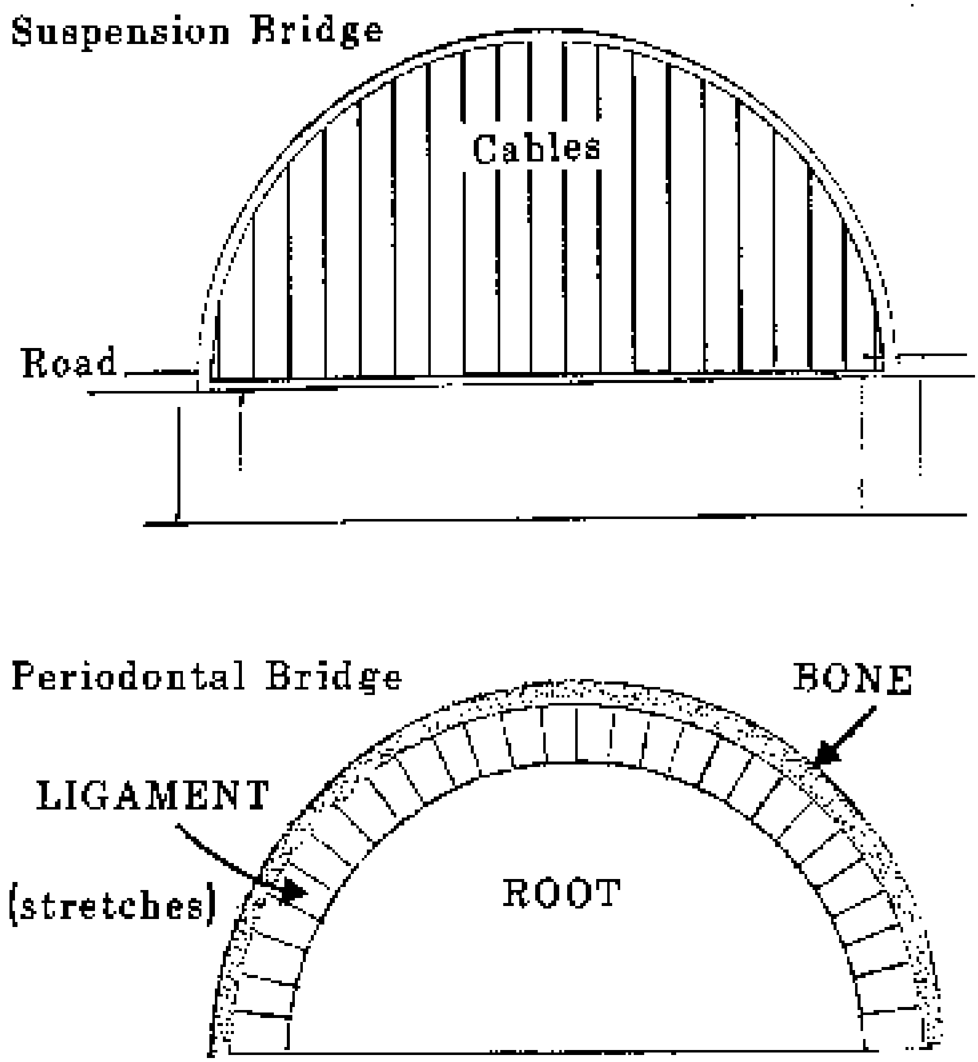


Fig. 3-7 The socket with the membrane is compared to the suspension bridge. The PDM stretches, which is different from a cable.

within the complete socket.

The prevailing idea in the past also was based on the finding that bone apposition was a slower process than bone resorption. Consequently, if bone resorption was more rapid than bone apposition, the bone would not serve as the anchor, but the tension on the ligamentous side would be the point at which anchorage would be manifested. That was a biologic concept, but again, of course, it did not take into account that the ligament simply cannot withstand a continuous deformation!

The fact that the ligament yields to continuous tension leads to rejection of the concept of mesio-distal tipback for orthodontic anchorage advantage. The old idea of toe-holding consequently is questioned, even for the promotion of osteoid tissue thought to be more resistant to resorption. Toe-holding is plausible, however, in the transverse plane!

Intrusive Force Requirements

The intrusive force was calculated from the root's widest cross sectional area. With a force of essentially 1 gram per square millimeter of enface root surface in the vertical direction, intrusion is successful if it is continuous. This ranges from 15 to 20 grams for the lower incisor to perhaps 60 to 90 grams for a molar (Fig. 3-8). Again, this is explained by the tension resistance of the periodontal membrane being overcome, as the teeth are pushed directly into the long axis direction of the socket. Thus, the entire socket is placed under compression. The whole root behaves similarly to the action horizontally on the compression side. Ironically, according to calculations, intrusion actually requires the least amount of force required for a tooth movement, and surprisingly is the easiest movement once started.

Keys to Intrusion

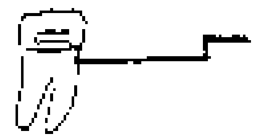
There are two keys to routine intrusion success. The first is that pressures be light enough. The second is that the force be continuous enough. As we stated

CAPACITY OF BLUE ELGILOY WIRE

A

CONCLUSION: Around 2,000 grams $.016^2$

LENGTH	FORCE OF BENDING
@ 30mm	+ 70 grams
@ 25mm	+ 80 grams
@ 20mm	+ 100 grams
@ 10mm	+ 200 grams
@ 5mm	+ 400 grams
@ 4mm	+ 500 grams
@ 3mm	+ 600 grams



B

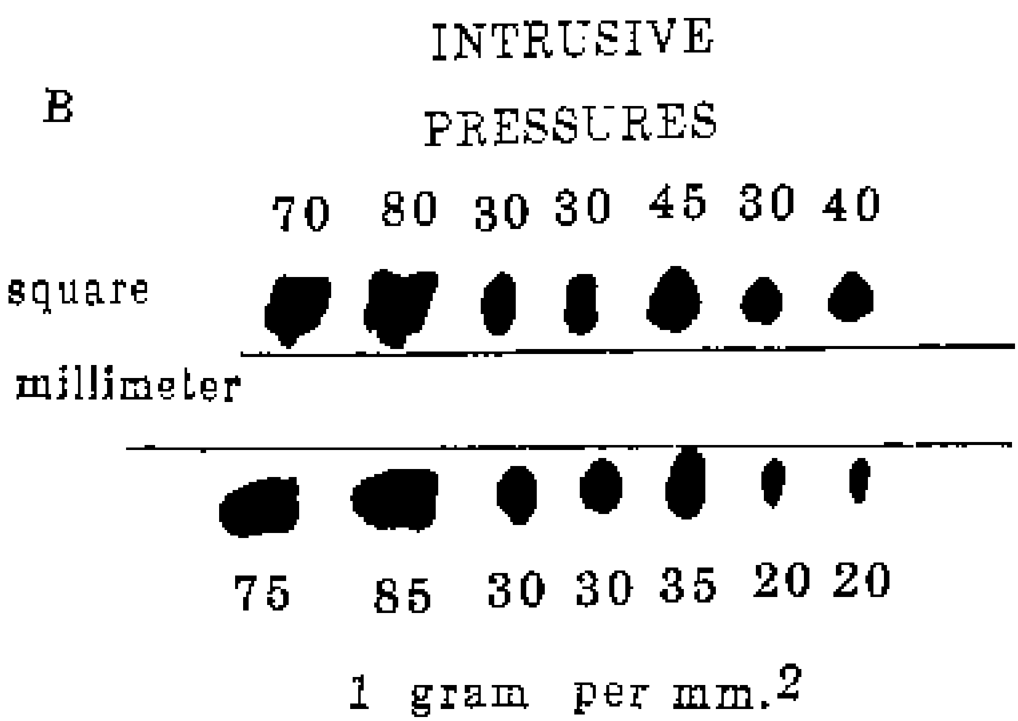


Fig. 3-8 **A.** The capacity of the standard $.016^2$ blue Elgiloy employed most frequently by the author.
B. Cross-section of roots to calculate intrusive forces reduced to 1 gram per $mm.^2$.

earlier, the force of eruption is estimated to be about 0.2 gram to perhaps 0.3 gram per square millimeter, or one-fifth of the amount of force usually employed to move the tooth. This would mean that in the average human lower incisor a force of 3 to 4 grams would constitute the force of eruption. Theoretically, double that force (0.4 to 0.6 gram per mm.^{2}) would stop it, and triple that force (or 0.6 to 0.9 gram per mm.^{2}) would intrude it. This fits closely the rating scale (see Figure 3-8). The capacity of the .016^2 blue Elgiloy wire also needs to be understood for force and pressure analysis in mechanics (see Fig. 3-8).

Another old misconception was that forces needed to intrude an anterior tooth would extrude the posterior teeth. However, as stated previously, excessive intrusive force produces sclerosis or stasis in the anterior teeth which are intended to be intruded. Too much intrusive force on a tooth desired to be intruded anchors that target tooth and the anchor tooth molar consequently moves. Particularly if pain ensues or respiratory obstruction persists the mandible is held open and the molar therefore extrudes. Masticatory influence was proven on an adult patient edentulous in the upper unilaterally; the lower molar extruded from the utility arch when no opposition was present and was maintained on the functional side.

Tooth extrusion is checked by the forces of mastication. In fact, the rachet principle for intrusion may obtain; forces of chewing push the tooth into the socket and it is then held by the appliance!

The records of patients employed to demonstrate intrusion possibility were shown in Chapter Two, but intrusion of upper second and third molars is shown in Figure 3-9 (T3). The technique employed was a Wilson "plug-in" unit with a loop formed in it for a pressure of about 80 grams. The third molars and then the second molars were intruded for correction of open bite.

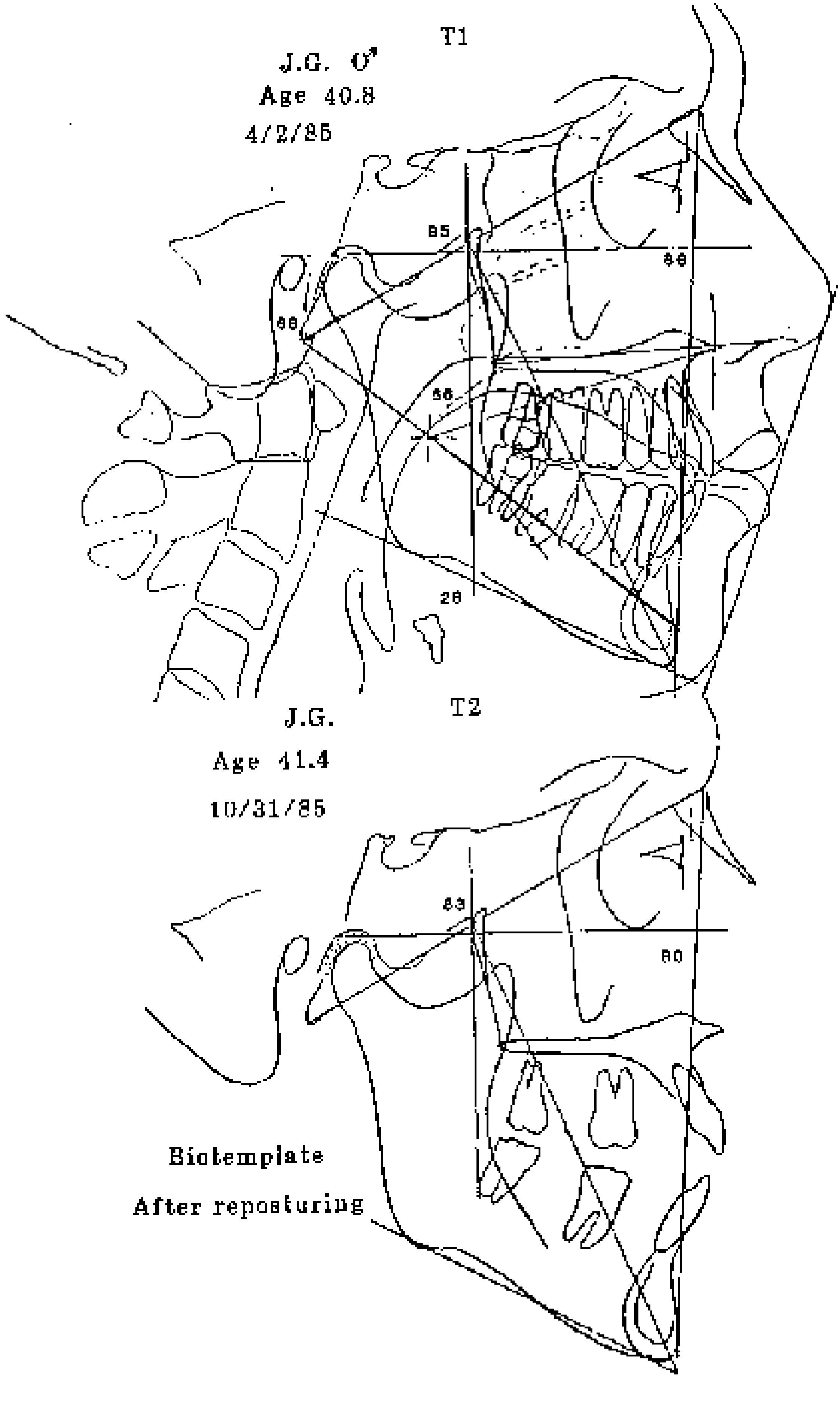


Fig. 3-9A Male TMD patient J.G.: T1 with contact on third molars only, and T2 after positioning of condyle.

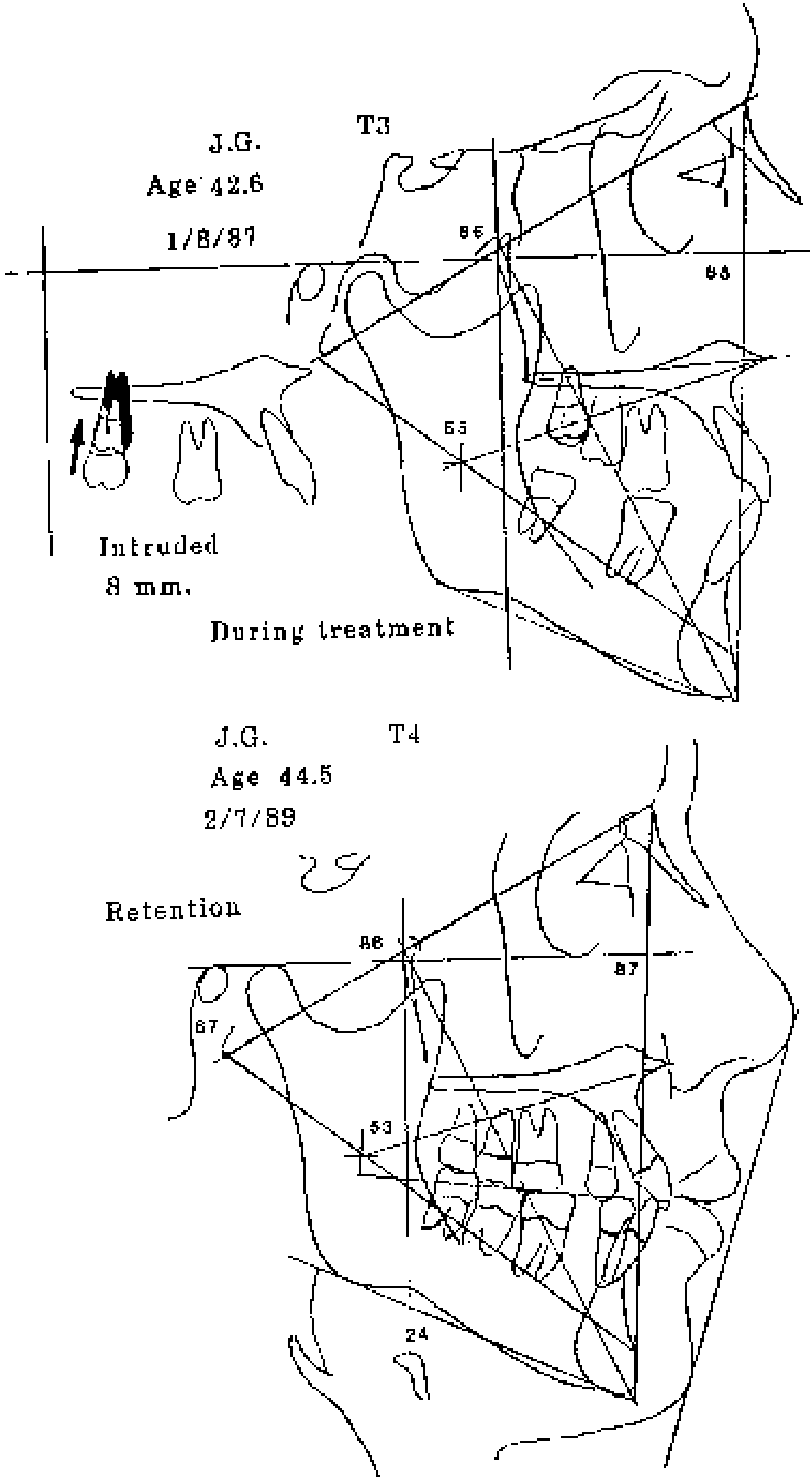


Fig. 3-9B Male TMD patient J.G.: T3 orthodontic intrusion of third molars, then second molars. T4 shows effect of intrusion on bite closure.

Movements for Space Closure and Space Opening

The wisdom of guiding teeth within the cancellous bone for efficiency in movement is well appreciated. This was pointed out and referred to as "medullary space" in 1898. The outer and inner table of the alveolus or the buccal and lingual cortical plates were also called a trough, or a channel.

When roots are placed against compact bone, movement is inhibited and consequently was referred to as "cortical anchorage". This resistance is employed deliberately for production of anchorage. The opposite, for prevention of anchorage, is called "cortical avoidance".

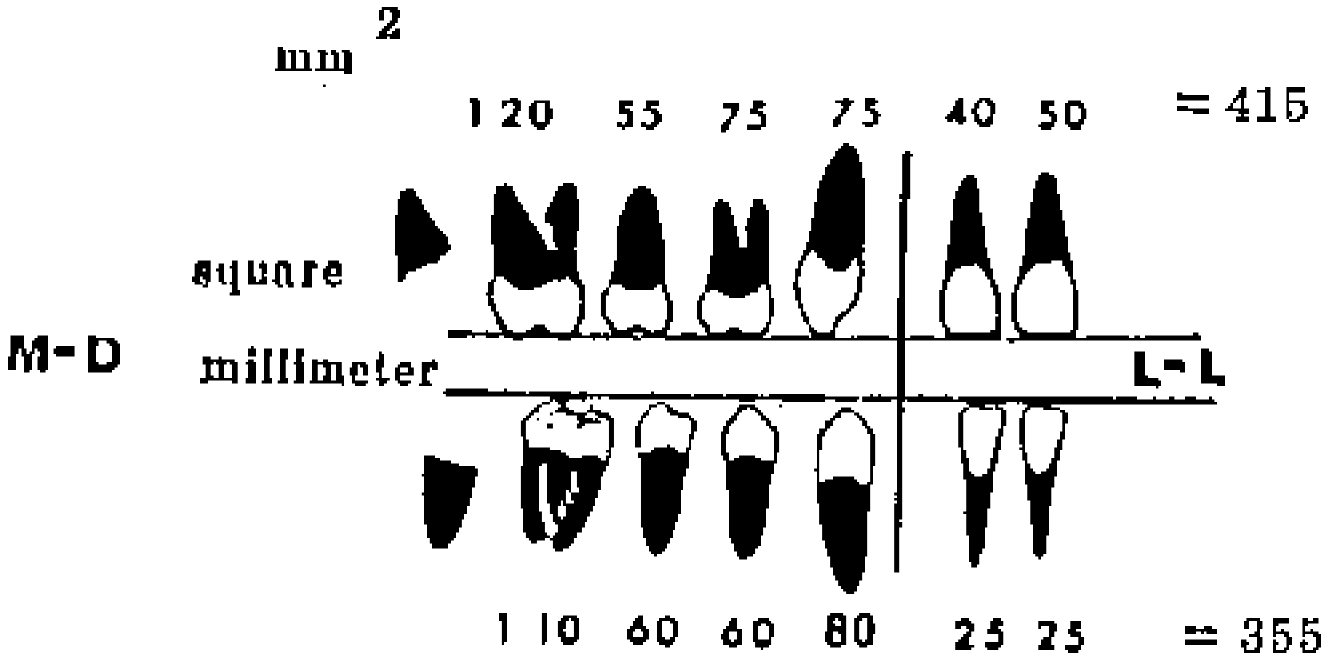
Canine Retraction

Ease of movement for the retraction of the canine in extraction cases is contingent on avoiding engagement of the root against the cortical plates. Many clinicians have concentrated on mechanisms for the rapidity of canine movements after extraction of premolars. The attention should actually be given to the amount of anchorage loss of the molar or posterior segment. In any technique two forces oppose each other.

The root rating scales are applied. These pressure values are more than a hypothesis because of the hundreds of clinically proven examples. Mesio-distal movement of a tooth, within the plates, requires the pressure of about 1 gram per square millimeter of root surfaces. The canine socket area, presented for resistance, is about 75 mm^2. The area of the molar is 100 to 125 $mm.^2$ That resistance when added to the second premolar, which is about 50 $mm.^2$, brings the value to around 175 $mm.^2$ total, to yield a 175/75 ratio or almost a ratio of 2.5 to 1. The patient K.B. shown in Figure 3-10 was treated at a time when forces used were still too heavy, but it serves to illustrate extraction problems.

Dr. Brian Lee measured hundreds of canines and showed that the silhouette

ROOT RATING SCALE



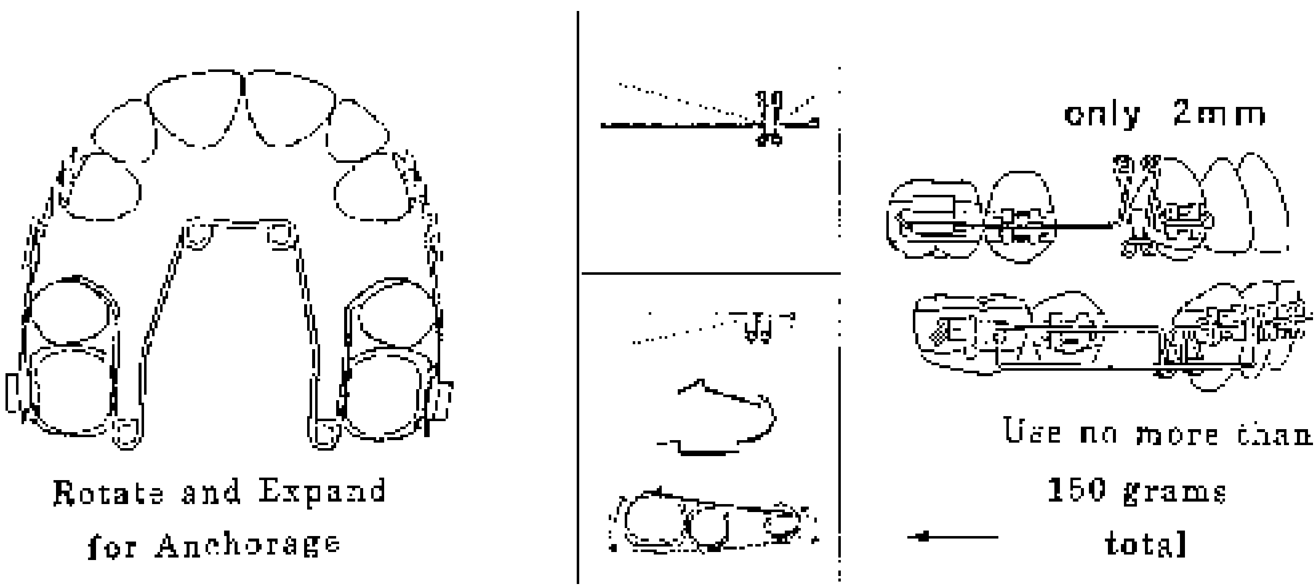


Fig. 3-10 Above: Cross-section of roots for sagittal directional movement at 1 gram per mm². Below: Calculate grams to activate canine retraction (75 and 80 grams respectively). Quad Helix may be used without "Button" when light force is used.

outline in the buccal-lingual contour of the lower canine is actually larger than the upper canine. The root of a typical lower canine actually bulges both buccally and lingually. The lower canine has an auspicious root, despite its smaller crown. Even with that, an average force of 80 grams made as continuous and as constant as possible, and **free of friction**, is the choice. Usually, with canine retraction sections a force of between 100 and 125 grams is employed for the adjustment which, dissipated over a one-month period, comes down to about zero and therefore **averages about 60 to 75 grams** for the life of the action.

In the experiments of Storey (see Chapter Two), forces of 300 grams and above causes sclerosis of the canine and loss of anchorage in the posterior segment. But the Storey experiments also included friction in the research design, as does the sliding of a tooth along a straight arch wire. If the wire becomes bent or curved from the forces of food during mastication, or curves are placed for uprighting flexion, the force to overcome friction can almost equal the force needed for retraction. The requirements for stabilization of the anchorage teeth then **involves also the ability to withstand the additional force of friction**. The "Synergy" bracket of RMO decidedly reduces wire friction compared to other designs, but still sliding is sliding. This is the consideration in the design of the free retraction sections (see Fig. 3-10).

The Lag Period

In any tooth movement, with the exception of extrusion movements, there is always an initial lag period. The reason for this becomes obvious when it is realized that before the tooth can move bone **resorption of the bony socket must occur**. Hyperemia must be stimulated and biologic initiation of bone resorbing processes takes time also, particularly in adults. Initially, the thin cortical bone -- the lamina dura -- must be resorbed. As stated previously, an excessive force scleroses the membrane area, and therefore the bony socket. When pressures exceed the tolerance of the blood supply and the interstitial fluid, the resorption process is delayed consistent with the hyalinization. The lamina dura in this event then acts as an anchor source or resistance, hence the delay in movement or the "lag period" (see Fig. 3-3). In order to biologically eliminate the socket, a frontal resorption is the best solution. Please remember that the objective initially is for the stimulation of the osteoclastic action, not tooth movement per se. The dissolving of the bone around the socket takes time -- it takes time to be initiated, and it takes time for it to be accomplished.

Therefore, for the adjustment for a tooth movement, the clinician is obliged to think first about stimulating of the cellular activity rather than immediate tooth movement. Hence the lag period is recognized. It varies in individuals but is classically present more often in adults, who possess a more differentiated bone. In a young patient with a more extensive blood supply to the lamina dura and the "cribiform" nature of the socket, the initial action does not take as long (from hours up to 14 days). In the adult patient, however, with a thoroughly differentiated total alveolar process, the initial reaction to eliminate the lamina dura may take weeks to respond.

When movement is slow in any direction, the tendency is to apply greater force. Such a course of action theoretically is absolutely contraindicated. When movement is not seen in all likelihood the force is already too great and should be reduced. In addition, all forces should be transformed to the idea of pressures when applied at the clinical level. Thus it is not the wire but how it is applied, despite what the manufacturer claims. (See Fig. 3-8 for flexion analysis of .016" blue Elgiloy.)

Cortical Bone Resistance

Clinical examples of cortical "hang-up" are numerous. For instance, during lingual retraction of the lower incisors, particularly with the use of a finger spring or a round wire in a bracket, two risks are involved. The first is that the root end may

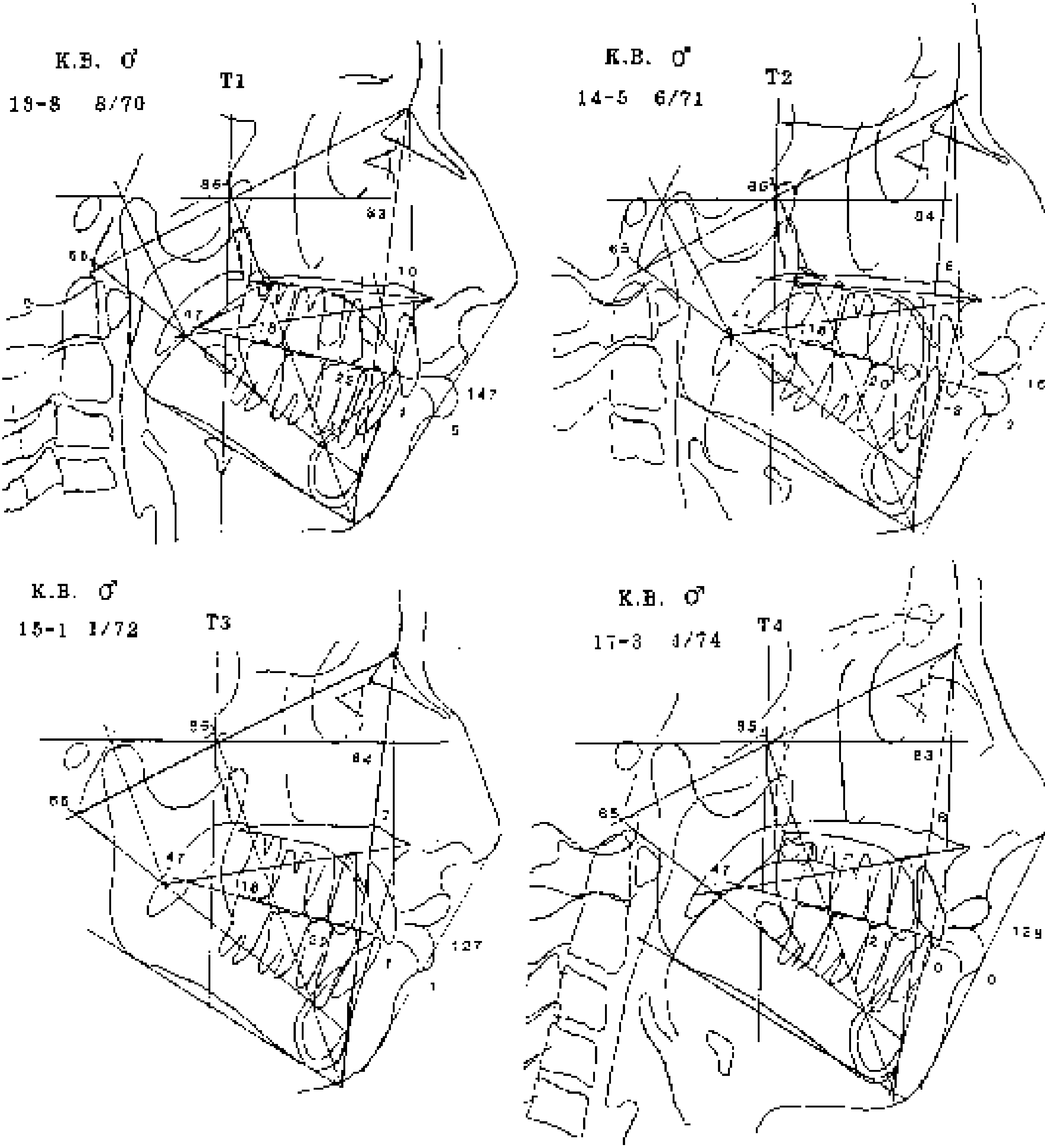


Fig. 3-11A Progressive analysis of K.B. after extraction of upper second and lower first premolars. Note pattern and deep bite in T1, first stage with older technique in 1970. Note worsening of bite at T2. T3 shows effects of utility arches and sectional mechanics. T4 shows final result after rhinoplasty. Note there was no mandibular rotation.

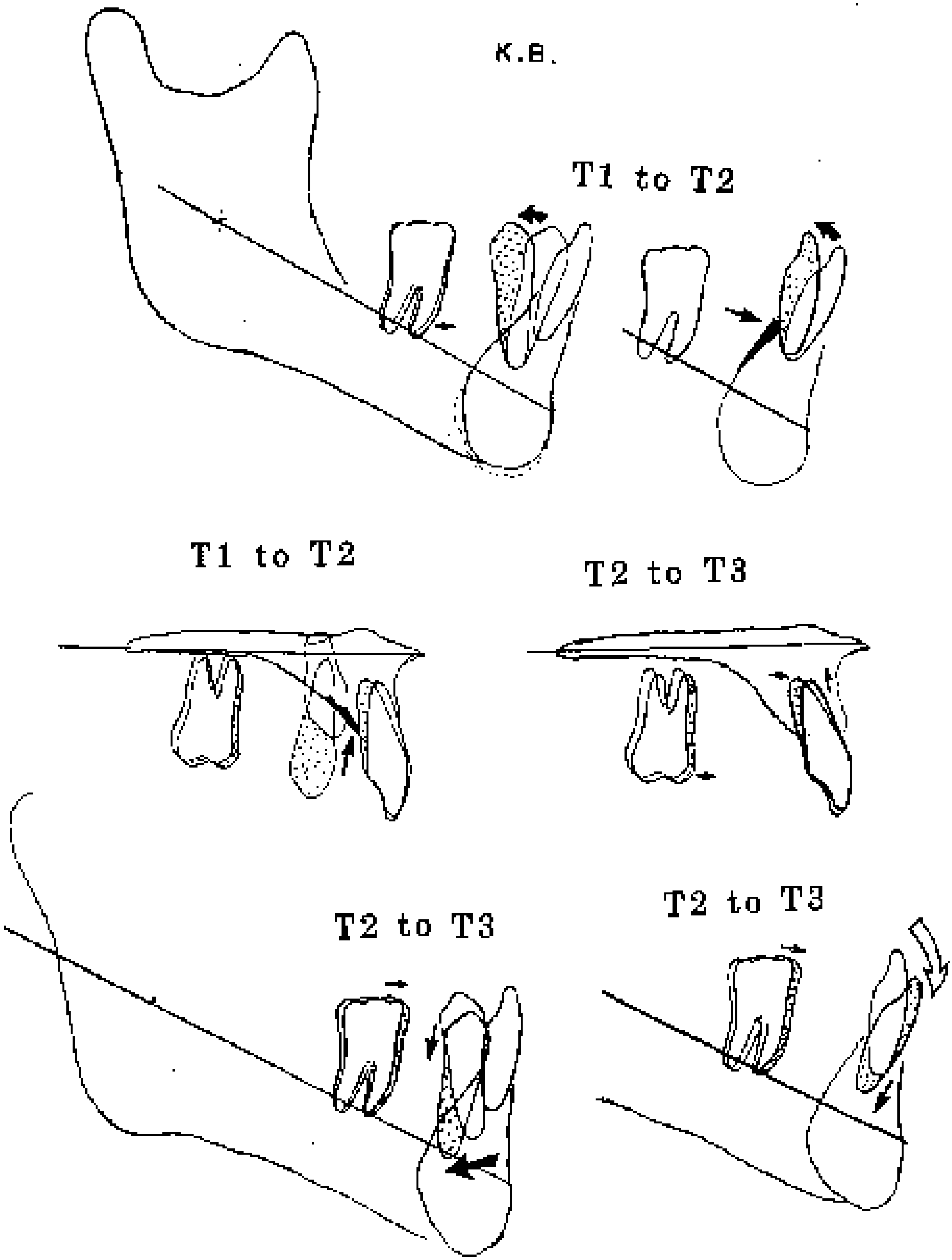


Fig. 3-11B Analysis of tooth movement T1 to T2 (first stage), T2 to T3 (second stage).

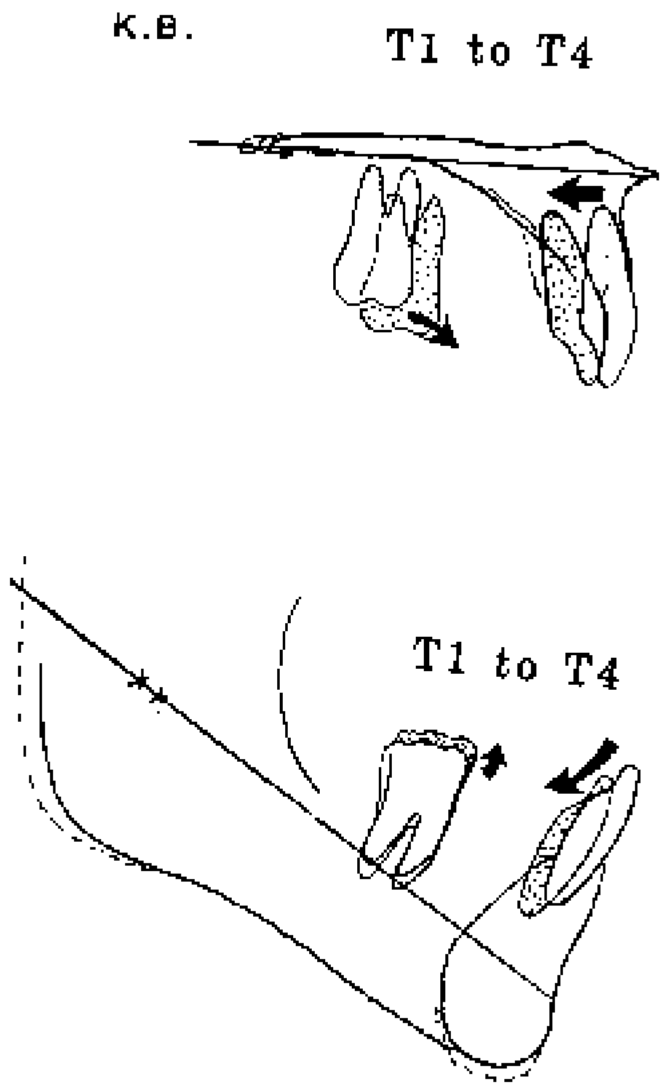


Fig. 9-11C Analysis of tooth movement T1 to T4. Note torque of upper incisor with .016 blue Elgiloy. Note stability of lower molar and intrusion and retraction of incisor.

tend to move labially. The lingual cortical bone, being more difficult to resorb, becomes an anchor point (Fig. 3-11). The labial surface of the root, engaging the thin labial plate, ultimately moves more easily. The tip of the root thus may actually move forward. With Bioprogressive methods this problem is minimized (see Fig. 3-11). Tipping was permitted in 1970 but by the 1980s lighter pressures were used, and tipping was all but eliminated without undue anchorage loss.

Cortical resistance is common in the treatment of impacted canines and canine retraction. Cortical bone is also a common obstacle in attempts to close space for missing first molars when the socket area becomes corticated.

Conical Root Shapes

The second risk is that a continued force may cause the tooth to extrude. For instance, with lingual tipping of the lower incisor, the cone-shaped root actually invites the action of an incline plane against the planum alveolare (see Fig. 3-11). Further contraction of the incisor segment eventually produces a deeper bite. This occurs even when steps are taken to try to prevent it when the retraction force is too great. Such a closing of the bite, produced iatrogenically, will occur even while the chin swings open. **This produces a false clinical impression with regard to the behavior actually taking place.**

Lower canines

The same example of cortical resistance can be seen in lower canine retraction. In the lower arch the canine erupting later is often blocked out labially, and extraction of the first premolar exposes a lingual shelf of bone which will need to be resorbed away as the canine is retracted and contracted (see Fig. 3-11). Therefore, during the canine retraction, and contraction typically, the root end of the lower canine may be initially displaced to the labial or the mesial. The cortical bone, **because little reverse resorption will occur through cortical bone**, becomes the site of resistance. Once the tooth is uprighted, and retraction pressure is still active, the apex of the root will move through the thin labial cortical plate. The root, if engaged against the lingual plate with too much force, **further stresses the posterior anchorage.** The canine crown will tip distally and lingually, and the canine will extrude under excessive force or attempts to move it too rapidly. This behavior is so commonly observed that there is no need for further discussion.

Upper Incisors

The upper incisor is the most common tooth to have "torquing" problems. The palatal plate contains swirls of almost fibrous-like bone which is very tough and resistant to resorption. When accidents occur, most frequently it is the labial plates of the alveolus that are fractured -- not the palatal shelf. As upper incisors are retracted the tendency is to experience the apex of the root to move forward. This means that palatal torquing action should be (1) started early in the course of treatment, (2) be continuous, (3) last long, and (4) be very light: in the range of 20 to 30 grams per tooth (see Fig. 3-11). In very poor anchorage conditions the palatal plate should be removed surgically.

Impacted Canines

Another example of cortical anchorage is seen in impacted upper canines, particularly the labial impaction in which the attempt is made to bring it downward into the arch through the labial cortical plate. This has proven so difficult in some patients that operators have suspected an ankylosis of the canine, when, in fact, it is just up against cortical bone that is resistant to excessive force being used to bring it into place. Records have shown that the incisors and premolar teeth used as anchors have been intruded before the canine has achieved a proper position. The reticular crypt should not be cleared away at surgery because the bone responds to a blood supply like an aneurysm.

Lower Molars

But the classic demonstration of cortical bone anchorage is found in the lower molar area. With the edgewise arch philosophy in the mid-1940s, students were taught how difficult indeed it was to close the space in the event of an early loss of the first permanent molar after it had been missing for one year or more. In fact, common practice was that the second molar was uprighted and space was maintained for a bridge for the dimensions of a premolar in such events. With the old techniques employed -- consisting of straight tie-backs, heavy pull coils, or heavy loops -- the remaining space filled in with cortex was simply not closed.

The answer to such events is quite simple in retrospect. After a tooth has been lost for a period of time the socket is healed and the alveolus becomes corticated over the extraction site. To close the space means resorbing cortical bone rather than cancellous bone. Heavy pressures hyalinize or sclerose both sides of the space. Closure is extremely difficult under such conditions. The answer to closing space when corticated bone is present is very light pressures.

Lower Buccal Anchorage

The last area of cortical anchorage to mention is indeed the thickness of bone on the buccal plate. A traditional technical difficulty was encountered in the uprighting of a lower second molar that had erupted in lingual crossbite. Sometimes banding, and the use of a wire to attempt to move the lower second molar buccally would result in the lingual movement of the first premolar before the second molar could be positioned correctly. Heavy criss-cross elastics also were problematic. The plate, sometimes 7 mm. thick buccolingually and also sometimes extending over half the length of the root, offers a profound resistance, and the tendency to use heavy pressures must be warned against. The more successful pressure is 0.5 gram per $mm.^2$ which resolves to about 50 grams only.

Lower Molar Anchorage -- Vertical Consideration

In the early 1950s, a study using cephalometrics and laminagraphy was conducted on patients being treated at age 8 with the classic Ribbon arch appliance. Intermaxillary elastics were emloyed for correction of Class II. It was discovered that **less anchorage loss occurred with Ribbon technique than was measured previously with the Edgewise mechanism.** Please imagine, even with only the first molars and incisors banded, less lower arch displacement was seen than that measured with all the teeth employed at age 12 (see Chapter One, Fig. 1-2).

In anatomical review it will be noted that the lower first molar, at the mixed dentition age, is surrounded by a heavy buccal plate and external oblique ridge. With an initial expansion action and with the effects of mastication, which bent the straight Ribbon wire downward mesial to the molar, a natural tip-back together with lingual crown torque was manifested. **Thus, with that root position a vertical displacement of the lower molar was inhibited by the bone on the buccal cortex.** The vertical and horizontal stability inhibition sustained the lower arch from moving forward under the pull of the Class II elastics (Fig. 3.12). This observation came to be taught as "cortical anchorage" in 1954 (see also Fig. 3-3). Figure 3-13 demonstrates sclerosing values.

This is all the more important when it is realized that the mandible grows on an arc and the natural eruption is dramatic in an upward and forward direction (Fig. 3-14).

"RIDGE" COMPLICATIONS

One of the conclusions reached from the use of the Edgewise appliance as an expansion device was the finding of dehiscence and the idea of the necessity to treat "to the ridge". Orthodontists consequently tried to **conform the final arch as close as possible to the original arch dimensions.** There was a bona fide reason to evolve to that theory which was based on experiences from treated patients with

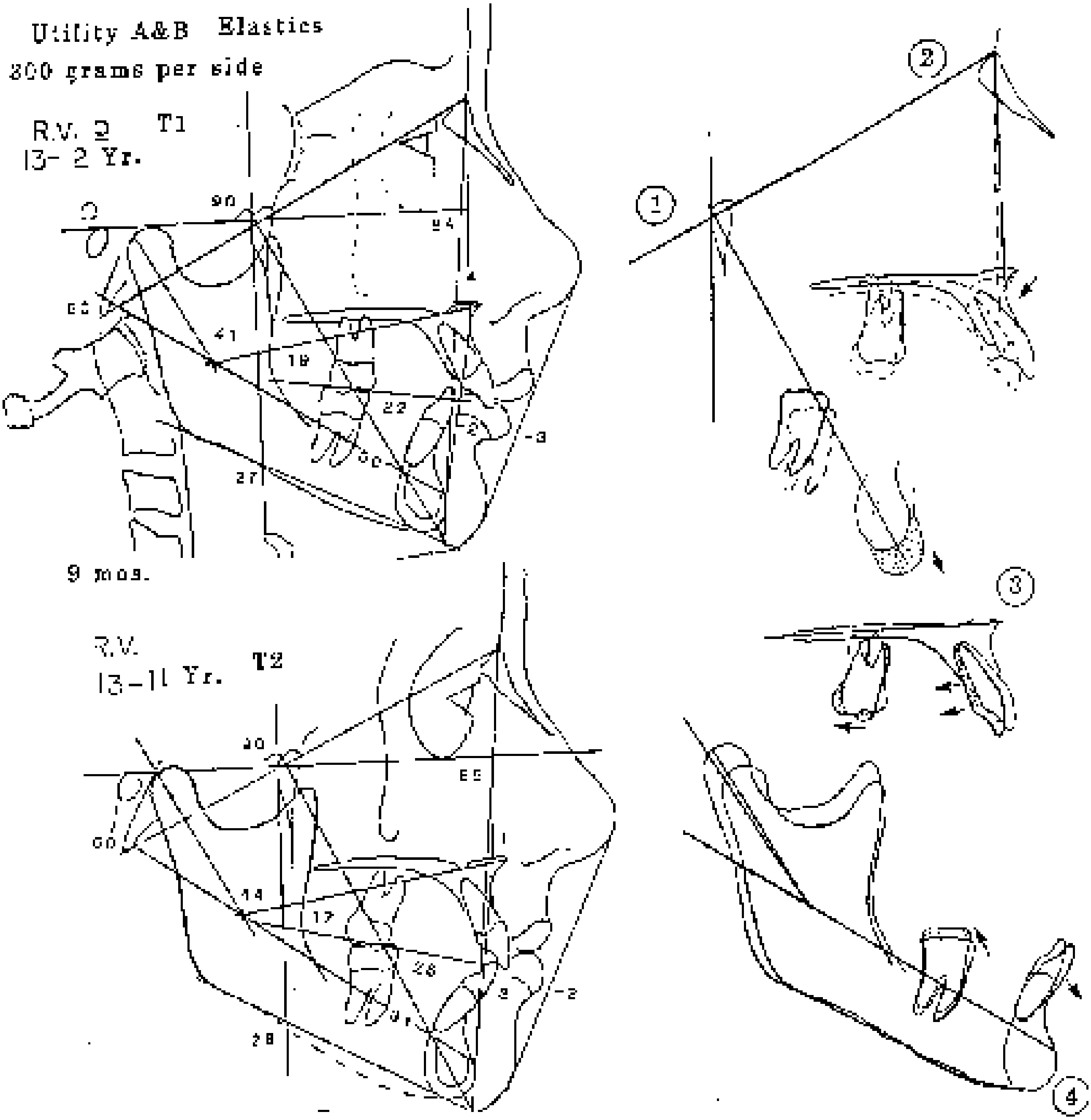


Fig. 3-12 A thirteen-year old female wore two elastics bilaterally to test vertical anchorage of molars off utility arches only. Note the changes in 9 months' time included palatal alteration and opening of Corpus-Condyle Axis. Patient was another 9 months in finishing.

BONE ENGAGEMENT

1 gram per mm.^{2}

For Sclerosis × 2 or × 3 grams

For cortical change 1/2 gram

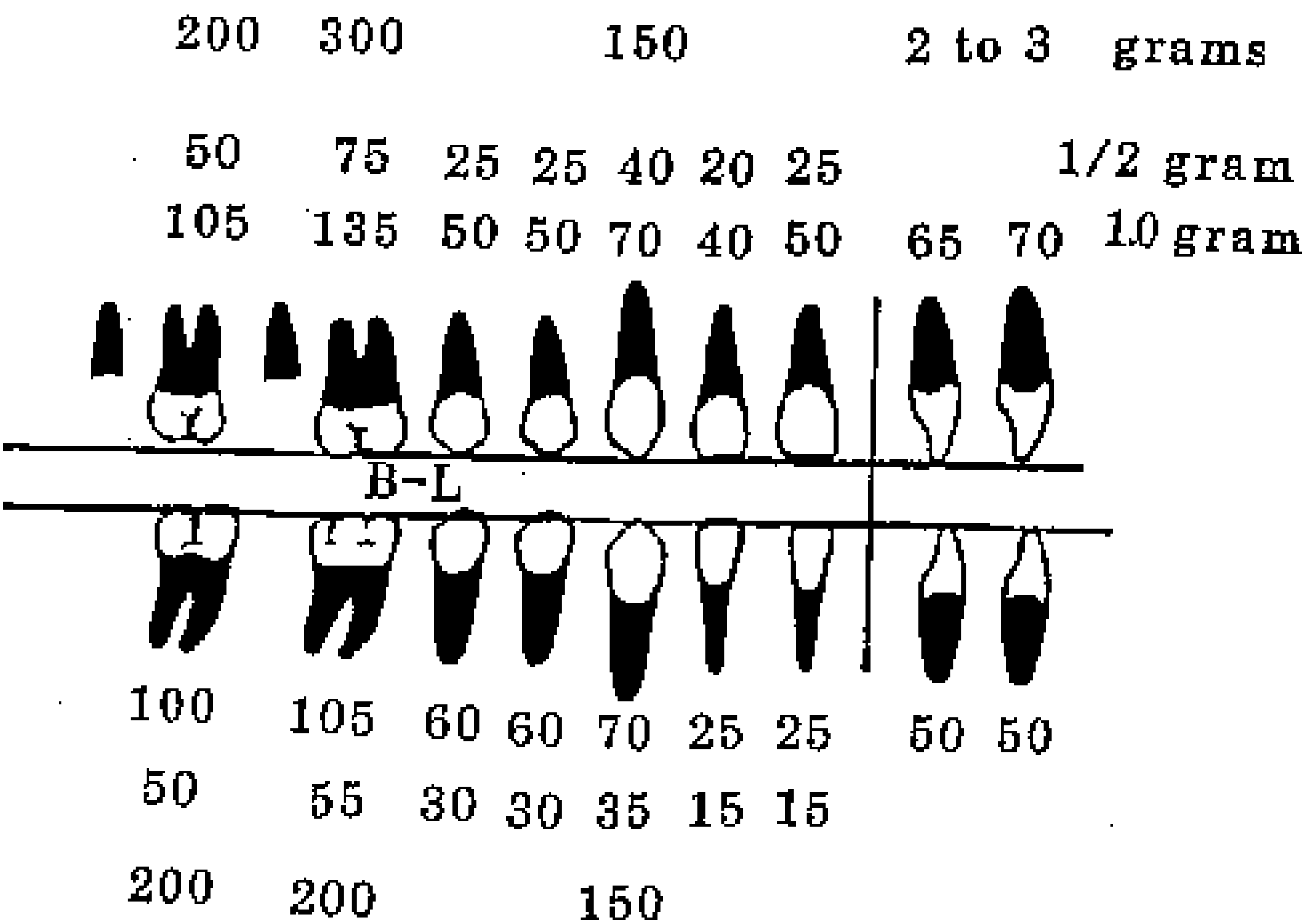


Fig. 3-13 Cross-section of roots in transverse plane. For anchorage the 1 gram per mm. is tripled. For ridge modification (growing alveolar bone) the force is ½ gram per mm. when against the outside plates.

ARCIAL GROWTH

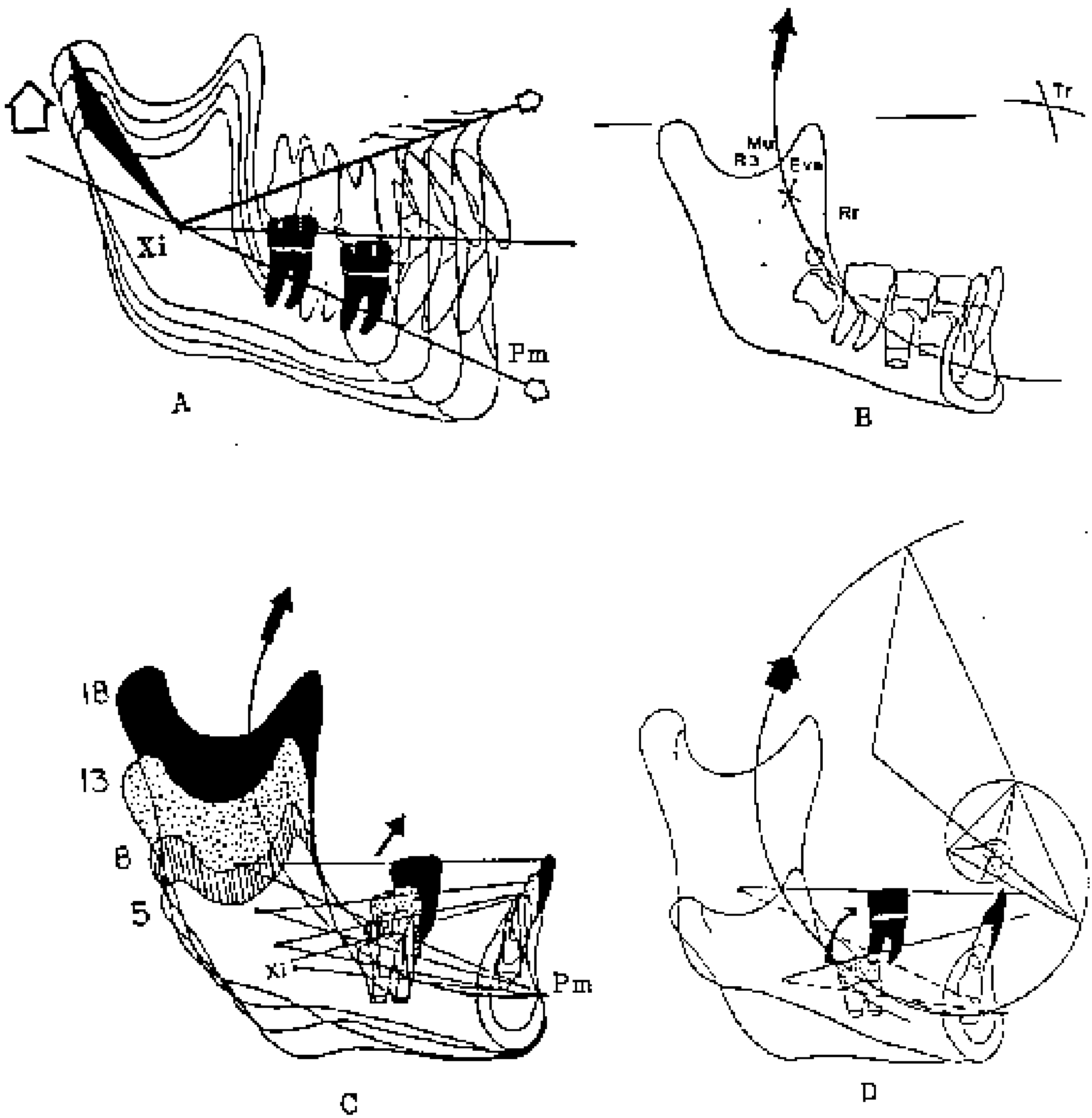


Fig. 3-14 Frontal growth bend observed in A. An arc was discovered, as shown in B. When applied to teeth it shows that space for molars is created by forward and upward eruption and development of alveolus. Note how this biologic phenomenon can affect anchorage consideration.

Edgewise and with the "rapid" philosophy.

Publications suggest that orthodontists, in the late 1920s and 1930s, were in a hurry. Because all the teeth could be manipulated simultaneously, orthodontists came to advocate waiting for all the teeth to be present before starting. Also, for any Class II case, intermaxillary elastics were to be applied immediately, at the same time the individual arches were being levelled and aligned. This regime was advocated prior to the advent of cephalometrics. It should be remembered that in the 1920s assumptions were made that the mandible was activated and that skeletal bones were being altered with impunity.

But, by the mid 1930s a number of uncomplimentary results were recognized in many patients:

(1) mandibles were rotated open,

(2) greater lip strain was produced,

(3) upper anterior teeth were extruded,

(4) gummy smiles were produced,

(5) incomplete and unstable results were noted, and even worse,

(6) stripping of the lower incisors was too common to be tolerated.

With this behavior the author concluded that pressure ischemia from the lower lip was being produced. The lip pressure needs to be released, not increased. Orthodontists tended to blame unsatisfactory results on a poor diagnosis rather than investigating the iatrogenic effects of the technique itself. Thus orthodontists became beholden to the ridge.

However, expansion with other light techniques revealed that successful results were experienced. If buccal pressures, for ridge modification, are desired they must be very, very gentle. This is theorized to be in the range of only 25-30 grams for a premolar (0.5 grams per $mm.^2$ of the root surface) (see Fig. 3-13).

The Edgewise Bracket and Early Problems

The Edgewise bracket was a model in that it really was the first bracket which permitted control of the tooth in all five requirements. One answer to the foregoing problems encountered with rapid treatment, however, was deemed to lie in the need for extraction of pre-molars, as advocated by Tweed. Most common was four first pre-molars, in more minor conditions the upper first and the lower second premolars were removed. In even more minor anchorage cases, in order to attempt to avoid expansion of the teeth off the ridge, four second premolars were extracted. Still later four second permanent molars were removed **under the auspices of the ridge theory** and for stability.

The loss of the gingiva on the labial plate of the lower incisors, as stated, was a disastrous occasion. A clinician needed only to experience one single case on the possibilities of major stripping to accept the concept of adherence to the original ridge. Flaps laid later would indicate that the teeth had been moved buccal or labial to the original alveolar process. Thus, such findings justified arch size reduction through extraction in order to try to keep teeth "on the ridge". Orthodontists in the 1950s who treated non-extraction were said to be "off base". This idea suggested that the ridge was likened to “basal bone” with its own genetic predisposition.

But, modification of the ridge is an everyday occasion, even by those professing to keep the teeth on the ridge. The best example of this is the retraction of the anterior teeth in a double protrusive patient, the forward movement of the lower incisors in a Class III case prior to surgery or the need for mandibular arch advancement in patients with retrusive lower dentures (see Fig. 3-4). Therefore, buccal-lingual (transverse) movement, or labial movement for incisor advancement is a major consideration in orthodontics, and is best achieved with light square wire such as $.016^2$ blue Elgiloy (Fig. 3-15).

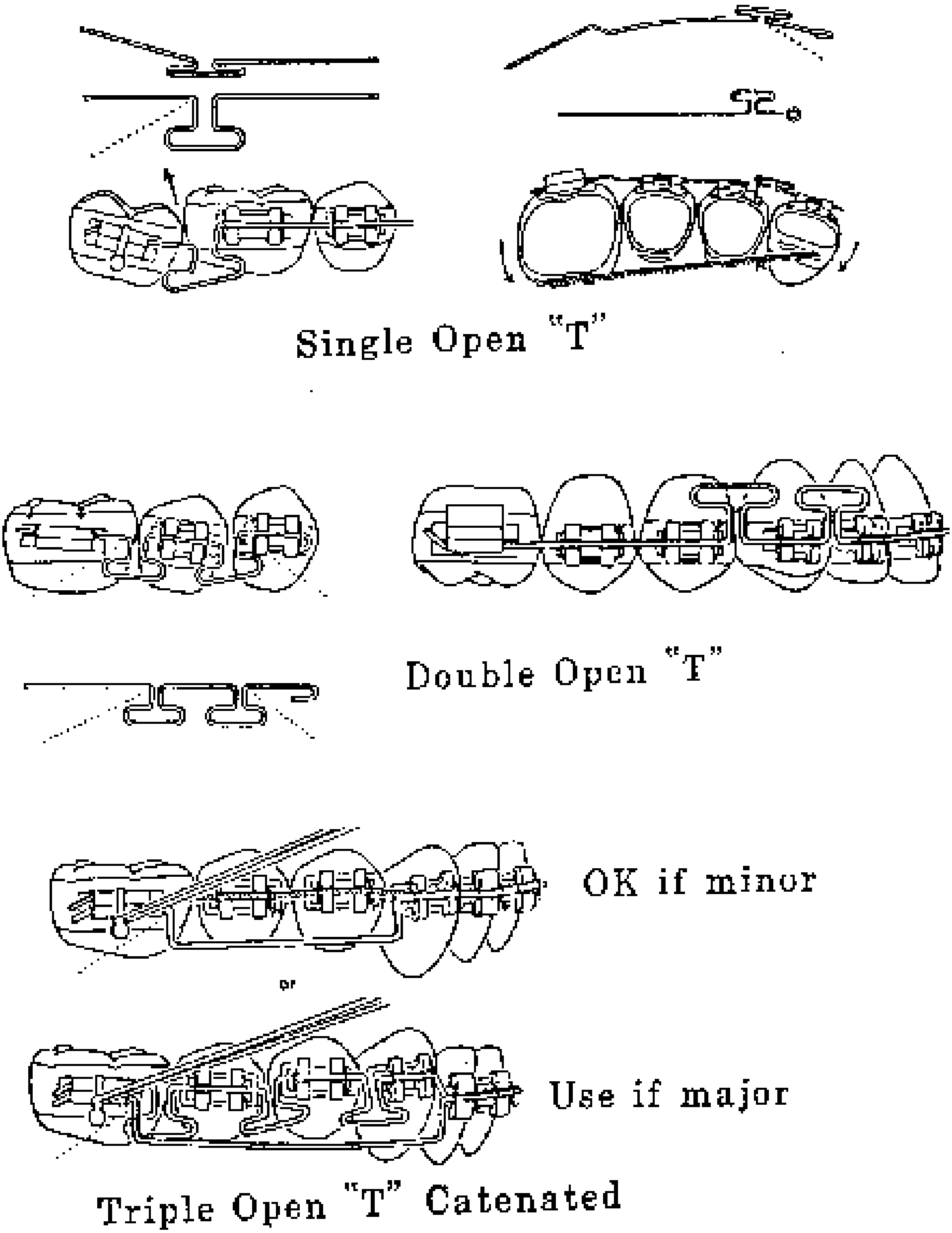


Fig. 9-15 To produce lighter continuous and controlled alveolar process development the square .016 blue Elgiloy has been found ideal when concatenated.

Root Resorption

The most common source of root resorption is in the upper incisors, as reported by Dr. Thomas Thompson, Dr. Dale Wade and others. Reasoning and logic suggested that the roots of these teeth are commonly moved over the greatest distance, such as in Class II, Division 2 or straight backward for retraction in Class II, Division 1. Consequently, some alterations were made in the original theory and application of the arch wire. Because necrosis (which is the cause of root resorption) always has its first stage as anoxia, the denial of oxygen and nutrients via the interstitial fluid may be the key factor.

Pressure Reduction for Ridge Modification

When the movement of roots of teeth is attempted for modification of buccal or labial cortical plates in expansion, or the palatal plate in incisor retraction, the pressure must be reduced from that employed for movements in cancellous bone. Direct resorption is desired because backward resorption from cortical bone is difficult. A build-up of buccal or labial bone in advance of the movement must be stimulated. It probably is encouraged from influences of the periosteum. The values in the original rating scale must be cut in half. This means 0.5 gram per square millimeter of presenting root surface in the labial buccal or lingual direction (see Fig. 3-13).

In addition, bodily movement is desired to help develop the alveolar process. This is preferred to breaking down the crests with tipping forces (which increases the pressure). It also necessitates later uprighting. The lighter pressures are also aimed at preventing root resorption. Time, patience and skill are required for expansion.

As a working hypothesis, if cortical stimulation and modification are intended, then forces in the range of 0.5 grams per square millimeter are appropriate. Thus, lighter pressures than ever before considered feasible are advocated. Concatination of the light $.016^2$ wire will help effect these values (see Fig. 3-15).

Expansion with the Crozat technique, with the Labiolingual technique, with the Frankel technique, and with other fixed light-wire techniques has proven successful. There is no question, however, that in some patients extraction may be the most conservative road to take. Many outstanding operators, and many enlightened orthodontic scholars seriously watching their patients many years later, have been led to an extraction level of less than 10% of their practice, if their patients are started early. This is with the use of techniques and proper biomechanics herein described. Black and Oriental patients are more frequently extracted for esthetic reasons. In fact, in the final analysis, the argument could be made that the only reason for extraction could be for esthetic reasons.

Possible Errors

Pressure ischemia of gingival tissue leads directly to stripping of teeth or gingival recession. Displacement of interstitial fluid in the connective tissue is a factor in the breakdown of the labial tissues in the lower incisor area. In addition, a rotation of the mandible (without a concomitant tipping of the palate) will result in an increased height or vertical maxillo-mandibular relationship. When rotation occurs (for bite opening) it requires a further stretching of the lips and a tightening or pursing of the lip muscles in order to close the mouth. But, ironically, in addition a rapid tipping of the teeth with round wire caused inordinate pressure on the root side of the alveolar crest. Later uprighting with heavy rectangular wires often forced the roots of the incisors, canines and premolars literally through the buccal plates. One significant answer, to the expansion dilemma, lay in the treatment of deep bite by intrusion of incisors to prevent increased lip strain. Intrusion in the lower may further take advantage of the wider bone in the symphysis.

In order to further reduce pressure ischemia, which would be followed by atrophy and dystrophy, surgical release of genetically endowed tight lips has been successfully employed by Ricketts, S. Fredricks and others. These techniques need to be recognized (Fig. 3-16) and are futuristic.

In most full-banded techniques in the 1940s orthodontists attempted to regulate the lower arch and then use it for anchorage to hopefully resist intermaxillary elastics; an upward and a forward displacement of the lower arch resulted. The tipping of the occlusal plane compounded clinical problems. All the teeth in the upper arch were simultaneously ligated into a continuous wire. Even following an accentuated curve in the upper arch wire, patients having intermaxillary traction experienced upper anterior extrusion. Contemporary straight wire advocates still employ this plan, although with lighter wires.

Answers

With research and experimentation the answer to the unsatisfactory results was (1) lighter force, (2) procedures to counter auto-rotational effects on the mandible, (3) control of anchorage to prevent extrusion, and (4 intruding before retracting the anterior teeth. In keeping with the principle of stimulation rather than destruction, the pressures were reduced (Fig. 3-17).

ORTHOPEDIC FORCES AND ANCHORAGE

Observation with extraoral therapy, mainly cervical traction on the upper molar, is considered from an anchorage point of view. The reason for this is that the upper first molars alone, when engaged with a Kloehn headgear and a cervical strap, provide enough anchorage to move the entire maxilla.

Torquing of the lower molar root under the lower buccal plate increases the lower arch anchorage. After that maneuver the use of heavy intermaxillary elastics attached to the lower arch has been shown to produce enough anchorage to tip the palate and also modify the mandible temporarily. The question is, how? (see Fig. 3-17 and Fig. 3-12).

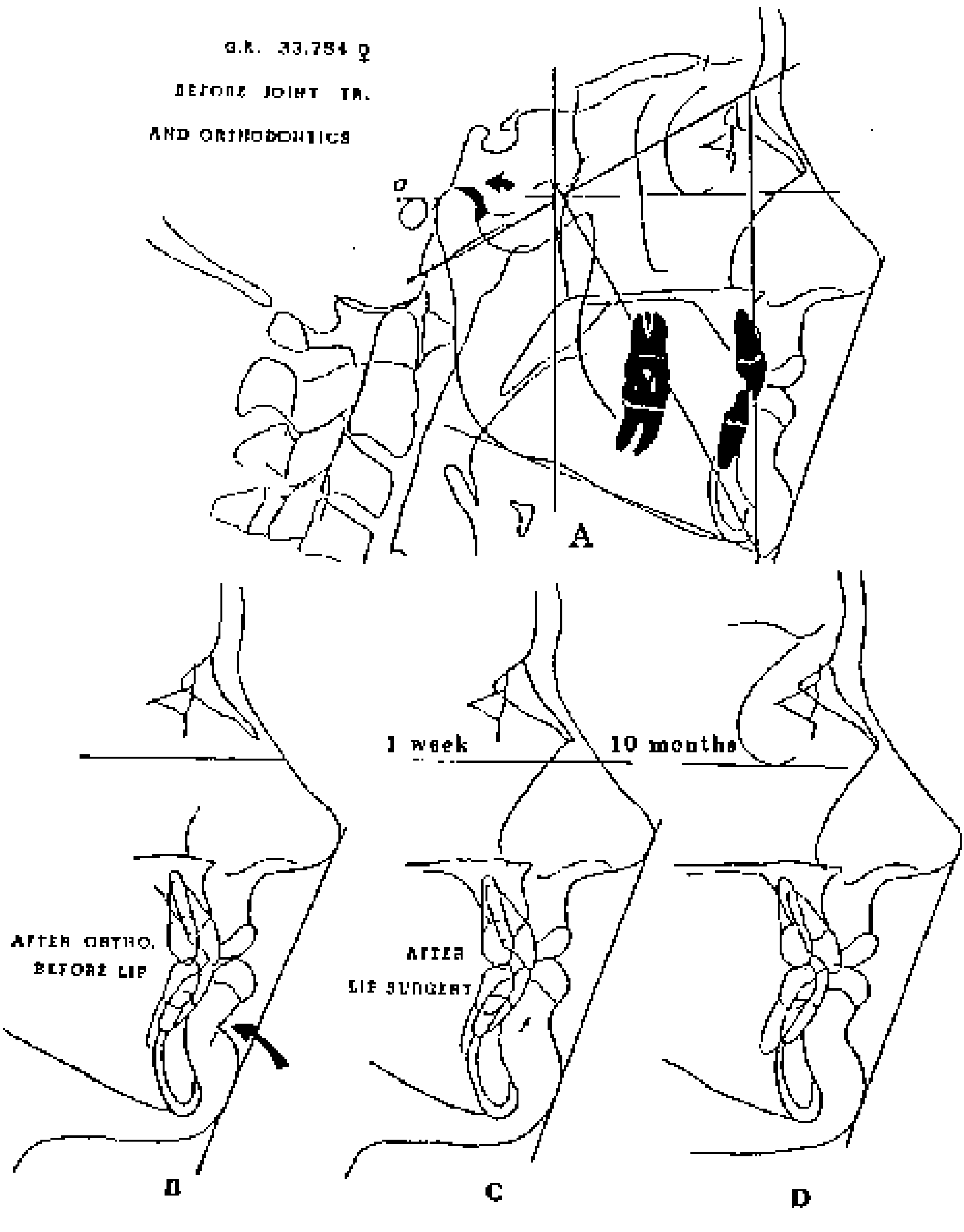


Fig. 8-16 In order to avoid flat mouths a surgical release of the lower lip is successful. This is an alternative to lip myofunctional therapy and to extraction. Lower arch length was corrected for 12 mm. of shortage in this adult female.

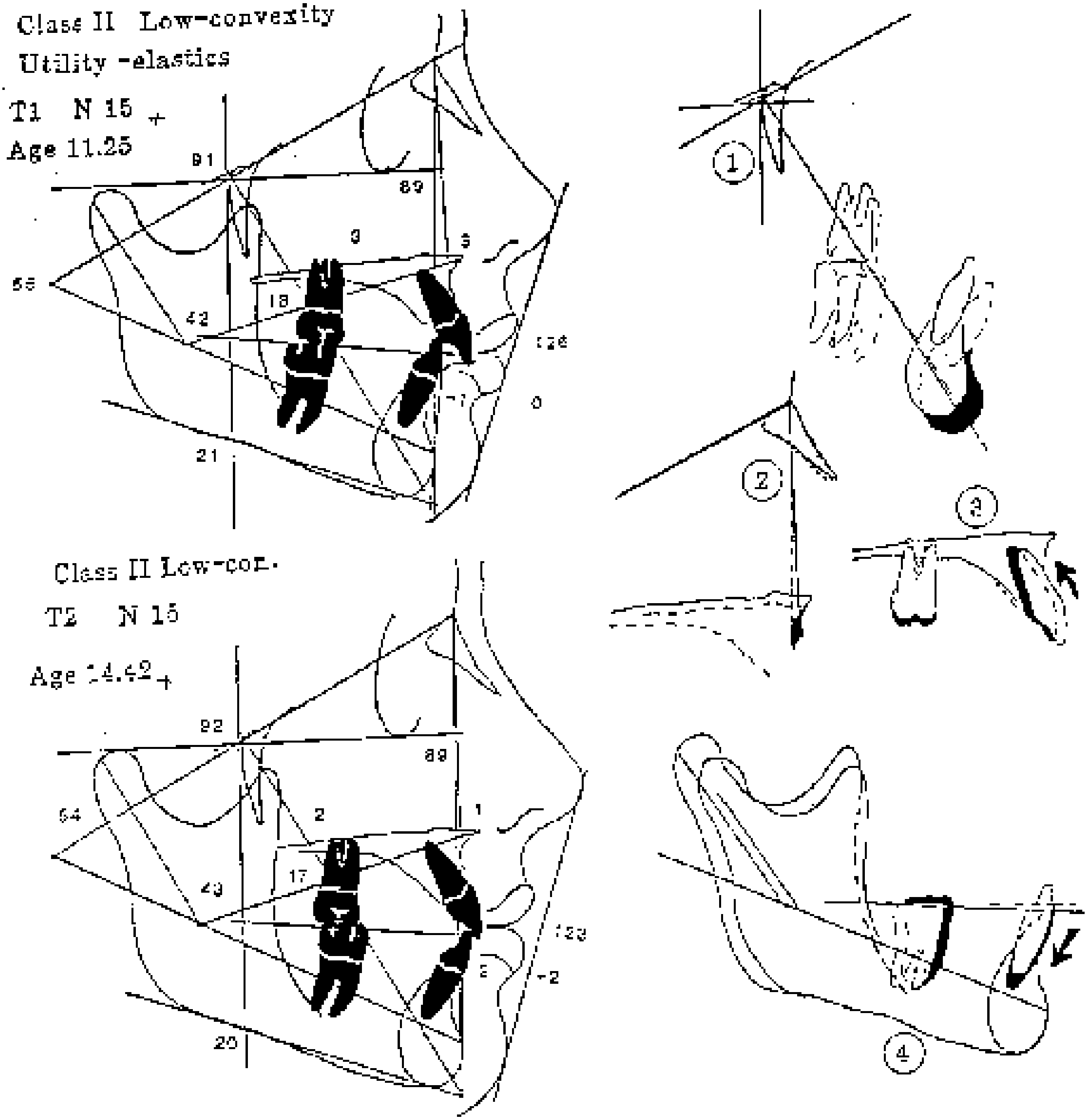


Fig. 3-17 A composite of 15 patients is shown, having been corrected with utility arches and elastics alone. Compare to Figure 3.12

Theoretically, forces beyond the level described for alveolar modification produce connective tissue, sclerosis and anchorage against the root. But if these forces are interrupted in nature, the teeth may serve for good anchorage without being inordinately damaged.

Particularly as the upper molar is rotated and expanded with the dental bow of the facial apparatus, the upper molar is sufficiently stabilized and the forces are then transmitted to the midfacial sutures. A force of 1 gram per square millimeter of maxillary sutures is needed hypothetically to move the maxilla, similar to the concept of movement of a tooth within the alveolus. This is calculated to be around 120 grams for a bodily movement of a molar. After arch length achievement with the face bow, when additional stress is dissipated against the upper incisors, that too adds in a secondary manner to modify the maxilla. A force of 300 grams on the deciduous second molar, when held upright, is shown to anchor that tooth. A force of 500 grams on the upper first permanent molar is proven to move the maxilla when not tied up with another application. Palatal separation is demonstrated with the quad helix using the molar alone for anchorage. The .038" blue Elgiloy wire (with the medium quad helix size) can exert 600 grams before reaching the proportional limit. Thus, if anchorage forces are required for "orthopedic" change the original root rating scales would be increased to two to four times the force required for tooth movement alone.

Temporary changes in the mandible by bending, apparently, at the junction of the body with the ramus may occur from vigorous elastics, which is seen in individual patients and suggested by composites of groups of patients (see Figs. 3-12 and 3-17).

When the orthopedic force with face bow and cervical traction are employed at the proper level, and when night wear only is prescribed, and when pain is not introduced, the lower molars will intrude in the majority of cases.

Non-Compliance Modalities

The Herbst appliance employed for Class II correction is another modality, but is not well understood. Mandibular growth stimulation is not as dramatic as often hoped for. A sample of Jasper-Jumper cases are shown (Fig. 3-18). Studies of patients three or four years after correction show very little of any increased growth with mandibular posturing. A composite of 138 patients treated by four different removable posturing appliances is shown in Figure 3-19.

SUMMARY

The title of this book could be "How to Think About Mechanics in Orthodontics" as an alternative to the subject "biomechanics".

Three general theories seem essentially to characterize the profession. The first is the proposition that teeth can be changed only within the alveolus. This postulate was the result of early work with cephalometrics following treatment with the Edgewise philosophy of the 1930s. It resulted, unfortunately, in the idea of a steadfast adherence to treatment "to the ridge" or to the skeletal bases. Tooth-borne anchorage was appraised along the individual arch and "anchorage reinforcement" was a common thought process. Total arch anchorage against the opposite arch became an issue with intermaxillary elastic traction.

The second precept is that some skeletal or orthopedic change can be induced.

The third idea is that growth, when available, can be used as an adjunct.

The last two concepts suggest that control of denture height is a clinical requirement and involves a thorough knowledge of "anchorage". The ideas promulgated hold that the oral environment can be modified. This attitude includes "ridge" modification. Finally, the utilization of growth is made a deliberate part in the planning procedure.

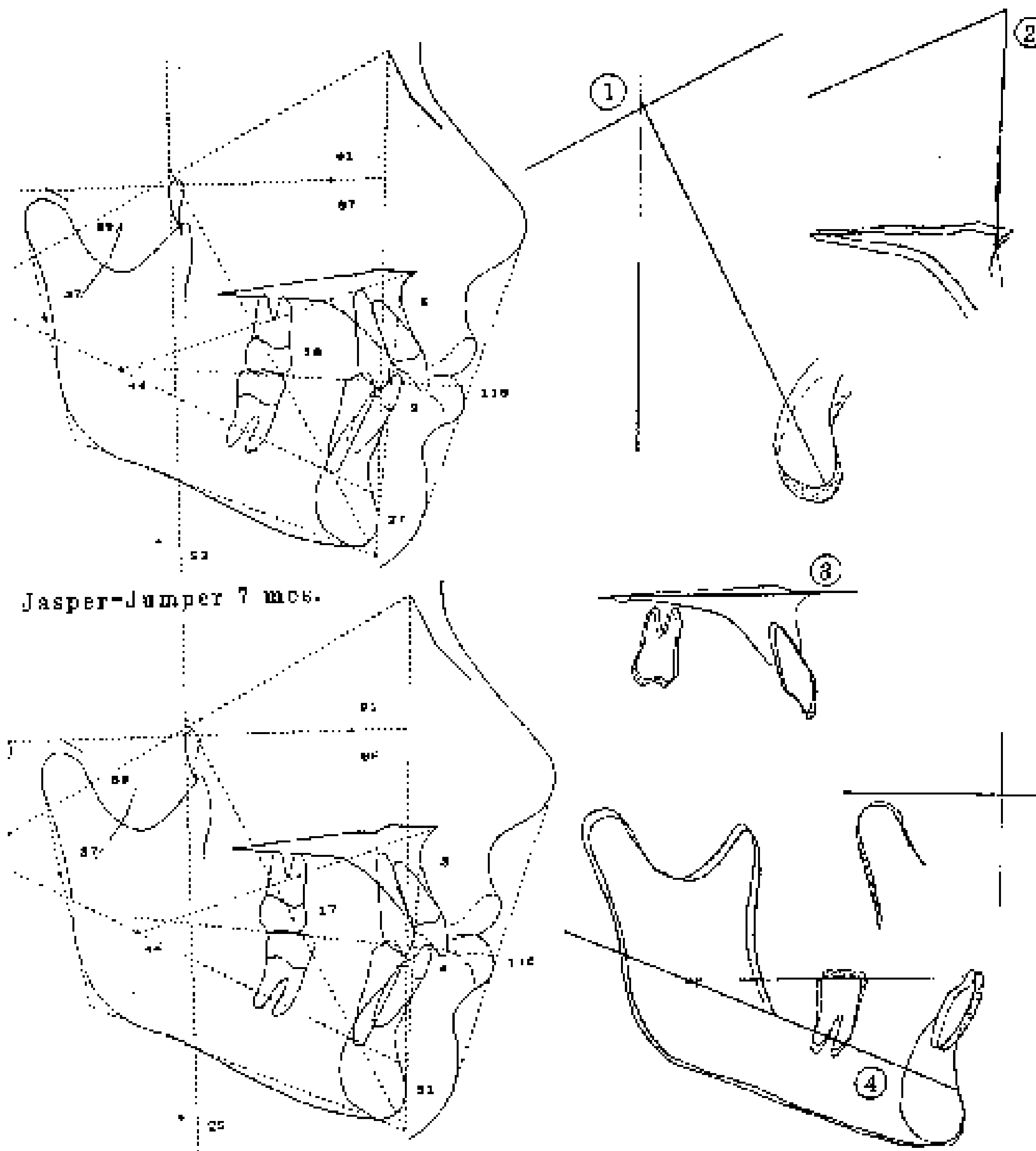


Fig. 3-18 Composite of 10 patients treated for 7 months with Jasper Jumper. Note forward movement of lower incisor and very little maxillary orthopedics. Compare to Figures 3.12 and 3.17 with intrusive mechanics and elastics.

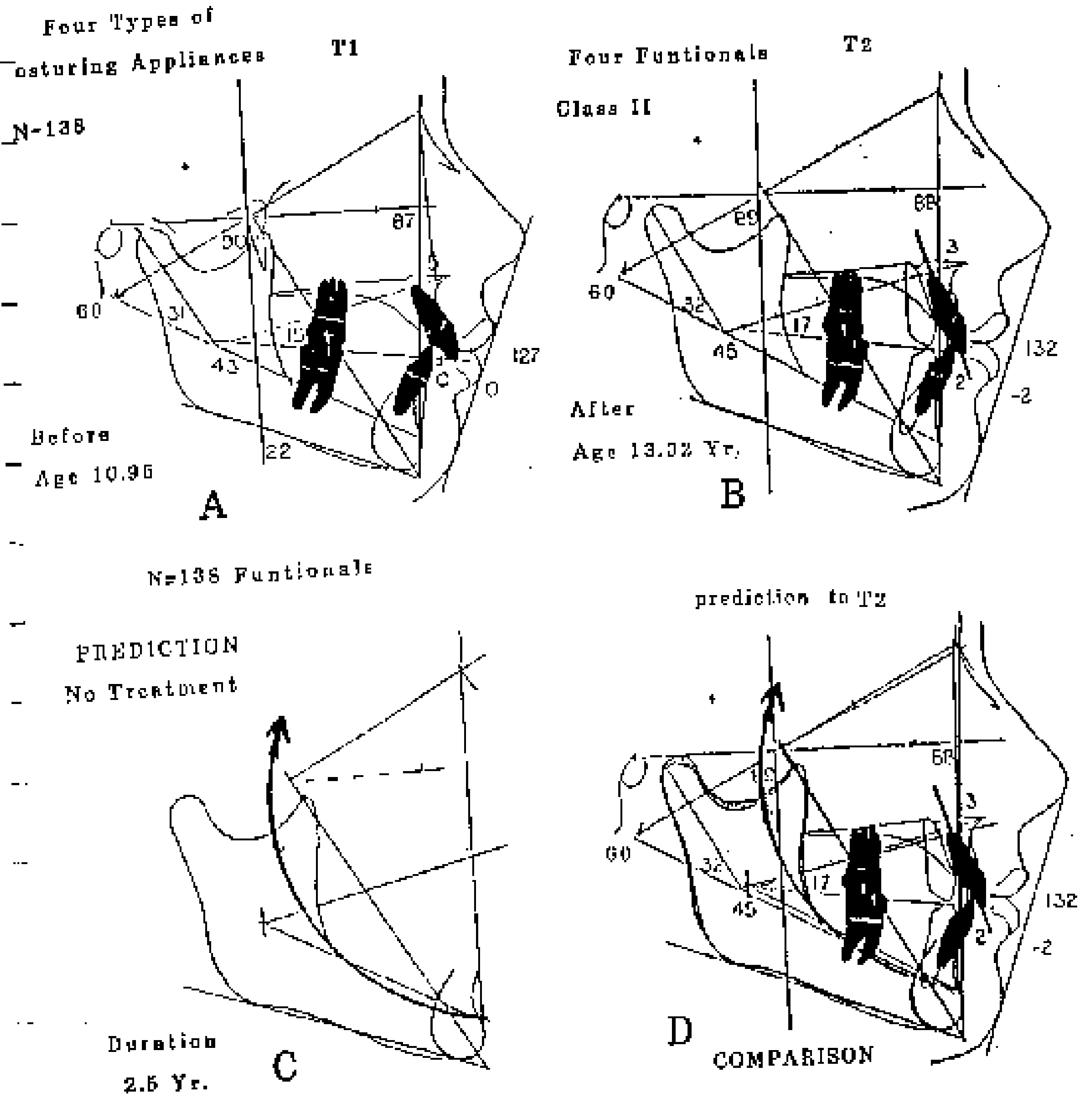


Fig. 3-19 Composites of four groups of posturing devices. A is T1, B is T2, C is the prediction of T1, and D is the comparison showing a slight undergrowth of the actual compared to the forecast.

Biomechanics is much more than just individual tooth movement. Complete orthopedics not only deals with bone, but also with nerves, muscles, connective tissues. Even epithelial tissues are involved in the process of clinical management.

Thus extraoral traction, quad helix, utility arches, sectional mechanics, and concatination of wires represent perhaps the most sophisticated aspects of contemporary orthodontics. In non-compliant patients fixed posturing devices are an option.

CONCEPTS OF
MECHANICS AND BIOMECHANICS

CHAPTER FOUR
GENERAL SUMMARY

It is obvious from a discussion of mechanics with leaders in orthodontics that differences lie in the basic beliefs concerning the optimal forces to be employed clinically. The controversies concern rapidity of movements, health of tissue, and anchorage. In the end, health and anchorage are the more important consideratins.

Throughout the past twenty-five years computer composites of treated patients have been derived after use of almost all the leading appliances. The comparisons point out distinctly different results according to the various mechanical regimes (Fig. 4-1).

The effort was made to explain contemporary concepts of force application. Even a given appliance can be used in a different manner. Therefore, the concern is not with an appliance necessarily, but with how it is employed.

To think only about orthodontic "force" is a cardinal error. Any force delivered must be analysed relative to its area of distribution. This means that force per unit area, or pressure, is the final issue, but it has been under-appreciated in the past. A "light" force that tips a tooth can produce a heavy pressure at the crest of the socket.

Chapter One

It was shown that applied mechanics serves only as a starting base. Biologic laws are the main consideration in order to understand the tissues' reaction to

MECHANICS DIFFERENCES

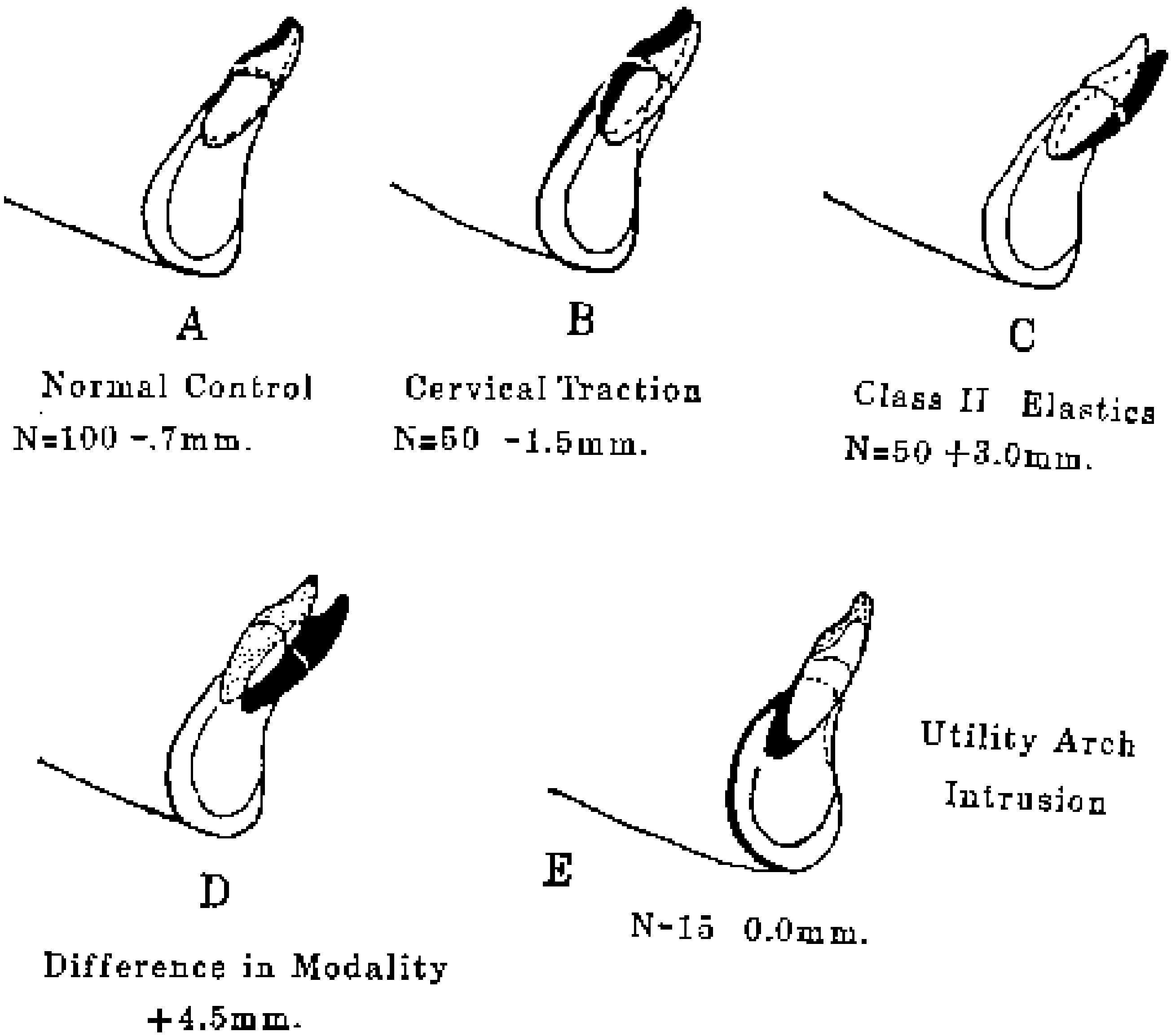


Fig. 4-1

A. As analysed in the older traditional method a control of 100 untreated subjects in 30 months is shown. [Published 1964]

B. Lower incisor behavior in 50 patients treated on the upper with cervical traction.

C. Results in 50 patients treated non-extraction with intermaxillary elastics.

D. Differences between B and C results.

E. The mean intrusion in 15 patients treated with utility arches and non-extraction.

pressures. **The body tends to make extensive efforts to return to a state of equilibrium when it is disturbed both chemically and physically.**

Both chemical and physical homeostasis were explained relative to treatment. This started with the explanation of cellular needs and went on to cover biologic laws, principally the "Law of Adaptation".

Both laboratory and clinical work have both been conducted in order to determine the best guides to follow. Possibly for the **most rapid changes** clinically a force of two (2) grams per square millimeter may apply. However, where the **preservation of anchorage** is concerned, and when safety from **root resorption** is sought, a force of 1.0 gram per $mm.^2$ of root surface is adequate. But particularly where ridge modification is desired, the forces are best reduced down to 0.5 gram per square millimeter of enface root surface against compact bone and connective tissue.

On the other hand, when orthopedics is the objective and when cortical anchorage of bone is to be utilized, the forces correspondingly may be increased to 3 to 4 grams per $mm.^2$ of presenting root surface, particularly on the cortex of the alveolus.

Ligament is a misunderstood tissue. It would seem that researchers in the past have assumed it to be like a tendon or fascia or periosteum. **Ligament functions as a checker or restrainer against a sudden action.** This ligamentous resistance, as during the force of mastication, is borne by the periodontal membrane. The membrane, or length of the ligament, is often no more than one-tenth to one-quarter of one millimeter. However, **ligament as a tissue cannot withstand a continuous deformation.** It stretches. This is seen in traumatic occlusion and under orthodontic manipulation. Ligament does not serve as a prolonged anchorage. This leads to the conclusion that bone and muscle are the main sources of resistance to tooth movements clinically.

The character of the alveolar process behaves almost perfectly according to

Wolff's Law of Functional Adaptation. It comes into existence and responds with the tooth when the environment permits. Orthodontics has perhaps been too preoccupied with the "ridge" and has not understood it from a biologic point of view.

Chapter Two

Next the issue was to deal with the analysis of pressure. Root ratings were presented which have for three decades worked very well as a clinical starting point. The values are modified depending upon the desires for anchorage or cortical avoidance or ridge modification.

Because the forces in the maxilla are resisted against sutures, and because the suture is also composed of ligament, and further because bundle bone lies on both sides of the suture, the characteristics of the suture were analysed. It is hypothesized that the same one gram per square millimeter would apply to the sutured alteration in growing children.

Based on the fact that movement of the maxilla is seen cephalometrically, the combined sutural resistance with deduction would suggest 300 square millimeters per side in children age 5, and enlarging to 700 or more in adolescent subjects.

Cortical bone was described as the chief source of anchorage, particularly for intermaxillary traction. Lip reinforcement was also described. The behavior of soft tissue was promulgated as probably being modified by dystrophic phenomenon.

If forces required to move molars are 2000 gram-millimeters of moment (100 grams at a lever distance of 20 mm.), then a blue Elgiloy .016" X .016" wire is adequate to move molars, and any larger wire is excessive. The proportional limits were described showing the need for longer lever arms by means of loops between teeth to cut down the force, increase the range, improve efficiency, and be more biologic in results.

Chapter Three

In Chapter Three, the sources of anchorage were arranged in a sequence and a hierarchy. This was nothing more than common sense reasoning. Eight factors were listed, starting with interstitial fluid and ending with growth.

For clinical acumen ten specific instances of anchorage considerations were pointed out. Most clinicians learn these the hard way – through mistakes. Perhaps if these are explained and conceived in the biologic sense, problems can be avoided.

With the understanding of these factors to be applied at the clinical chair routinely, two great opportunities lie before the orthodontist. The first is orthopedic change in the young patient which can reduce the need for extraction or for surgery later. The second is the success of lateral expansion when practiced with the principles laid down. This can save patients from extraction while, at the same time, receiving beautiful faces and pleasing smiles.

Orthodontic Diagnosis

The complete abstract idea of the term Diagnosis as employed in orthodontics often is conceived to be the etiology, the description of the skeletal conditions, the classification of the dental arrangement, the situation of the esthetics, and in addition the treatment objectives or plan. As used, it actually includes a prognosis. But patients do not die from a malocclusion, although one patient tried to commit suicide because of a prognathic mandible. Therefore, orthodontic **diagnosis is the determination of the nature of the patient's needs or desires toward some degree closer to perfection!**

The decision in planning mechanics rests in the end with the orthodontist's goals. These goals, in turn, are decided by the orthodontist's "concept of possibility". Like it or not, beauty of the face and a pleasing smile enters into the final plan.

Dr. Carl Gugino has theorized the "clinical norm", as described by Dr. Paul

Simon in 1920, to be the "Zero Base". The peak of the curve of distribution is 0.0 on a histogram with plus or minus clinical deviations from from that 0.0 value. When a number of conditions are taken into account, weighed and combined, they determine the "degree of difficulty". That difficulty in turn rests with the amount of change required, which comes back again to a forecast of the objectives. This is an unavoidable situation in orthodontics.

What is the *Zero Base*? Where is the peak of the curve for the face and for the teeth from which variation can be compared?

In 1950 the author, from data on normal growing children and adults, set objectives for the skeletal profile by maturity at a 0.0 mm. convexity for males and a +2.0 mm. convexity for females with clinical deviations at ±2 mm. For the dental profile the lower incisor to APo was found to be +1.0 mm. at 22° ±2.0 mm. The interincisal angle was found to be 130°. This was employed as ideal, but broader samples led to a position of +2.0 to +2.5 mm. for the lower incisor to APo, and experience showed that Caucasian patients could be set as much as +5.0 mm. or more in specific cases.

In 1990, forty years later, the author studied 133 children from the deciduous or early mixed dentition ($\bar{X}$=6.3 years) to maturity. Corrected for termination of active growth the age was 16.3 years, but in chronology the average age was 19.2 years. The findings of a generated computer composite are shown in Figure 4-2.

The morphology of the face as determined from computer studies in 1968 was confirmed by a second, larger group of patients in 1990. (See Fig. 4-2 for values for the facial axis, total height, denture height, facial depth and convexity; and please review the manual *Progressive Cephalometrics: Paradigm 2000*.) The position of the lower incisor was +1.5 mm. ±2.0 at 23° with an interincisal angle of 130°. The mean lower arch depth (from mesial of the molar to incisal center was 23.5mm. ±1.4 mm. Therefore, the original Zero Base of 1950 was essentially confirmed.

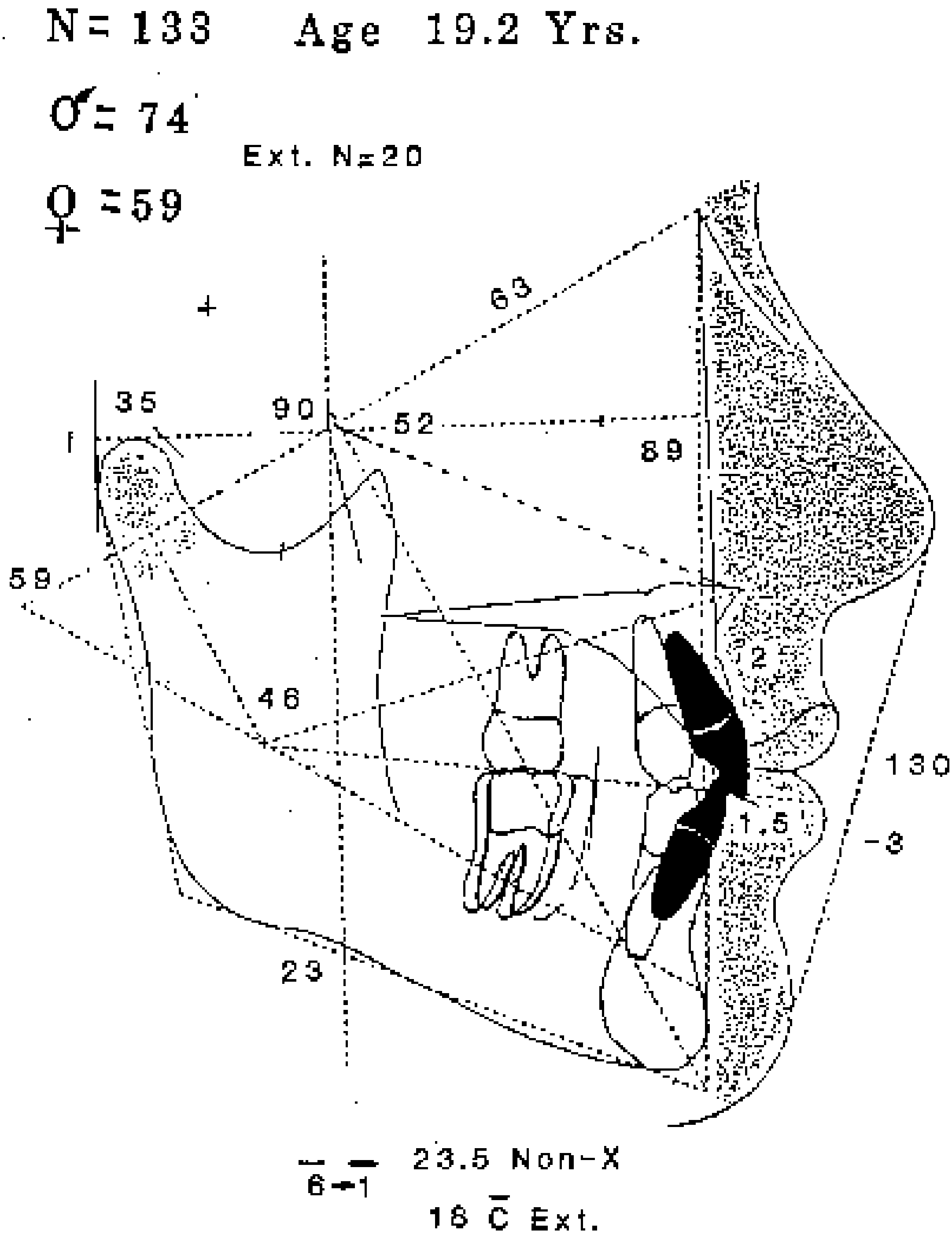


Fig. 4-2 A computer composite of 133 subjects at age 19.2 years. Twenty were four-premolar extracted. Forward lower first molar is position with extraction and posterior molar is position non-extracted. Note, ideal skeletal values almost identical to values reported in 1969. Note, the esthetics is the ideal described in 1954. This constitutes a contemporary Zero Base.

Consequently, in setting objectives and determining anchorage, specific emplacements must be considered at least as a concept.

A plea is made for monitoring patients with headplates and ongoing analysis routinely. It is only by using this tool of cephalometrics **with the four-position analysis** (shown in Fig. 3-1A & 1B) **that understanding of mechanics and biomechanics can be gained.** Other manuals, therefore, need to be consulted for sophistication in practice.

Quite frequently a clinician may react for expediency rather than sound biologic principles. Let us hope that the profession will provide a lasting service with both health and beauty as its foundation.