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The Design of a Palatal Expansion Appliance

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205

THE DESIGN OF A PALATAL EXPANSION APPLIANCE

by

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DEDICATED TO

My Father

For the uncompromising principles
that guided his life.

My Mother

For her tremendous love and magnificent
devotion to her family.

Joan

For making my life what
dreams are made of.

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VITA

Kelly Richard Conway, the son of Thomas William Conway, Sr., and Betty (Domet) Conway, was born October 21, 1958, in Omaha, Nebraska.

Kelly attended St. Patrick's school in Omaha, NE for his elementary education. His secondary education was completed in May of 1976 at Pope Paul VI High School, Omaha, NE. While attending high school, Kelly was elected a member of the National Honor Society and the Society of Distinguished American High School Students.

In September, 1976, Kelly entered the University of Nebraska-Omaha, as a chemistry major, receiving the degree of Bachelor of Arts cum laude in May, 1980. While attending the University of Nebraska-Omaha, he was an active member of the American Chemical Society and placed on the Dean's Honor List from 1976 to 1980.

In September, 1980, he entered Creighton University Boyne School of Dental Science in Omaha, Nebraska, receiving the degree, Doctor of Dental Surgery, in May, 1984. In January 1984, while attending Creighton University, he was a student instructor for the occlusion technique course. In April, 1984, he received the American Equilibration Society achievement award for outstanding performance in the Science of Occlusion and Temporomandibular Joint

Function during undergraduate dental education.

Upon completing his dental education, Dr. Conway served as an instructor at Creighton University Boyne School of Dental Science in the departments of Fixed Prosthodontics and Periodontics for one year.

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TABLE OF CONTENTS

LIST OF ILLUSTRATIONS

Figure		Page

CHAPTER I

INTRODUCTION

Orthodontic correction of malocclusion comprises treating varying degrees of skeletal and dental dysplasia. Posterior crossbite is a specific dysplasia whose etiology may be of skeletal and/or dental origin. Dipaolo[35] has conveniently categorized the etiology of posterior crossbite as follows (Fig. 1):

Type I: Skeletal Deficiency. Maxillary apical base width deficiency which may be accompanied by a basal length deficiency.

Type II: Dentoalveolar Deficiency. Bending of the alveolar process with or without undesirable axial inclination of teeth which are in crossbite.

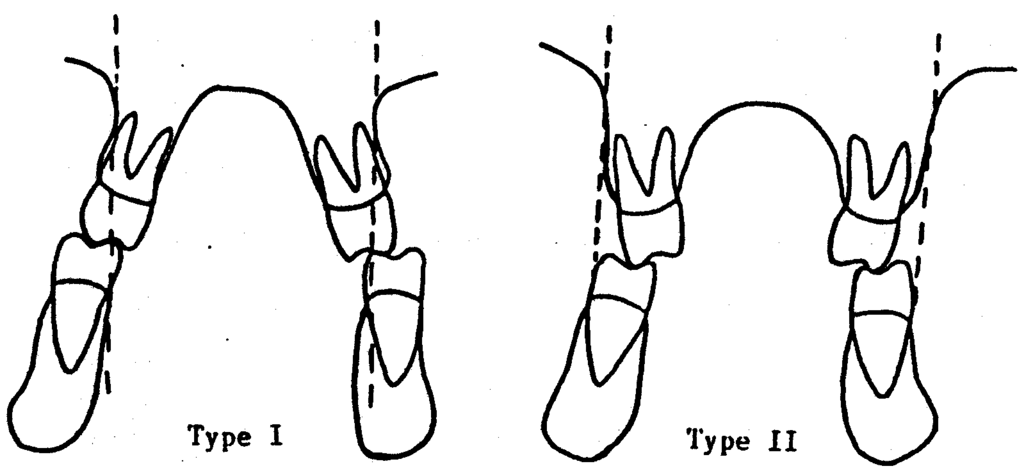


Figure 1. Two types of crossbite. (Dotted lines show relation of maxillary apical base to lower buccal segments.) (Dipaolo[35])

If the etiology of posterior crossbite is due to a skeletal deficiency (Type I), orthopedic alterations are necessary to correct the skeletal disharmony. If the etiology of posterior crossbite is due to a dentoalveolar deficiency (Type II), orthodontic alterations are necessary to correct the dentoalveolar disharmony.

Researchers have proposed a variety of treatment modalities for the correction of posterior crossbite.[35] Palatal expansion therapy is a routinely used treatment modality for the correction of posterior crossbite. A wide range of appliances are available to expedite palatal expansion treatment: fixed, semi-fixed, or removable, and those utilizing orthopedic and/or orthodontic movement. The forces involved may act through orthopedic (bony) movement, bodily tooth movement, tooth tipping, or a combination of these.[38]

The relative amounts of skeletal vs. dental changes that can be expected with palatal expansion therapy are related to the following treatment variables:

Patient's Age
Rate of Expansion
Magnitude of Applied Transverse Force
Retention Protocol
Appliance Design

Today, the vast majority of palatal expansion appliances utilize a key method of activation which relies on proper patient cooperation to achieve successful clinical results.[44] Numerous intratreatment problems have been attributed to improper patient compliance with appliance activation.[79,106]

It is within this context that the following research was undertaken. In order to maximize control over the variables encountered with palatal expansion therapy, a prototype palatal expansion appliance was designed. This prototype palatal expansion appliance design, which satisfies the primary objective of palatal expansion therapy, "controlled lateral expansion", and minimizes patient cooperation factors, will be presented.

In Chapter III, Methods, the prototype palatal expansion appliance design will be described in detail. Mechanical drawings, representing each component part of appliance, will permit three-dimensional visualization of the appliance. In Chapter IV, Results, the prototype palatal expansion appliance function will be explained in detail. In Chapter V, Discussion, the prototype appliance will be compared to the conventional palatal expansion appliances routinely used in orthodontics today.

CHAPTER II

REVIEW OF THE LITERATURE

HISTORICAL BACKGROUND

In 1860, Emerson C. Angell[2] published the first account of palatal expansion therapy. Angell's work, "The Permanent or Adult Teeth," appeared in two parts (April and July) in the San Francisco medical press. Angell inserted a screw appliance between the maxillary premolars of a 14 and a half year old girl and widened her arch one-quarter inch in two weeks (Fig. 2). Following the expansion period, Angell observed a space between the two central incisors and concluded the maxillary bones had separated.[2,106] Angell's conclusion created much turbulence in the orthodontic establishment circles and prompted rebuttal articles from influential members of the profession. John DeH. White, editor of Dental Cosmos, prefaced his edition with this comment: "With no disposition to assert that such a thing is utterly impossible, yet when taking into consideration the anatomical relations existing between the right and left superior maxillae and the other bones of the face with which they articulate such a result appears exceedingly doubtful."[106]

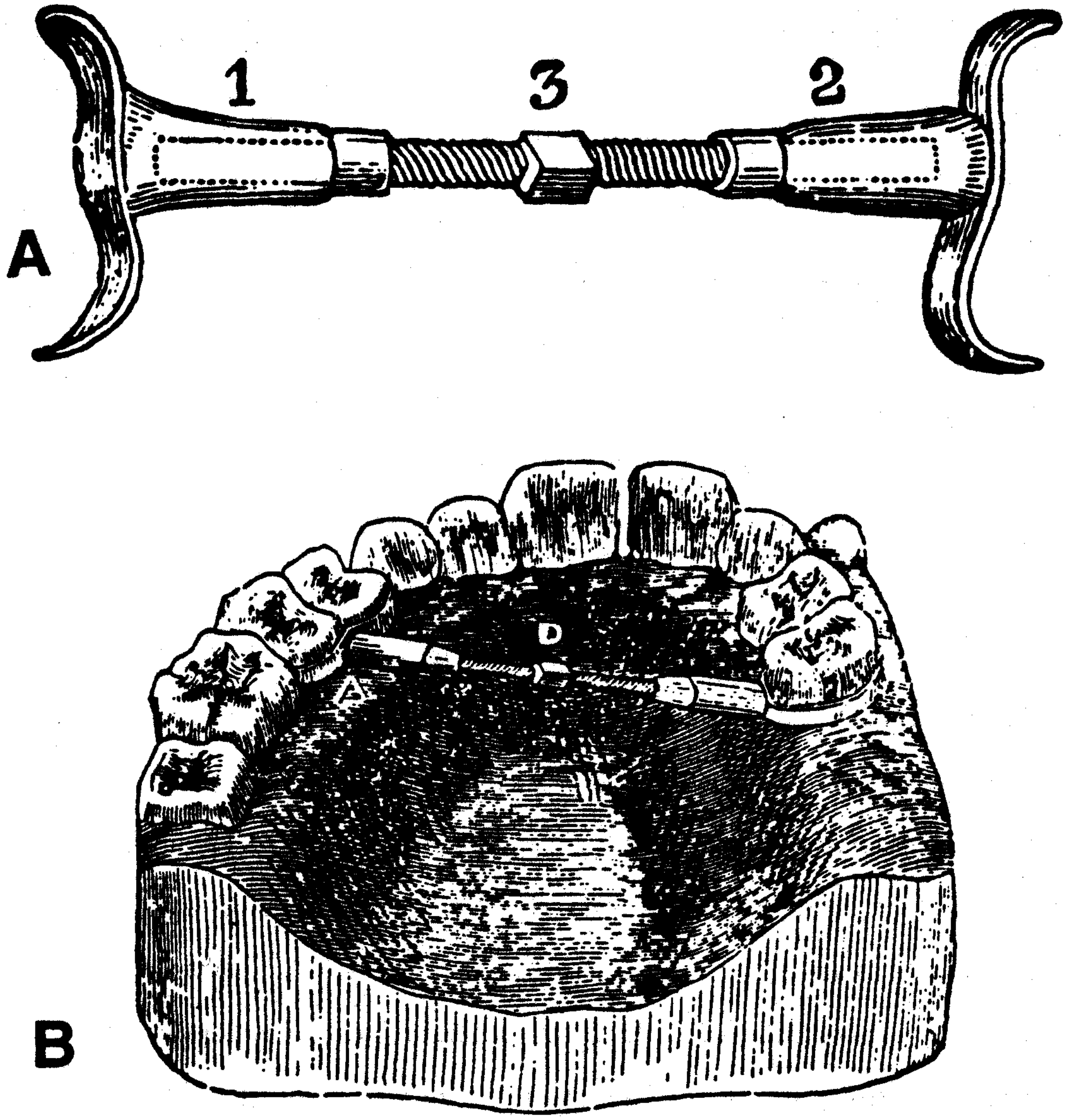


Figure 2. E.C. Angell's[2] palatal expansion appliance.
A. Palatal expansion appliance made by E.C. Angell. Note that the screw has been drawn with two right hand threads instead of a left and a right.
B. Palatal expansion appliance on cast at the completion of rapid expansion. Note the presence of a median diastema.

In a subsequent article, "Irregularities of the teeth and their treatment," Angell[3] reaffirmed his contention that the maxillary bones had separated during treatment. Furthermore, other dental surgeons and general surgeons had examined the study models illustrating the treatment change and confirmed Angell's conclusion that the maxillae had separated.

This corroboration, however, still failed to convince the influential members of the profession. Further rebuttal articles were published by the editorial board of the Dental Cosmos. The persuasive strength of the opposition to palatal expansion therapy accounted only partially for its demise. Failure to substantiate the facts anatomically also contributed to its abandonment. Professor M.H. Cryer, an influential anatomist, felt the midpalatal suture could not be opened because of the buttressing and circummaxillary structures.[106] The notable influence the functional concept of development had on the dominant powers of the orthodontic community partially accounted for the silencing of palatal expansion therapy. The functional concept of development held that if teeth were gently moved into their proper functional positions utilizing conservative orthodontic measures, bone would develop to support this movement. Abandonment of the technique in the United States became apparent by the early 20th century. The European orthodontic community continued to use this procedure during the years of American abandonment.[47,48,106]

In 1956, the palatal expansion technique was re-introduced by Professor Gustav Korkhaus, while visiting the University of Illinois, Department of Orthodontics. Through his efforts, new interest in palatal expansion therapy was revived in the United States.[48]

ANATOMICAL CONSIDERATIONS

OSTEOLOGY

The maxillae form the substance of the upper jaw and the majority of the floor and lateral walls of the nasal cavity. They are suspended from the craniofacial complex by a series of fibrous sutural articulations. The maxillae articulate with the following cranial and facial bones (Fig. 3):

Cranial Bones

1. Frontal
2. Ethmoid

Facial Bones

1. Nasal
2. Lacrimal
3. Inferior Nasal Concha
4. Vomer
5. Zygomatic
6. Palatine
7. Opposite Maxilla

These bones act to strongly buttress the maxillae at their posterior superior margins, leaving the anterior inferior margins free and vulnerable to lateral displacement.[106]

The palatal complex consists of the premaxilla, the maxillae, and the palatine bones. The premaxilla is a small, median, unpaired triangular shaped segment of bone just anterior to the incisive foramen. Enlow[37] states the maxillary-premaxillary sutures close during the first or

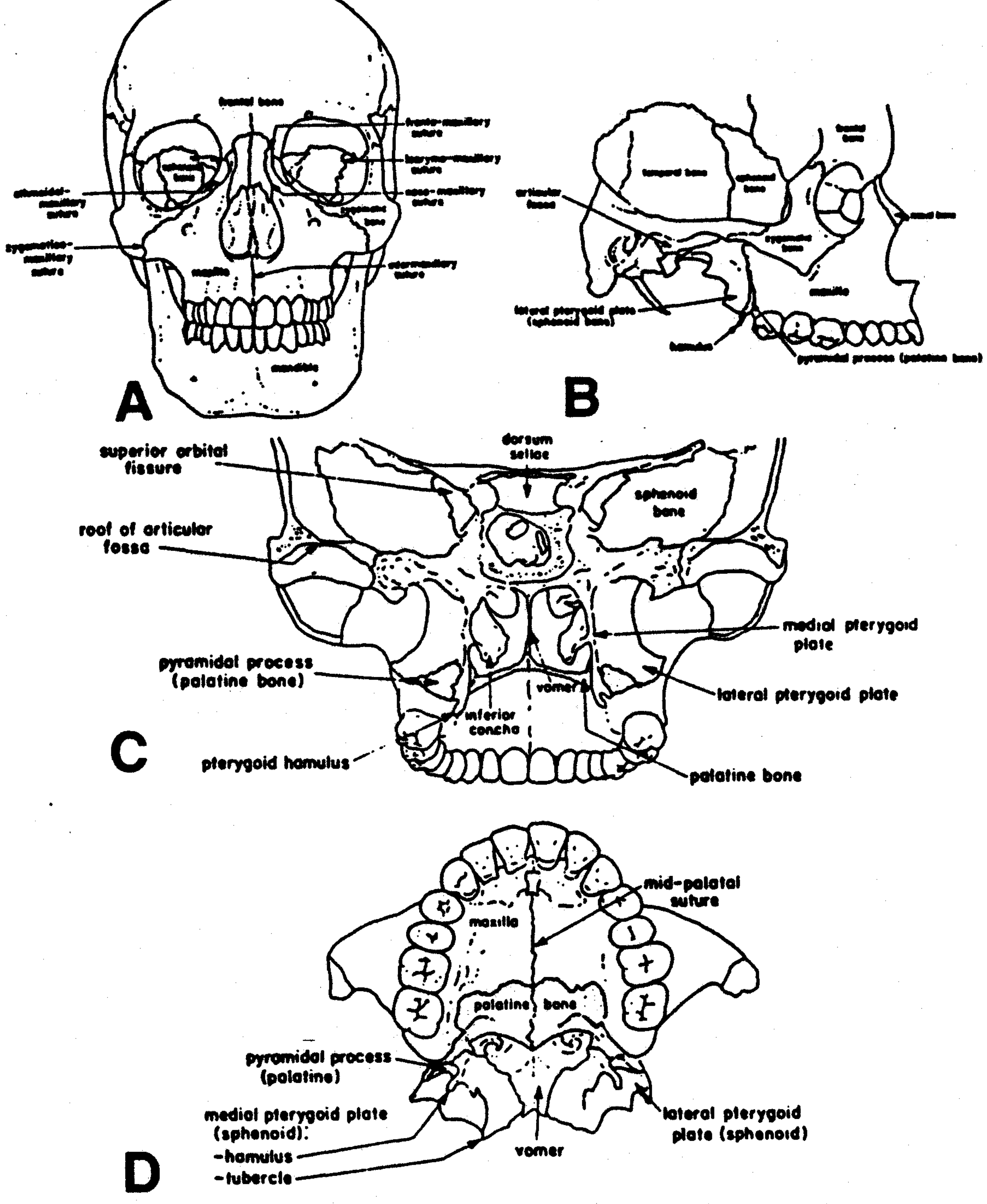


Figure 3. Circummaxillary Articulations (Bishara and Staley[14])
A. Frontal view C. Posterior view
B. Lateral view D. Inferior view

second year and ossify to form a single bone. Traces of the maxillary-premaxillary sutures in the adult are usually not evident upon anatomical inspection.[106] The paired maxillae are united in the midline by a fibrous intermaxillary sutural articulation at their palatine and alveolar processes. The paired palatine bones articulate with the posterior margins of the maxillae at the transverse palatal suture completing the hard palate or floor of the nose and lateral walls of the nasal cavity. The interpalatine suture joins the palatine bones at their horizontal plates thus forming a continuation of the intermaxillary suture which collectively is designated as the midpalatal suture.[106]

Moffet[74] has used the term "articular remodeling" to refer to a sequence of events which produce a change in the shape or location of an articular surface through cellular activity. Articular remodeling is a stimulus response phenomenon in which the stimulus is mechanical and the response is biological. The stimulus is a force which acts to compress or stretch a joint. This force may be of natural origin or it may be associated with therapeutic activities. The response consists of cellular activity resulting in both the deposition and resorption of bone and articular tissue. The magnitude and type of cellular response created by a given stimulus is dependent upon the microstructure of the articulation. The fibrous sutural joints of the circummaxillary complex are most easily remodeled because of their vascularized fibrous articular tissue. This tissue serves as microligaments which interconnect the adjacent facial and cranial bones.

SUTURAL ANATOMY

The midpalatal suture along with the other circummaxillary articulations are of importance allowing the maxillae to functionally adapt to its new environment after palatal expansion therapy is completed. Melsen[72] has studied the postnatal development of the midpalatal suture on human autopsy material and grouped it into three stages according to sutural morphology. These three stages correspond to the stages of development used by Bjork and Helm.[16] During the first stage, or "infantile period", the suture is broad and Y shaped when viewed in coronal section, with the vomerine bone being lodged in a furrow between the two maxillary bones (Fig. 4A). During the second stage, or "juvenile period", the suture is found to be more wavy following a serpentine course and longer in the vertical aspect (Fig. 4B). During the third stage, or "adolescent period", the suture is characterized by a more torturous course with increasing interdigitation forming mechanical interlocking (Fig. 4C). At this stage of development, separation of the maxillae would not be possible without fracturing the interdigitated islets of bone. Melsen stresses this later developmental characteristic of

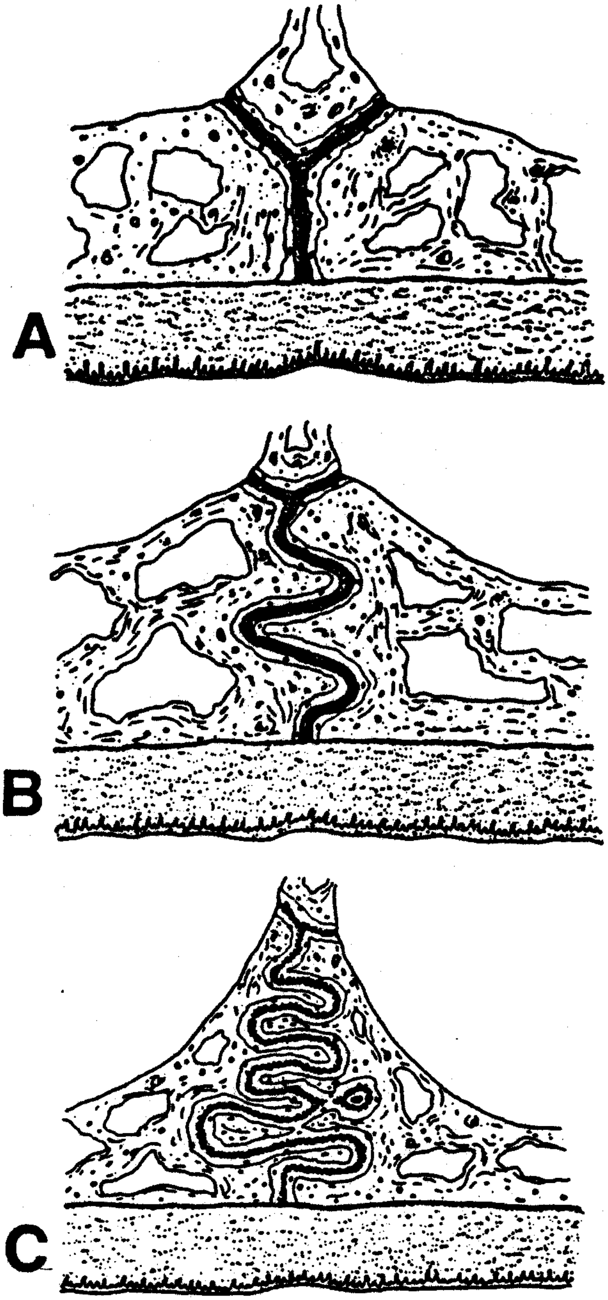


Figure 4. Diagrammatic illustrations of the development of the human midpalatal suture, viewed in coronal section with the vomer above and the palatine processes of the maxilla to the right and left. (Melsen[72])
A. Infantile
B. Juvenile
C. Adolescent to adult

interdigitation or mechanical interlocking is unique to humans. Therefore, Melsen concluded the effects of palatal expansion therapy on the midpalatal suture taken from animal experiments cannot be applied to human conditions.

Orthopedic alteration of the maxillae with the palatal expansion therapy is dependent on sutural patency. With advancing age, sutures are normally obliterated by calcified tissue (synostosis). Presently, there is much controversy over when the circummaxillary sutures close. Some researchers say that they remain patent until the middle of adult life.[86,87] Melsen[72] has stated that transverse growth of the midpalatal suture is continued up to the age of 16 in girls and 18 in boys. Bjork,[15] using tantalum implants, studied sutural growth of the upper face in a sample of Danish boys. He found that sutural growth ceased at age 17, on an average about 2 years earlier than condylar growth and growth in body height.

Persson and Thilander[87] have suggested that palatal sutures may exhibit closure during the juvenile period, but a marked degree of closure is rarely found until the third decade of life. They have also suggested that great variations exist among individuals with regard to the start of closure as well as the advance of closure with age. Intrasutural closure variations were also noted in their research. A significantly greater degree of sutural obliteration was observed on the oral side of the palatal vault when compared to the nasal side. Their further findings confirmed earlier observations that the midpalatal suture starts to close more often in its posterior part than in its anterior part.

ANATOMICAL CHANGES OCCURRING WITH PALATAL EXPANSION THERAPY

OVERVIEW

Palatal expansion therapy is intended to separate the maxillae and correct an existing disharmony between maxillary and mandibular apical denture bases. Attainment of increased maxillary apical base width is achieved through combinations of varying amounts of orthopedic and orthodontic movements. The appliance is designed to deliver a transverse biomechanical force upon activation.[11,13,24,47,48,49] The magnitude of the applied force, and the method of activation, vary with appliance design.

Initial clinical changes observed with palatal expansion therapy are lateral tipping of the maxillary posterior teeth as the periodontal soft tissues are compressed and stretched in response to the applied force. This stage of orthodontic response appears to be complete within one week.[11,26,54,101] Further orthodontic movements occur as the buccal alveolar plate remodels from the continued force application.[11,101] Orthopedic separation and repositioning of the maxillary segments occur as the applied transverse biomechanical forces surmount the bioelastic strength of sutural elements. To obtain orthopedic separation of maxillae: Storey[101] observed that 1) forces present must be sufficiently high to either exceed the tensile strength of or induce changes in the sutural connective tissue so that they no longer resist movement of bones, and 2) forces must be present which overcome the extramaxillary musculature and occlusal interdigital forces. When appliance activation is complete, the maxillae continue to translate laterally until a new dynamic equilibrium is obtained when the applied force is reduced below the tensile strength of the sutural connective tissue. Remodeling and reorganization of sutural and skeletal tissues continue during the retention period as the expanded maxillae are stabilized.[11,36,101,102]

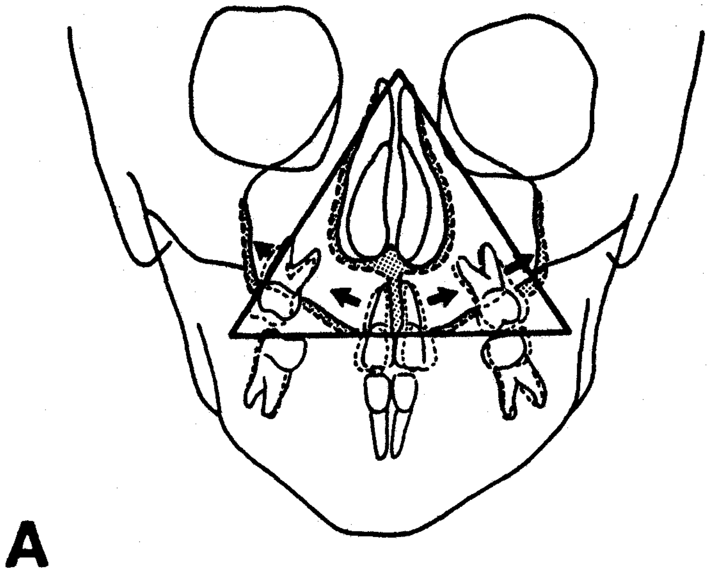
MAXILLARY SKELETAL CHANGES

The effects of palatal expansion therapy on the maxillae have led many researchers to describe a characteristic geometric pattern of maxillary separation.[11,26,36,49,54,59,101,102] The expansion pattern appears to be asymmetric which has been attributed to variations in the rigidity of the circummaxillary articulations.[11,117]

Viewed frontally, a triangular expansion pattern is noted with the apex pointed toward the nasal cavity and the base located near the incisors (Fig. 5A).[11] The palatal shelves appear to swing laterally with greater movement at the alveolar crest than at the palatal vault. Therefore, the midpalatal suture opens with a nonparallel inverted "V" pattern as the maxillae separate. Storey[101] has noted that the center of rotation for maxillary expansion from the frontal view is through the frontonasal suture.

Viewed occlusally, a triangular pattern of sutural opening has also been observed. The base of the triangle is located anteriorly in the incisor region with apex located posteriorly (Fig. 5B).[11] Therefore, the widest separation is observed anteriorly with progressively less separation posteriorly. These findings agree with Wertz[117] whose research suggested that when viewed occlusally, the midpalatal suture appeared to open in a nonparallel manner, with the widest opening at anterior nasal spine and diminishing posteriorly. These findings were also substantiated on dry skull material which underwent a simulated palatal expansion mechanotherapy.

Viewed sagittally, when the midpalatal suture opens, the maxilla moves downward and forward with concurrent downward and backward mandibular rotation. An increase in the opening of the pterygomaxillary fissure has also been demonstrated from a sagittal view. When viewed sagittally, Wertz[117] felt that a downward displacement of the maxilla was a routine finding, but a forward displacement to any degree was limited to isolated cases. Wertz also suggested that the final position of the maxilla, post-expansion, is unpredictable. He found about 50% of his sample cases demonstrated post treatment relapse during the period of



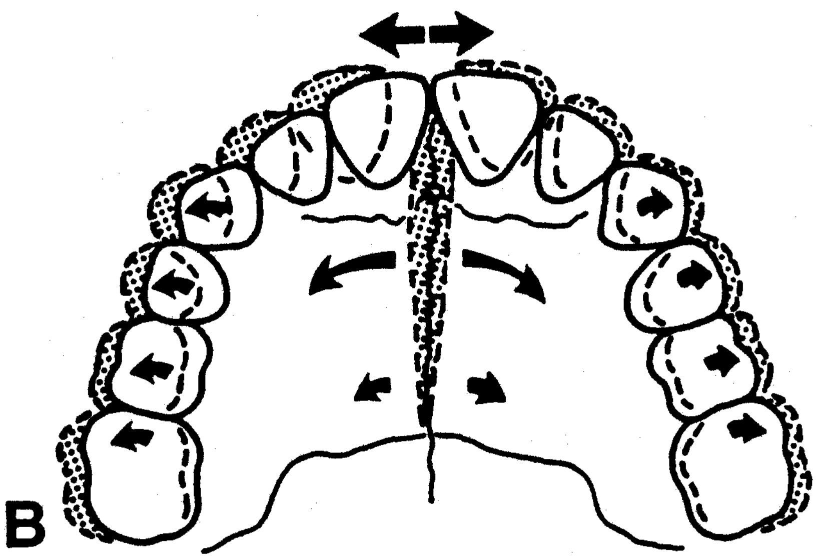


Figure 5. Geometric pattern of maxillary expansion. (Bell[11])

A. Triangular pattern of maxillary expansion in the frontal plane, includes orthopedic and orthodontic movement.

B. Occlusal view of maxillary expansion illustrating midpalatal suture opening.

stabilization.

Krebs[63,64] studied midpalatal suture expansion with the aid of metallic implants. Metal implants were inserted bilaterally in the zygomatic process of the maxilla, and in the hard palate lingual to the canines and first molars. Posteroanterior radiographs were used for measuring the distance between the implant images. Krebs evaluated the maxillary apical base expansion by measuring the distance between the implant images in the zygomatic process of the maxilla. Krebs found, upon completion of rapid expansion therapy, the maxillary apical base expansion was usually followed immediately by a slight relapse. Krebs found the distance between the zygomatic implant images to decrease by an average of 10-15% during the first 3 to 4 months of fixed retention. After an average period of 15 months, about 70% of the maxillary apical base width increase was maintained. The greatest increase in the maxillary apical base width occurred before and during puberty. After this period the effect of expansion on the maxillary apical base was smaller in relation to dental arch expansion. Krebs felt this phenomenon applied to both sexes, but at an earlier age in girls than boys, consistent with the findings of Bjork.[15,64]

Krebs[63] noted that the maxillae rotated in both the sagittal and frontal planes. In a clinical study of slow maxillary expansion using implants, Hicks[54] found that the maxillae were tipped between -1° and $+8^{\circ}$ relative to each other. Krebs explained this phenomenon by showing a greater increase between implant images in the alveolar arch than between implant images in the zygomatic process of the maxillae. Therefore, tipping of the maxillae results in less width increase at the sutural level than at the dental arch level.

Vomeromaxillary disarticulation has also been observed with maxillary separation.[47,61,106] Varying degrees of disarticulation have been reported ranging from complete to eccentric disarticulation (Fig. 6). Straightening of septal deviations has been attributed either to a downward pull on the vomer during palatal expansion, or, to bony freedom if complete vomeromaxillary disarticulation occurs.[106]

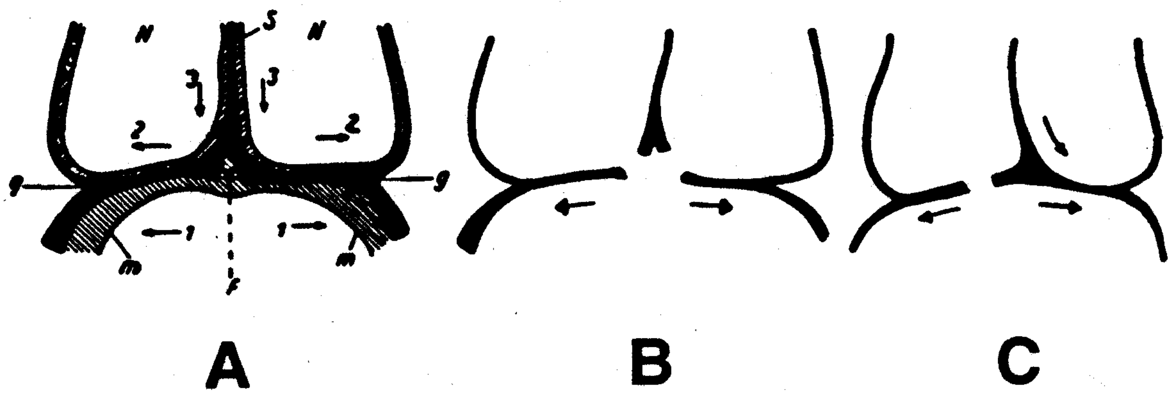


Figure 6. Illustration of the widening process of the midpalatal suture viewed in coronal section. (Korkhaus[61])
A. Normal vomeromaxillary articulation.
B. Centric vomeromaxillary disarticulation.
C. Eccentric vomeromaxillary disarticulation.

Changes in palatal vault morphology have been reported by Haas.[49] As a result of the angular displacement of the maxillae, Haas suggests that the palatine processes of the maxillae are lowered. This finding is contrary to Davis and Kronman[27] who reported that the height of the palatal vault does not decrease with palatal expansion.

SUTURAL CHANGES

The effects of palatal expansion therapy on the sutures have been studied by histologic examination of autopsy material from experimental animals and humans. Melsen[72] reported a different human sutural morphology when compared to animals, as was previously noted. This difference accounts for difficulty when drawing inferences from experimental animal studies.

Ten Cate and associates[102] have examined the effects of rapid palatal expansion on the sutural development and structure of the albino rat. Their experimental study has suggested a sequence of sutural adaptation to rapid palatal expansion. An initial inflammatory response is set up within the suture as a result of the applied force. The next sutural response is one of osteogenesis and fibrillogenesis, followed finally by remodeling. The basic mechanism of sutural adaptation to palatal expansion involves injury followed by a proliferative repair phenomenon, and further fibroblastic remodeling ultimately leads to regeneration of the suture. Programmed cell death has also been reported to be an integral feature in sutural development.

Melsen[71] described the effect of rapid palatal expansion in man in relation to the morphology of the midpalatal suture at different ages and gave a histological analysis of the healing process at various time intervals. Melsen reported a true stimulation of sutural growth was found only in children who had not attained maximum pubertal growth. In older individuals, expansion was attended by numerous microfractures in the sutural region. Melsen attributed this fact to the strong interdigitation of the bone processes, which prevents the two halves of the suture from separating without microfractures in the suture line (Fig. 4C). The post-traumatic reaction around these microfractures is of significance for the course of healing. The formation of bone bridges between the two halves of the maxilla was observed, thus preventing further growth in the suture from taking place.

Ekstrom and associates[36] have examined in vivo the mineralization in the midpalatal suture after rapid palatal expansion. Their findings suggest that after 3 months post-expansion, the process of mineralization in the expanded suture has become fairly well established. These findings provide possible contributory support to Krebs'[64] research showing an initial immediate relapse of the expanded maxillae due to the presence of immature sutural connective tissue elements found immediately post-expansion.

MAXILLARY DENTOALVEOLAR CHANGES

The maxillary alveolar processes are found to bend laterally as the teeth tip within the alveoli, and the mucoperiosteum of the palate stretches in response to the expansile force. Continued remodeling of the buccal alveolar plate occurs until the applied transverse force dissipates. Zimring and Isaacson[120] suggest residual loads acting upon the appliance at the end of the active expansion phase of treatment were shown to entirely dissipate within a five to seven week period. Furthermore, any residual forces present in the displaced tissues after stabilization will act on the alveolar processes causing them to rebound.[106] To compensate for the alveolar bending and dental tipping, and to allow for subsequent uprighting of the buccal teeth, Haas[48] suggests the need for overcorrection of the apical base discrepancy.

The force of expansion is applied directly to the dentition which will move laterally along with their respective maxilla as will the teeth not held by the appliance. This movement is basically rotational, and the teeth will gradually increase their buccal inclination to a degree consistent with the rigidity of the appliance.[106] Hicks[54] reported that the lateral tipping of the posterior teeth appeared to be a prominent factor contributing to dental arch width change observed during the first week of expansion. This tipping is usually accompanied by some degree of extrusion. Therefore, the change in inclination of the posterior teeth during expansion is due to a combination of alveolar bending and dental tipping.

The recoil tendency of the periodontal and palatal tissues, occlusal interdigitation, as well as the effect of buccal musculature, are considered significant factors in returning the expanded posterior teeth to their original inclination once retention is discontinued.[11,54,76,101]

Davis and Kronman[27] have reported significant increase in maxillary intermolar and intercanine width after palatal expansion. An average maxillary intermolar width increase of 6.7 mm., and average maxillary intercanine increase of 3.6 mm. were reported. Their findings illustrate that the maxillary intermolar width increases to a greater degree than the intercanine width. The mandibular intermolar and intercanine width had a tendency to follow their maxillary counterparts.

Krebs[64] has shown that width of the maxillary dental arch was greatly increased by rapid expansion therapy, but the gain in many cases was not stable. Krebs' findings indicate a steady decrease in dental arch width up to 5 years after the treatment. Krebs also noted that the gain in dental arch width remained stable while a fixed retention plate was worn.

Krebs'[64] findings were in agreement with those of

Linder-Aronson and Lindgren. Linder-Aronson and Lindgren[68] reported that at 5 years post-retention, 45% of the increase in maxillary intermolar width initially achieved by rapid palatal expansion was maintained. The mean final increase in the maxillary intercanine width was only 23% of that initially achieved by rapid palatal expansion.

When the midpalatal suture opens, a transient midline diastema between the maxillary central incisors is clinically evident (Fig. 7). The midline diastema will continue to increase until the active expansion is completed.

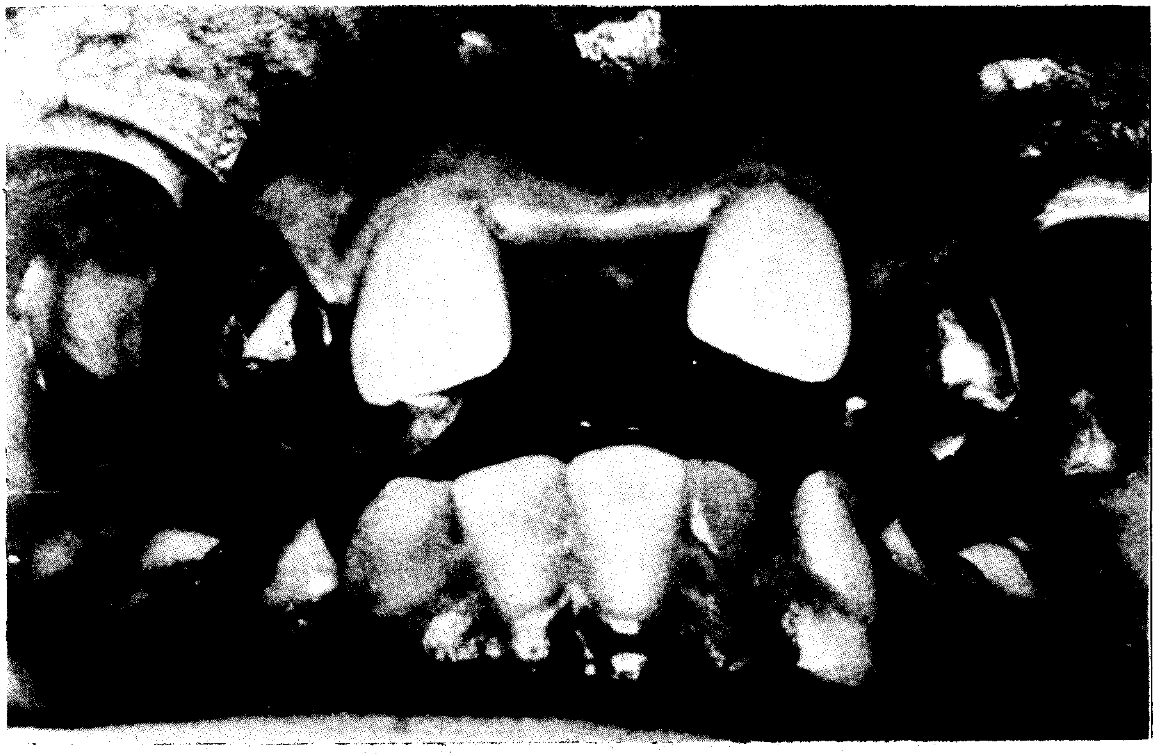


Figure 7. Superior median diastema accompanying palatal expansion therapy. (Timms[106])

Wertz[117] suggests the amount of separation between the central incisors should not be used as an indication of the amount of suture separation. If the central incisors are not included in the appliance, these teeth will return to their original position under the elastic recoil of the transeptal fibers.[48,106] Therefore, bioelastic activity of the stretched periodontal and palatal tissues restores normal incisor alignment through mesially oriented up-righting movements.[11,76,101]

The maxillary central incisors have also been reported to extrude and upright with expansion. The up-righting of the incisors is thought to be a response caused by the stretched circumoral musculature.[48,117]

MAXILLARY PERIODONTAL CHANGES

During palatal expansion therapy, considerable load is transmitted to the dentition and circummaxillary suture system.[59] The reactions to the applied force in the buccal periodontium have been considered by some researchers as having greater implication in terms of the longevity of the dentition.[45] Anatomically, the buccal alveolar plate is thin and therefore vulnerable to destruction upon lateral expansion.

Greenbaum and Zachrisson[45] examined the periodontal tissues present at the buccal aspect of the maxillary first molar in post-orthodontic patients who had undergone palatal expansion. They further classified the sample into slow expansion therapy performed with a quad helix appliance and rapid expansion therapy performed with a Haas appliance. Greenbaum and Zachrisson reported that whatever the movement pattern experienced by the dentition involved, the post-treatment degenerative changes of the buccal tissues appear to be minimal when compared with similar tissue not exposed to the forces of palatal expansion therapy.

The stretched palatal mucoperiosteum that accompanies palatal expansion therapy has been considered by some researchers as contributing to the relapse tendency of the expanded maxillae.[26,76] Muguerza and Shapiro[76] attempted to relieve the stretch of the mucoperiosteum after slow expansion by making incisions along the palate down to the cortical bone 3 to 4 mm. lingual to the free gingival margins of the posterior teeth. Their findings suggested that these release incisions did not effectively reduce the relapse tendency.

Barber and Sims[4] have investigated the effects of rapid palatal expansion on the external root structure of teeth directly attached and unattached to the expansion appliance via scanning electron microscope. They reported all directly attached premolars exhibited active root resorption which was primarily confined to the buccal surface. Generally, the longer the directly attached tooth remained in fixed retention, the more extensive the buccal root resorption. In contrast, unattached neighboring teeth showed no evidence of root resorption. Repair by deposition of cellular cementum followed the active resorption which could be observed even after 9 months of retention.

MANDIBULAR SKELETAL CHANGES

With palatal expansion therapy, the maxillae swing laterally, the alveolar processes bend outward, and the posterior teeth tip buccally disrupting the occlusion. Furthermore, the maxilla is observed to move downward and forward with a concomitant tendency for downward and backward mandibular rotation. This new mandibular position decreases the effective length of the mandible and increases the vertical dimension of the lower face.[47,48,49] Therefore, the combination of maxillary skeletal and dental displacement contributes to the downward and backward mandibular rotation and opening of the mandibular plane.[14,27] Wertz[117] however, reported that mandibular displacement and subsequent recovery were usually noted in the post-expansion phase.

MANDIBULAR DENTOALVEOLAR CHANGES

With palatal expansion therapy, the maxillary molars have been observed to expand laterally and thereby increase the maxillary dental arch width.[11,14,47,64,68] Some researchers report that the mandibular molars have a tendency to follow the maxillary molar expansion and upright.[27,46,47,48,49] Haas[47] explains this phenomenon with the following hypotheses:

1. Occlusal forces were altered by the expansion so that the normal lingual force vector exerted on the mandibular buccal teeth was lost.

2. Lateral movement of the maxilla carried the attached buccal musculature with it and therefore diminishing its influence on the mandibular buccal teeth, thereby allowing the tongue musculature to exert a disproportionate force.

3. The expansion appliance thickness caused a downward displacement of the tongue and increased its lateral force on the adjacent mandibular buccal teeth.

Gryson[46] recorded changes in maxillary and mandibular intercanine and intermolar width before and after rapid expansion therapy. The sample consisted of 38 patients, ranging in age between 6 and 13 years. Gryson reported an insignificant mean increase in mandibular intercanine distance of 0.2 mm. A significant mean increase in the mandibular intermolar width of 0.4 mm. was reported. Gryson explained an insignificant increase in mandibular intercanine width and a significant increase in mandibular intermolar width to be attributed to the theory that lower arch expansion is the result of occlusal forces uprighting the teeth, in agreement with Haas.[47,48,49] Gryson concluded there was no correlation between the change in mandibular intercanine and intermolar distance with respect to the increase in maxillary intercanine and intermolar distance. Gryson also concluded that the influence of rapid palatal expansion upon the mandibular dentition appears to be minimal, owing itself primarily to the altered occlusal interdigital forces uprighting the teeth.

FUNCTIONAL CHANGES OCCURRING WITH PALATAL EXPANSION THERAPY

In association with palatal expansion, various functional changes have been reported in the literature. An increase in nasal width has been demonstrated by many researchers as a response to rapid palatal expansion.[11,14,47,48,49,61,63,64,104,116,117]

Anatomically, immediately following rapid palatal expansion there is an increase in the width of the nasal cavity adjacent to the midpalatal suture.[14,47,48,49,117] The maxillae move laterally and thereby move the outer walls of the nasal cavity laterally. The net effect is to increase the intranasal capacity. Bishara and Staley[14] have reported that the nasal cavity width gain averages 1.9 mm. but can widen as much as 8 to 10 mm. at the level of the inferior turbinates.

Hershey and associates[53] reported a reduction of nasal airway resistance by an average of 45% to 53% with rapid palatal expansion therapy. This reduction was maintained even after appliance removal. Warren[114] suggests that although the average internasal width increase is small, the aerodynamic functional change is considerable. Airflow varies inversely as the fourth power of the radius of the tube through which it passes. Therefore, a geometric increase in airflow is observed with minimal increase in anatomical separation.

Wertz[116] examined the effect of rapid palatal expansion on nasal respiration in two groups. One group had difficulty in nasal respiration, and the other group had normal nasal respiration. He reported that the group exhibiting breathing difficulty before treatment, only one of four experienced an increase in nasal airflow, and the other three exhibited a mild decrease. The group with no difficulty in respiration experienced either a mild increase or a mild decrease in nasal airflow. Wertz concluded that opening the midpalatal suture for the purpose of increasing nasal permeability cannot be justified unless the obstruction is shown to be in the lower anterior portion of the nasal cavity and is accompanied by a maxillary arch width deficiency.

Timms[106] suggests that altering the mode of respiration from oral breathing to nasal breathing with rapid palatal expansion therapy may help to correct the etiology of many deep-seated afflictions. Timms suggests the patient should always be viewed from both medical and dental standpoints when considering palatal expansion therapy. Timms concluded that in certain instances, respiration may be the primary or even only reason for carrying out rapid palatal expansion therapy. Warren and associates[115] have studied the nasal airway following rapid maxillary expansion. Their findings suggest that maxillary expansion for airway purposes alone is not justified, contrary to Timms' conclusion.

Another consideration which may account for the increased nasal airway resistance in children may be enlarged lymphoid tissue blocking off the nasopharyngeal airway. Spontaneous regression of lymphoid tissue during growth will improve nasal breathing irrespective of palatal alteration.[14]

Other functional changes have been observed with palatal expansion therapy. Increasing the maxillary arch width thereby correcting a bilateral functional posterior crossbite may allow for generating more normal mandibular movement patterns, avoiding functional shifts, and aid in establishment of symmetrical temporomandibular relationships. Expansion of the deciduous dentition, correcting transverse dental and skeletal disharmonies, has been found to encourage a favorable eruption pattern of the underlying permanent dentition. Furthermore, the long-term benefits of achieving more harmonious skeletal and dental relationships may minimize deliterious anatomic and functional growth factors.[11]

TREATMENT VARIABLES WITH PALATAL EXPANSION THERAPY

Treatment variables as they relate to palatal expansion therapy have been discussed by many researchers.[11,14,26,35,47,49,54,58,59,106] The relative amounts of skeletal versus dental changes accompanying palatal expansion therapy are primarily related to the following treatment variables:

Patient's age
Rate of expansion
Magnitude of applied transverse force
Retention protocol
Appliance design

PATIENT'S AGE

The patient's age is a critical factor when determining if palatal expansion therapy can be attempted non-surgically. The individual's skeletal age (biologic maturity) must be assessed prior to initiating conventional palatal expansion treatment. Clinicians have commonly reported difficulty separating the maxillae in post-pubertal individuals.[11,47,48,49,54,63,64]

With increasing age, numerous mechanical interlockings (bridging of bone spicules across the suture) are woven into the circummaxillary suture system providing increased resistance to expansion. Thus, palatal expansion in both adolescents and adults may involve fracturing of the bony sutural interdigitations.[49,59,71,72,106]

Enhanced skeletal response in younger age groups has been associated with a greater cellular activity in the growing suture.[11,26,101,102] Brin and associates[19] utilizing cyclic nucleotides as indicators of cellular activity and new bone formation, have reported sutural bone cells of young cats were more responsive to palatal expansion forces than that of corresponding cells of older animals. Melsen[72] cautions that interpretation and human application of this data may be difficult due to different existing sutural morphology.

Timms[106] reports that an age effect operates insofar as the fulcrum line of maxillary separation is nearer to the activating force with increased years. In young children, the fulcrum may be as high as the frontonasal suture,[101] while in adolescence it is much lower, even producing a pivotal effect with portions above the fulcrum moving slightly medially.[84,106]

Krebs[64] reported that the greatest increase in maxillary apical base (skeletal change) occurred before puberty. After this period, the effect of the expansion on the maxillary apical base was smaller in relation to the widening of the dental arch (dental change). Therefore, there is a tendency for the effect of expansion therapy on the maxillary apical base to decrease with age; this applies to both sexes, but at an earlier age in girls than boys. These findings are consistent with Bjork[15] who has shown that with normal growth, increase in maxillary width ceased at 16 to 17 years of age for boys, whereas for girls, it had ceased as early as at 14 years.

Bishara and Staley[14] suggest the optimal age for expansion is before 13 to 15 years. Although it is possible to accomplish expansion in older patients, the results are neither as predictable nor as stable.

RATE OF EXPANSION

The rate of palatal expansion has been investigated by numerous researchers.[11,14,26,47,49,54,63,64,76,98,102,106,117] Presently, there are two schools of thought concerning the rate of palatal expansion, rapid vs. slow. The skeletal and dental effects of rapid and slow expansion therapy have been documented histologically, radiographically, and clinically for both human and nonhuman primates. Considerable controversy remains as to which rate should be followed during the expansion procedure.

The vast majority of rapid expansion procedures utilize an expansion screw device for generating and transferring force from the appliance to the maxillae and circummaxillary suture system. The rapid expansion procedure occurs at an activation rate of 0.2 to 0.5 mm. per day. The period of active treatment is from one to four weeks.[11,14,47,48,49,59,63,106,117] The activation schedule is most often determined on an empirical basis, dependent on the desired amount of expansion and the patient's tolerance to the increased load.[11]

Isaacson and Ingram[59] have reported that a single activation of the expansion screw produced from about 3 to 10 pounds of force in the patients under observation. Furthermore, expansion forces as high as 22.5 lbs. were recorded in one of the older patients in this study. Their findings suggested that there is significant increasing resistance to expansion with increasing maturity and age. Thus, with multiple daily activations, cumulative force loads of 20 pounds or more were present. Advocates of the rapid procedures believe that these high magnitude forces maximize the orthopedic effect by overwhelming sutural connective tissue before substantial orthodontic movement can occur. Therefore, the net effect of the rapid palatal expansion procedure is to maximize the skeletal displacement and minimize the dental displacement (tipping). Clinically, Krebs[64] has reported that with rapid palatal expansion therapy, approximately one-third to one-half the achieved maxillary arch width increase is due to skeletal separation, with the remainder being of dental origin.

The histologic picture of the rapidly expanding sutural tissue shows free floating bone fragments, numerous microfractures,[11,71] cystlike formations,[101] highly vascular disorganized connective tissue of an inflammatory nature,[19,71,101] and dystrophic ossification with immature bone tissue.[36,71] Storey[101] reported that rapid palatal expansion creates tears in the collagenous fiber network of the suture and ultimately results in a less than desirable skeletal response at the sutural bony margins. With rapid expansion procedures, sufficient retention periods are necessary to allow for residual force dissipation, remodeling, and reorganization of the sutural and bony elements. Suggested retentive periods are 3 to 6 months.[36,61,63,64,101,117] However, some researchers have recommended even longer retentive periods.[21,47-50,105]

Slow expansion procedures employ lingual arch or removable plate appliances with expansive capability. The slow expansion procedure occurs at a rate of 0.4 mm. to 1.1 mm. per week. The period of active treatment is usually from two to six months.[14] The force systems incorporated in slow expansion procedures vary from several ounces up to two pounds.[11] Slow expansion procedures utilize a much lower force range and slower activation schedules than rapid expansion procedures. These two factors account for the decreased likelihood of generating cumulative forces by allowing increased time intervals between activations, thereby enhancing the force dissipation process.

Orthopedic separation of the maxillae has been documented by researchers using the slow expansion procedures.[10,54,98,101] However, with slow expansion procedures we find an increased likelihood of orthodontic movements as the tensile strength of suture is not overpowered.[11,54,101] Clinically, slow expansion procedures are reported to achieve a more favorable skeletal response in younger age groups with deciduous and mixed dentitions.[11]

Skieller[98] studied the skeletal and dental changes occurring with slow palatal expansion. Skieller accessed the increase in width of the maxillary apical base by measuring the distance between images of metallic implants inserted in the upper jaw obtained from serial postero-anterior radiographs. Skieller employed a removable expansion plate which was activated two times per week for an expansion rate of 0.5 mm. per week. Skieller reported that approximately 20% of the arch width increase was due to orthopedic separation of the midpalatal suture; the rest was accounted for by tooth movement. Significant increased growth at the midpalatal suture was also reported associated with slow palatal expansion therapy. Furthermore, the greatest effect on sutural growth for girls occurred during the pubertal growth spurt.

Hicks,[27] in a clinical study using 2 lb. forces with expansion rates of 0.4 mm. to 1.1 mm. per week over 8 to 13 weeks, reported that skeletal separation of the maxillae accounted for 24 to 30% of the linear dental arch width increases in 10 to 11 year old patients, and 16% in the 14 to 15 year old patients. These values were lower than those reported in an experimental study which found that skeletal increase accounted for 45 to 64% of the total increase in dental arch width.[26] Variability between humans and monkeys in sutural morphology,[72] biologic responsiveness, and load distribution to the facial skeleton may account for this difference.[27]

The histologic picture of the slowly expanded suture suggests that the separation rate of the maxillae allows for the maintenance of sutural tissue integrity during maxillary repositioning and remodeling.[11,26,36,54,101] Storey[101] suggests an expansion rate of 0.5 to 1 mm. per week at the nasal aspect of the midpalatal suture permits physiologic sutural adjustments. Storey feels this expansion rate will allow bone of sufficient maturity to maintain permanent retention of the changed bony relations and allow for sufficient adaptation of the soft tissue matrices. In addition to the maintenance of sutural integrity, other advantages of slow maxillary expansion include: reduced residual stress loads within the expanded maxillae,[59,61] reduced evidence of abutment tooth tipping,[54] and empirical clinical observations of reduced skeletal relapse potential.[11,26,54,59,61,101] Retention periods of 3 months or less appear adequate following slow maxillary expansion to allow for sutural regeneration and stabilization of the separated maxillae.[10,11,36,54,101]

Timms[106] reports that when comparing slow and rapid maxillary expansion basal bone displacement, it is necessary to understand where the anatomical points of rotation are located. With slow expansion, the buccal teeth rotate about their apex which moves the buccal alveolar plate laterally and gives the erroneous impression of widening the apical base (Fig. 8A). With rapid expansion, the buccal teeth rotate about a point high in the maxilla, which moves the buccal alveolar plate laterally and actually widens the maxillary apical base (Fig. 8B).

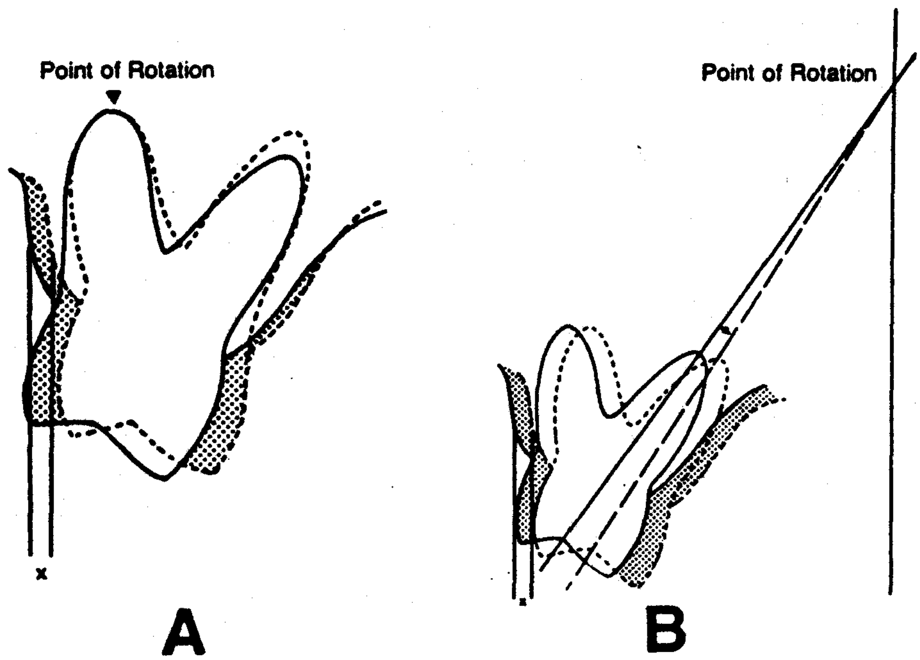


Figure 8. Illustration of the orthopedic and orthodontic movement observed with slow and rapid palatal expansion therapy. Both forms move the buccal plate (x) and give the impression of widening the apical base, which is erroneous in slow expansion. (Timms[106])
A. Slow expansion - tooth rotating about itself.
B. Rapid expansion - tooth rotating with maxilla.

MAGNITUDE OF APPLIED TRANSVERSE FORCE

Varying degrees of orthopedic and orthodontic forces are present when employing palatal expansion appliances. The magnitude of the applied force delivered by the palatal expansion appliance is dependent upon appliance design.

Isaacson and Ingram[59] and Zimring and Isaacson,[120] in a series of experiments, used dynamometers in the expansion appliances to measure the forces produced by rapid maxillary expansion. Isaacson and Ingram[59] have shown that one activation of the Haas expansion screw appliance produced from 3 to 10 pounds of force (Fig. 9). They have also shown that a smaller load was produced per activation in younger patients as compared with more mature patients. In general, greater forces were generated in the higher age groups with values ranging from 10 to 22 pounds. These findings suggest the facial skeleton increases its resistance to expansion significantly with increasing maturity and age.

During the phase of active expansion, using a Haas expansion screw appliance, it has been shown that the maximum load produced by any single activation occurs immediately at the time of appliance activation and begins to dissipate soon thereafter. Intratreatment accumulation of residual loads soon develops due to the progressive failure of preceding loads to fully dissipate in the interval between activations (Fig. 9A). Furthermore, incremental loads produced by a single activation remained quite consistent throughout active treatment irrespective of the total load on the appliance at the time of activation. The facial skeleton offers resistance to expansion and does not respond to appliance activation by immediate movement, but rather, the load is stored as potential energy in the appliance itself. An apparent age differential was also noted, and it was observed that older individuals required more time between activations to fully dissipate loads produced by the appliance (Fig. 9B). Progressive failure of succeeding loads to fully dissipate between activation results in accumulation of residual loads. The residual loads acting upon the appliance at the end of active expansion have been shown to dissipate within a 5 to 7 week period. This allows for new circummaxillary equilibrium to be attained during the post expansion phase.[59,120]

Marcotti[69] has experimentally examined the transverse changes in the maxillae due to different points of force application. The findings reported indicate that the pattern of lateral displacement is related to the position of the lateral force in relation to the center of resistance of each maxilla. The anteroposterior position of the force used in sutural expansion produces different effects on the maxilla. It was noted that when the expansile force was located nearly opposite to the center of resistance of the maxilla, the bony segments were displaced

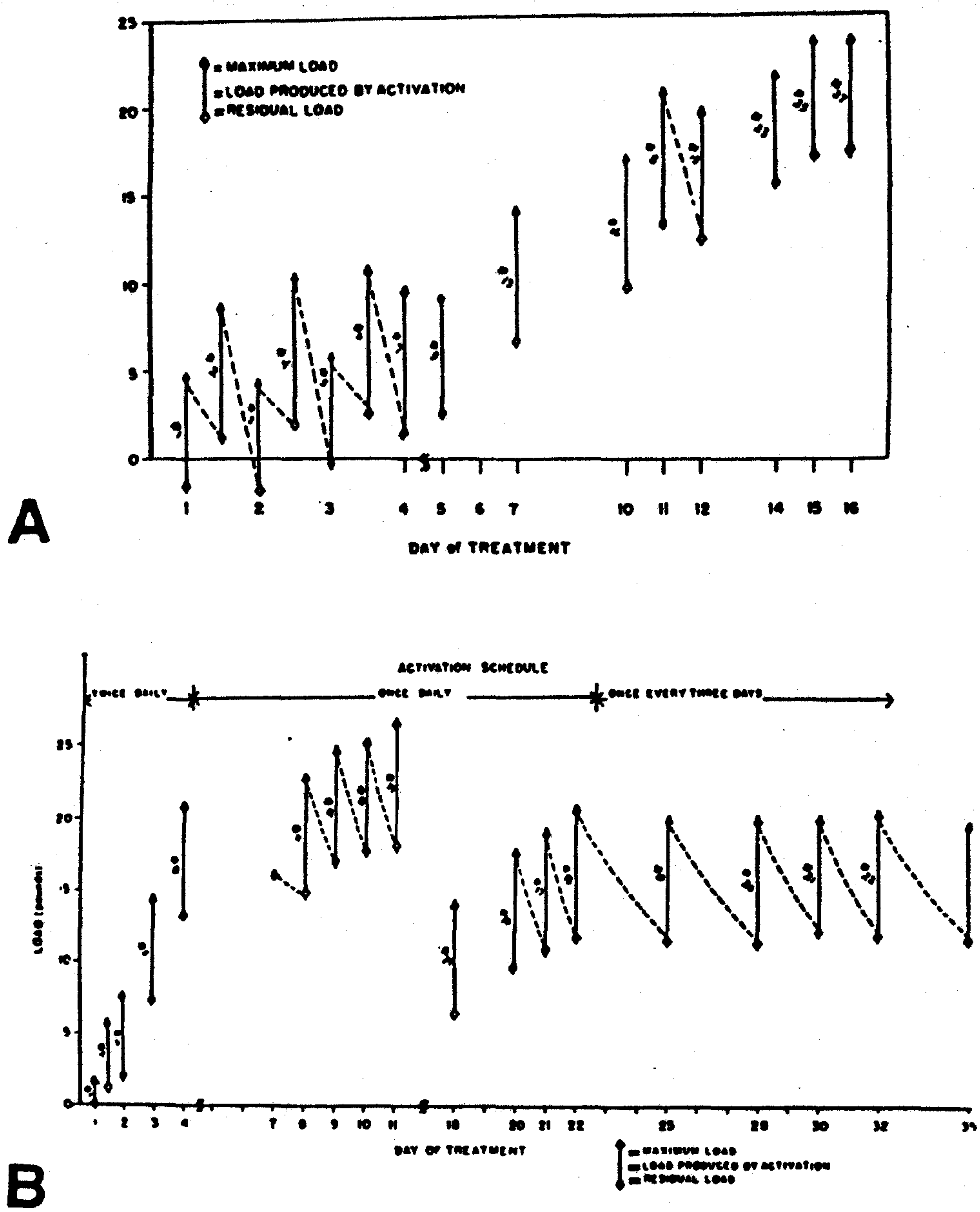


Figure 9. Diagrams illustrating the magnitude of applied transverse force during rapid palatal expansion therapy. (Zimring and Isaacson[120])

A. Summary of forces produced during activation of 13 year old male patient. Note the constancy of increment of load produced by each activation.

B. Summary of forces produced during activation of 15½ year old female patient. Notice the rapid accumulation of forces on a twice daily activation schedule followed for the first four days of treatment.

in a nearly parallel fashion (translation). The experimentally determined center of resistance of the maxilla was found to be located between the deciduous molars or between permanent premolars. When the expansile force was located in a anteroposterior position not through the center of resistance of the maxilla, variable amounts of regional separation of the maxilla were observed. Therefore, arbitrary anteroposterior positioning of the palatal expansion unit may produce undesirable regional separation of the maxillae.

Chaconas and Caputo[24] have examined the distribution of stress exerted by various palatal expansion appliances through the craniofacial complex using a three dimensional anatomical model. They reported that stresses produced by the fixed expansion appliances were concentrated in the anterior region of the palate, progressing posteriorly toward the palatine bones. These stresses were observed to radiate superiorly along the perpendicular plate of the palatine bone to deeper anatomic structures, such as the pterygoid plates of the sphenoid, the zygomatic, nasal, and lacrimal bones. Removable expansion appliances were observed to exhibit similar stress characteristics. However, increased activation decreased retention of the appliance and lessened the observable stress.

RETENTION PROTOCOL

A stable maxillary complex is not achieved until the residual forces which tend to collapse the expanded maxillae are dissipated.[11,36,61,101] Insufficient retention periods have resulted in substantial skeletal relapse.[11,101,104] Hicks[54] observed that the amount of relapse is related to the method of retention after expansion. In a clinical study of slow palatal expansion, Hicks reported that relapse amounts of 10 to 23% of expansion with fixed retention, 22 to 25% with removable retention, and 45% with no retention. Other research similarly has indicated more favorable relapse control with fixed retention appliances following palatal expansion.[26,47-50,61,117] Krebs[64] found that after fixed retention was discontinued, there was a substantial reduction in dental arch width which continued for up to 5 years. Krebs also noted that the increase in width of the maxillary apical base was not lost by relapse.

Retention periods of 3 to 6 months are normally recommended to allow for reorganization and stabilization of the rapidly expanded maxillae.[11,36,61,63,64,102,117] Some researchers suggest even longer retention periods following rapid palatal expansion.[21,47-50,105] The maintenance of sutural integrity and reduced stress loads within the tissues, indicating a reduced skeletal relapse potential, have been empirically observed with slow palatal expansion.[11,26,59,61,101] Retention periods of three months or less have been reported to be adequate allowing sutural regeneration and stabilization following slow palatal expansion therapy.[10,11,36,54,101]

The expansion unit is stabilized when active expansion is completed. The appliance which was used in the expansion procedure is the most common retention device. Haas[47] suggests the use of a quick cure acrylic palate following the removal of the stabilized appliance. The acrylic palate is constructed to be loose fitting, thus it stimulates the patient to subconsciously place the tongue against it. This aids in retraining the tongue to assume a more normal posture which it was unable to do previously in the constricted maxillary arch.

APPLIANCE DESIGN

Angell[2] in 1860 performed palatal expansion with a relatively simple screw type appliance (Fig. 2). Timms[106] commented on Angell's simple appliance design by stating, "This does not mean that it cannot be improved or that improvements are unnecessary." Researchers have proposed a variety of palatal expansion appliance designs, each meeting with varying degrees of success. The concept of controlled lateral expansion remains the chief concern of palatal expansion appliance design.

Timms[106] suggests a list of criteria as an objective approach to appliance design which is based on the biomechanical requirements of palatal expansion therapy. Ranking them in descending order of importance, the criterion list is as follows:

1. Rigidity:

Resistance to rotation is given top priority due to the considerable load that is transmitted by the appliance. A rigid appliance maximizes orthopedic movements while minimizing orthodontic movements. Some researchers recommend the use of cast metal cap splints for fixed tooth attachments rather than orthodontic bands.[20,22,55,106] The cap splints are inherently more rigid being composed of cast metal. The cap splints also increase the appliance contact area on the abutment teeth which adds to the appliance rigidity. When orthodontic bands are used for appliance retention, some rigidity is sacrificed due to the flexibility of the orthodontic band material and the decreased contact area on the abutment teeth.

2. Tooth Utilization:

The number of teeth incorporated in the appliance design directly affects the load distribution and the retention of the appliance. As the number of teeth incorporated in the design increases, the load distribution varies directly with the increased periodontal surface area. This reduces the likelihood of isolating load at specific points by permitting it to be distributed over a wider area. The appliance retention varies directly with the number of abutment teeth incorporated in the appliance design. However, as the number of abutment teeth increases, the difficulty in obtaining a path of insertion for the appliance is significantly increased. The appliance retention is also dependent on a number of other factors: the adhesion between the appliance and the abutment teeth, the precision of appliance fit, and the shape of the clinical crowns. These factors may alter the selection of fixed tooth attachments chosen for the design.

3. Expansion Unit:

The expansion unit used for palatal expansion may be a screw, spring, lingual arch wire, or a magnet. A screw device must be selected to be of sufficient length to complete the expansion without interruption. Isaacson and Ingram[59] have shown that a single activation of an expansion screw produced between 3 to 10 pounds of force; therefore, the screw expansion unit is capable of delivering orthopedic loads. Spring appliances have also been shown to deliver forces within the orthopedic range.[24,81,82] However, Timms[106] suggests that spring expansion units reduce rigidity and control.

4. Economy:

The appliance design should be one which minimizes clinical chair time and is least intrusive on the oral space. Furthermore, the appliance should be designed so that it can be simply fabricated out of readily accessible materials.

5. Hygiene:

Timms[106] gives hygiene the lowest priority on the appliance design criterion list. It is suggested that any deleterious effects seen with the palatal expansion appliance are superficial and reversible in well-managed patients.

EXPANSION UNIT DESIGN VARIATIONS

The expansion unit is responsible for transferring the transverse biomechanical force to the maxillae during expansion as well as maintaining the incremental increase previously attained. Four expansion units have been incorporated in palatal expansion appliance design:

Expansion Screw
Spring
Lingual Arch Wire
Magnet

EXPANSION SCREW

Today, many variations of the expansion screw are readily available for use in orthodontics (Fig. 10).[12,13,28-32,39,62,65,77,78,89,97,99,109-113] The expansion screws have undergone considerable evolutionary change since their introduction to orthodontic therapy.

Schienbein[94] has reported on the development of orthodontic appliance screws. The first expansion screws did not have a guidance mechanism to secure the appliance against torsion. Nevertheless, it permitted controlled, directed development of force, and became the foundation for today's expansion screw designs. The variations that arose for the original device may be described as the first generation expansion screws.

The first generation expansion screws were designed

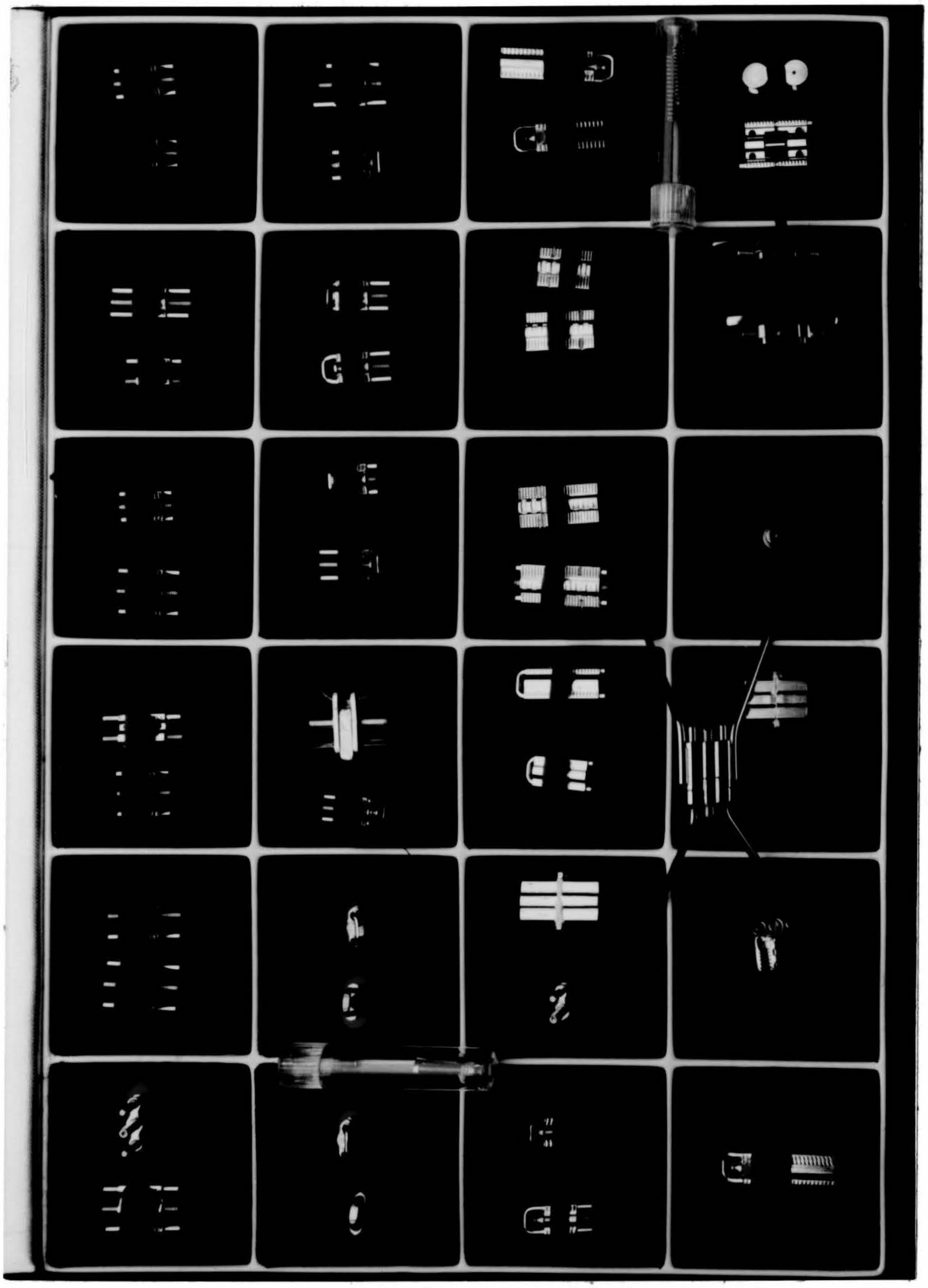


Figure 10. Expansion screw design variations. (Dentaurum[28])

for 3-dimensional arch and tooth repositioning. These expansion screws were incorporated into simpler removable appliances, and an increased population of children could be provided removable appliance therapy rather than relatively few patients with costly fixed orthodontic treatment.

Subsequently, second generation expansion screws were developed having unique design features of single and double guide pins. These features provided for increased functional stability and became the basis for force development for a long period of time. Problems developed with these second generation expansion screws due to corrosion and mechanical damage. Concurrently, new materials were developed for the expansion screw bases which simplified their fabrication and use by the patient. Rubber was replaced initially by heat cured resins and later by cold cured resins for use in expansion screw bases. Cold cured resins appeared to be almost ideal in terms of their fabrication and application properties.

During the past decade, technical advances in materials and the construction of precision mechanics, have led to the creation of third generation expansion screws. The present expansion screws are technically improved devices which have permitted skeletalization and miniaturization. The material used in fabrication of these technically improved devices was designated as the Universal V2A steel alloy.[94] The Universal V2A steel alloy expansion screw was developed to overcome the disadvantages of the chrome and nickel-plated screws. Corrosion and allergic reactions to nickel were two major drawbacks overcome by the use of this steel alloy. The palatal expansion screws using Universal V2A alloy are designed with specific opposing threading and guidance posts so they retain tension and remain free of torsion even at maximum displacement. The functional operating range of expansion screw opening varies with specific design.[28] The present expansion screws are routinely imbedded in an acrylic resin base which is adapted to the palate and attached by a wire framework to the dentition. The appliance is activated by inserting a key into the screw head on the threaded shaft and rotating it in the direction of opening.

Nazif[79] has reported two cases of accidental swallowing of orthodontic expansion appliance keys (Figs. 11 & 12). In case report #1, floss had been ligated through the key handle; however, while attempting to activate the appliance, the key slipped from the mother's fingers into the pharynx and was subsequently swallowed. Radiographic examination revealed a foreign body in the stomach (Fig. 11). Following an uneventful observation period, the key was identified in the stool two days later. In case report #2, the parent had been activating the appliance when the key became lodged in the keyhole. When attempting to free the key from the appliance, the dental floss which had been tied to

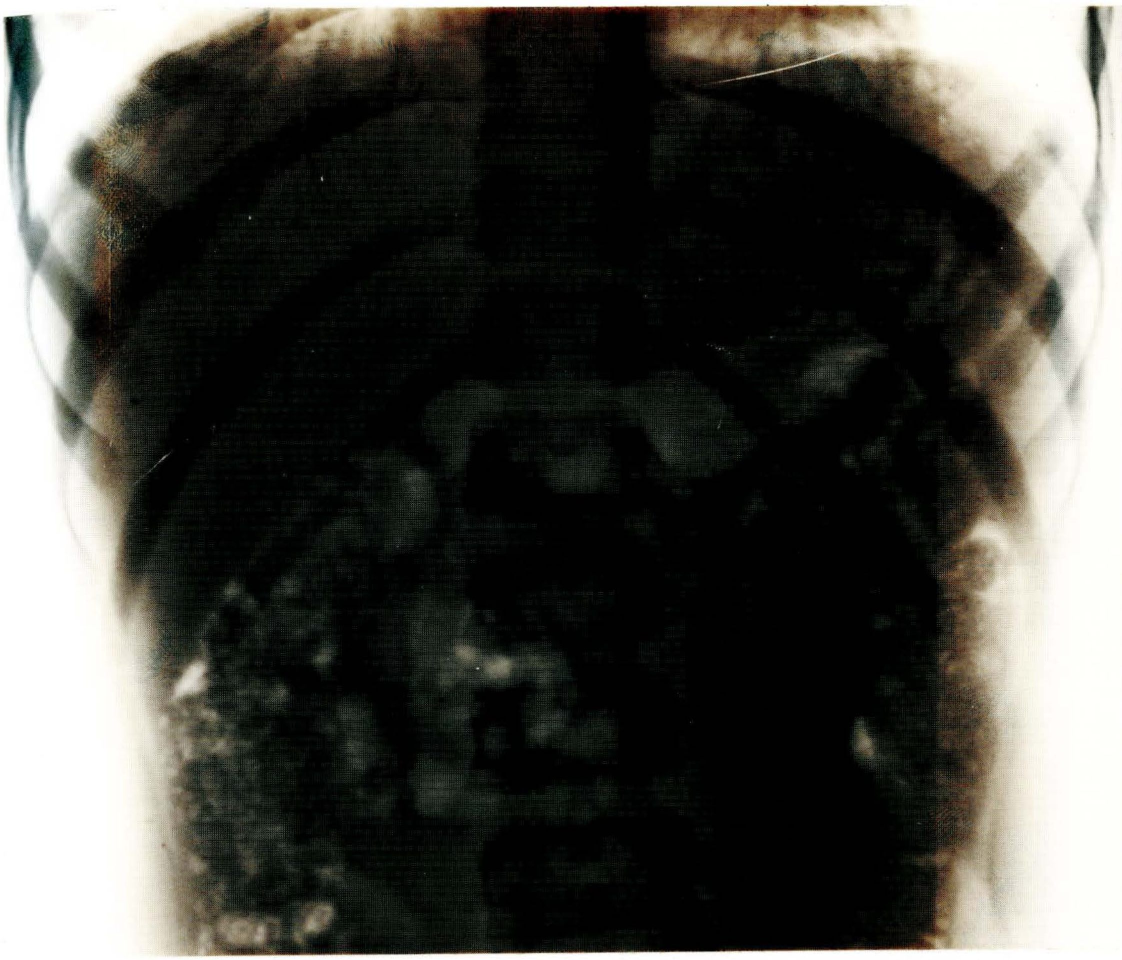


Figure 11. Case report #1. Frontal radiograph of the abdomen illustrating the presence of a foreign body (key) in the stomach. (Nazif[79])

Figure 12. Case report #2. Frontal radiograph of the abdomen illustrating the presence of a foreign body (key) in the stomach. (Nazif[79])

the key handle became disconnected. When the key was freed, it slipped into the pharynx and was swallowed by the child. Radiographic examination revealed the appliance key in the stomach (Fig. 12). The key was not recovered during a two-day observation period. On the third day, followup radiographs of the gastrointestinal tract revealed absence of the foreign body.

Nazif discusses the possible sequelae that exists if the key is lodged in either the gastrointestinal tract or the respiratory tract and recommends a simple modification of the key to prevent such complications. Soldering the open contact that exists in the key handle will prevent the floss from slipping through the handle after it is ligated in place. Furthermore, shortening the length of the key in relation to the available working space will also facilitate adjustment of the appliance and reduce the risk of accidental swallowing or aspiration.

The standard skeleton expansion screw is an example of a heavy duty steel expansion screw with double guide pins. The threaded screw spindle is not enclosed by a stainless steel case, and therefore, is called a skeleton expansion screw (Fig. 13).[28,29] A totally encased expansion screw encloses the screw spindle within a stainless steel case which augments expansion unit rigidity (Fig. 14). The encased expansion screw maintains double guide pins to prevent appliance rotation under load.[28,30] A unique

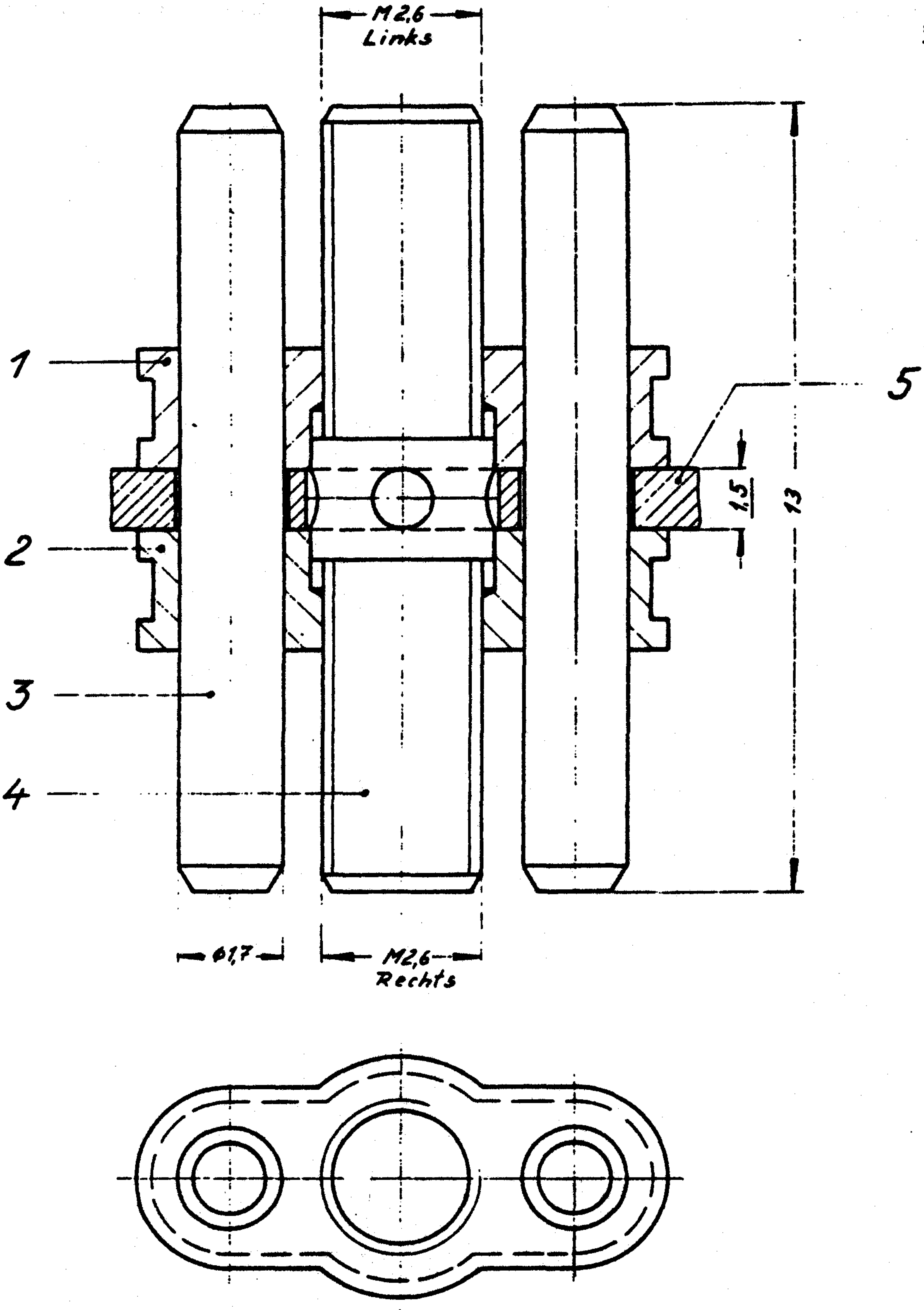


Figure 13. Skeleton expansion screw, No. 600-210. (Dentaurum[29])

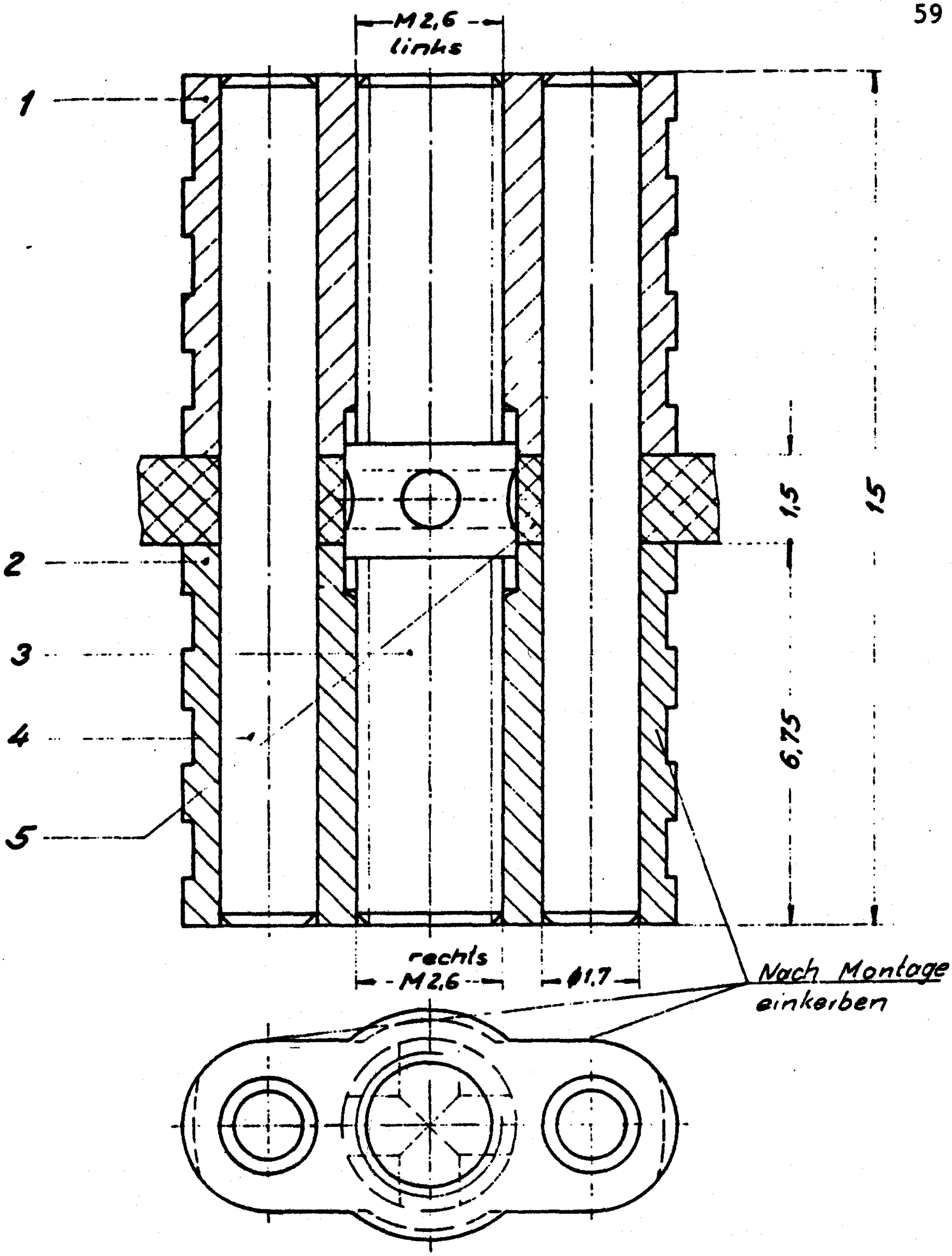


Figure 14. Encased expansion screw, No. 601-110. (Dentaurum[30])

variation of the palatal expansion screw design is the fan-type expansion screw (Fig. 15).[28,31] This design allows for sectional expansion of the anterior segment as the expansion screw is opened, rotating about a hinge device located posteriorly.

Nardella[77] has proposed a twin expansion screw design which permits differential anterior and posterior expansion (Fig. 16). This design offers the advantage over the fan-type expander, permitting a regulated degree of posterior expansion to take place concurrent with anterior expansion.

Wallshein[110,111] has proposed two expansion screw designs with a means to prevent screw disengagement. This feature will prevent disjunction of the main body sections upon maximum opening. Wallshein[110] describes the use of enlarged terminal abutment components which prevent disengagement of the expansion screw spindle from the main body sections while providing full range of adjustment (Fig. 17). Wallshein[111] has also reported designing an expansion screw with a stabilizing rod which slides within the confines of the main body sections and thus prevents disengagement of the main body sections (Fig. 18).

Wallshein[110,111,112,113] has also disclosed a means for preventing the expansion screw spindle from being backed into the main body sections due to externally applied forces. Wallshein[112] has accomplished this by deforming

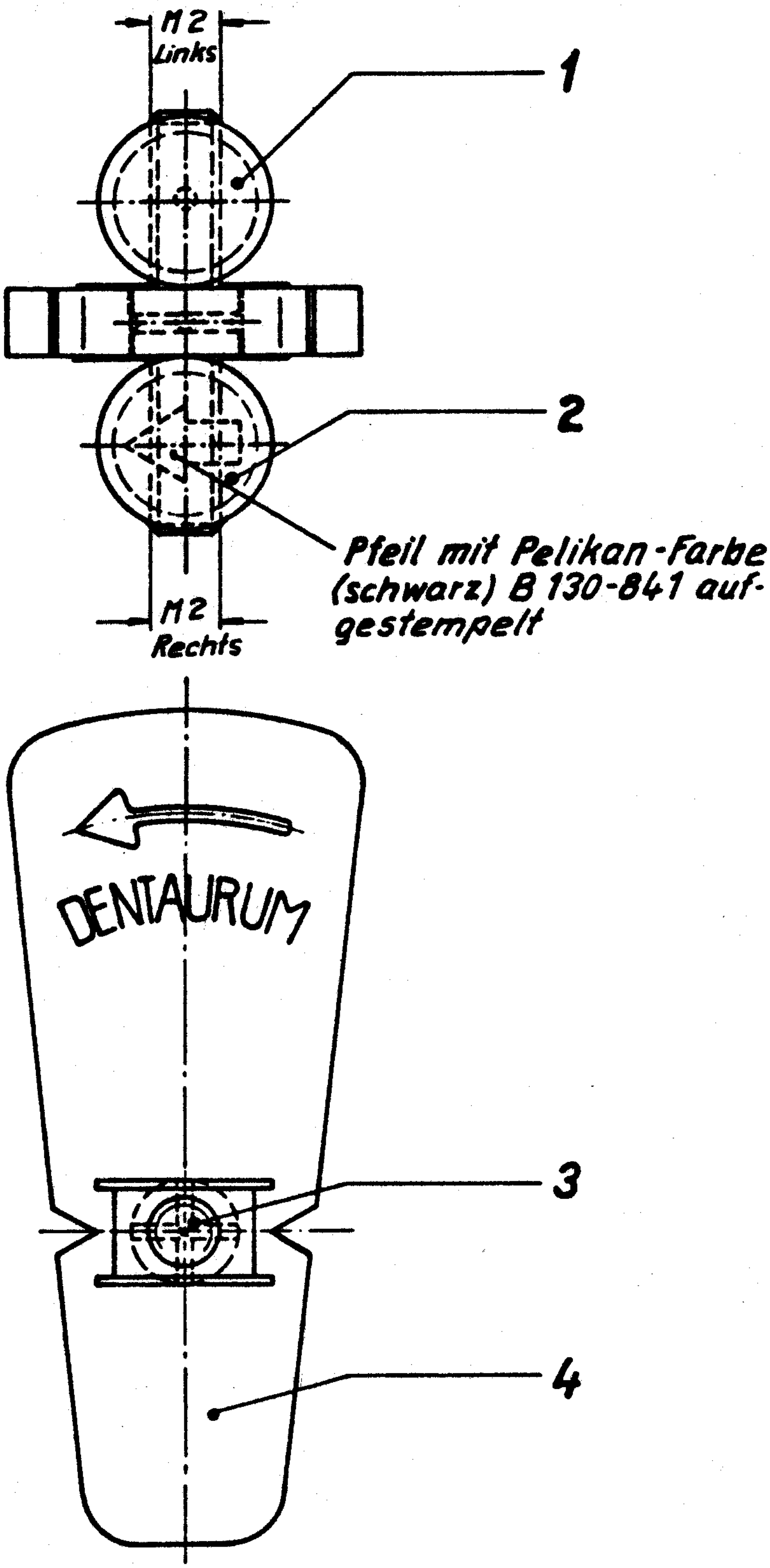


Figure 15. Fan-type expansion screw, No. 606-600. (Dentaurum[31])

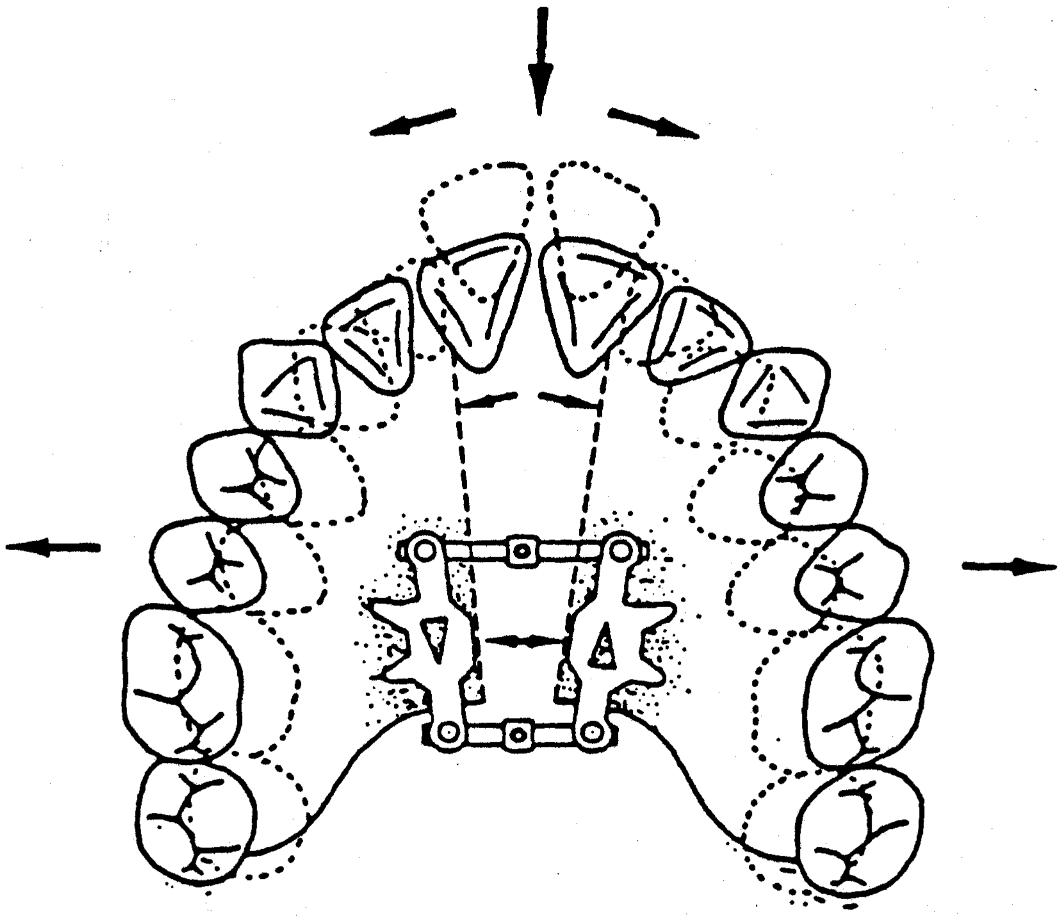


Figure 16. Twin expansion screw. (Nardella[77])

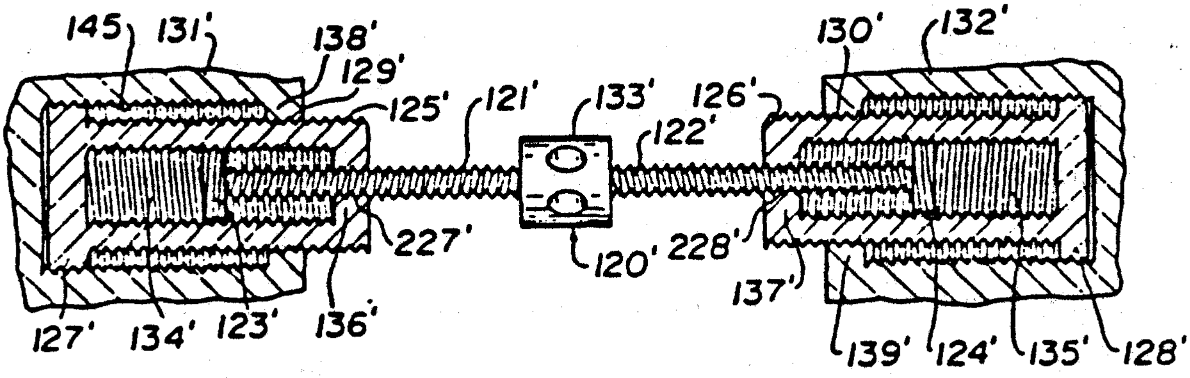


Figure 17. Expansion screw with enlarged terminal abutment components designed to prevent screw disengagement. (Wallshein[110])

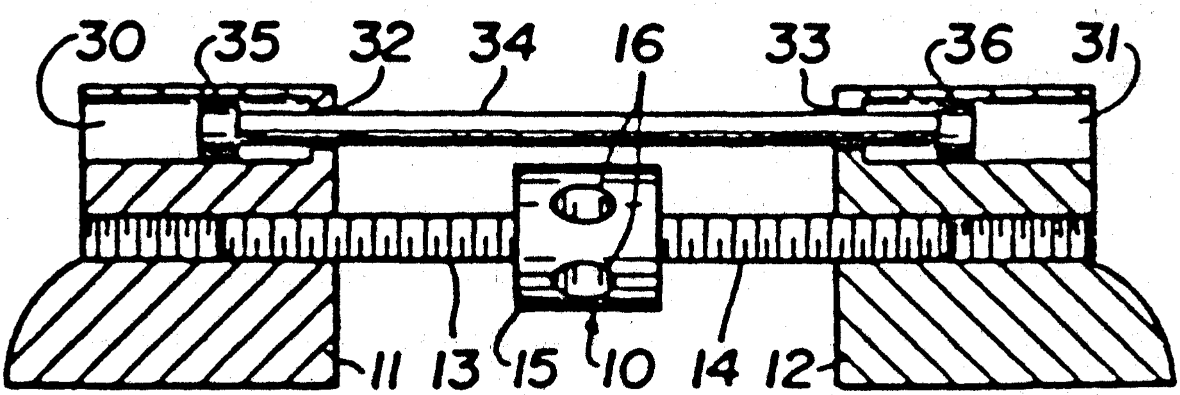


Figure 18. Expansion screw with confined stabilizing rod designed to prevent screw disengagement. (Wallshein[111])

threads on the expansion screw spindle which prevents counter rotation of the spindle and backing off of the expansion screw under load (Fig. 19). Wallshein[113] has also designed expansion screw stabilizing rod offset bores which provide a means for binding of the stabilizing rod under externally applied forces thereby preventing backing off of the expansion screw (Fig. 20).

Spino and Warren[99] have proposed a telescopic expansion screw design (Fig. 21). The threaded screw components are totally encased within an outer telescopic casing. This expansion screw design would accommodate a very narrow palatal vault morphology, yet expand to a large overall final dimension.

Specific orthodontic expansion screws are designed with a metal framework incorporated along with the expansion unit.[12,13,39,57,62,65,83,97,107] The expansion units are constructed without an acrylic base and therefore, do not contact the palatal mucosa. The metal framework is adapted to clear the palatal mucosa and is soldered to orthodontic bands placed on the abutment teeth. Biederman[12] reports that significant drawbacks of the acrylic based expansion appliances are soft tissue irritation and food impaction under the acrylic plate.

The Hyrax appliance,[12,13,83] an acronym for hygienic rapid expansion, was developed by Biederman to circumvent the problems accompanying the use of an acrylic

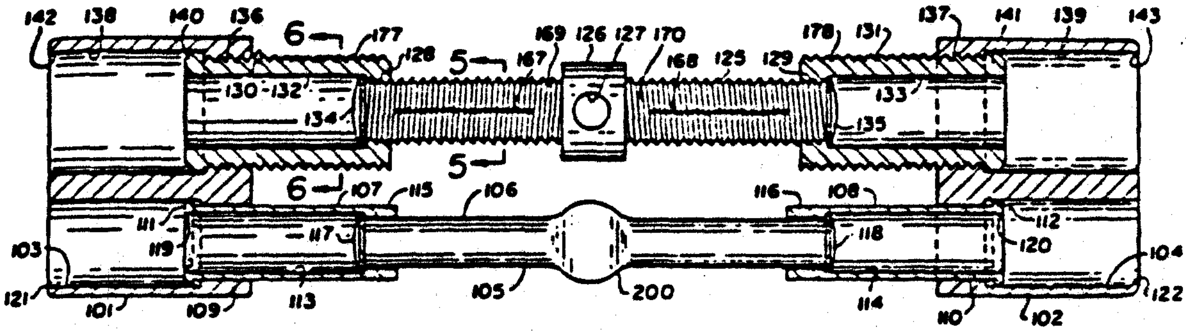


Figure 19. Expansion screw with deformed screw threads designed to prevent the expansion screw spindle from being backed into the main body sections under load. (Wallshein[112])

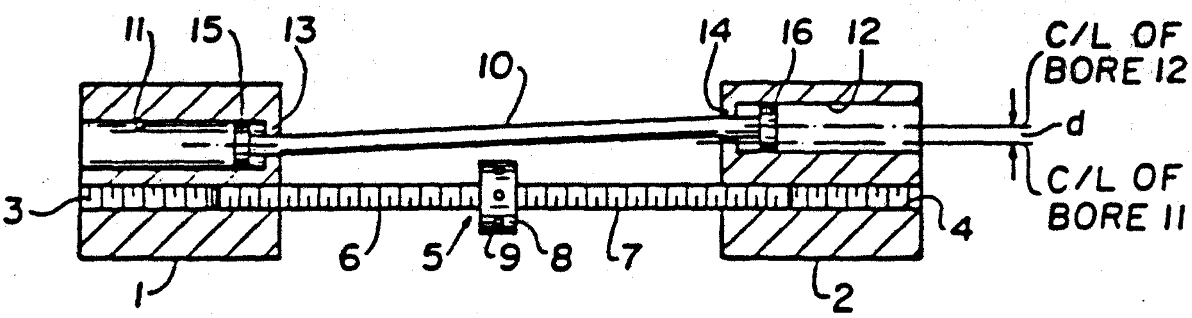


Figure 20. Expansion screw with stabilizing rod offset bores designed to prevent the expansion screw spindle from being backed into the main body sections under load. (Wallshein[113])

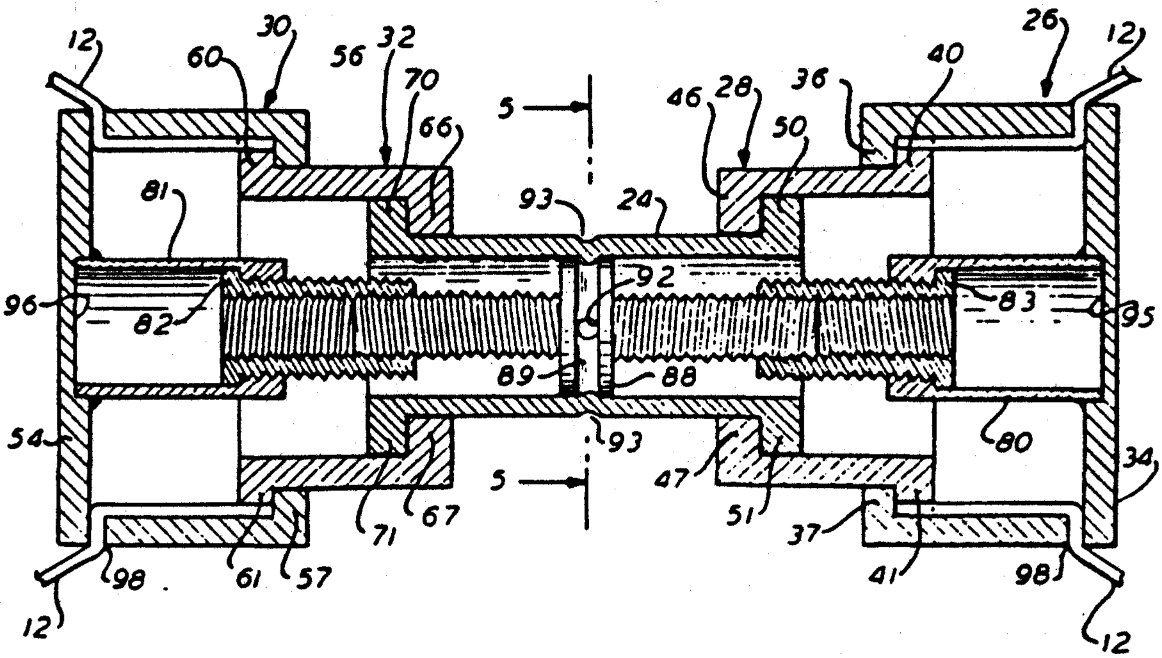


Figure 21. Telescopic expansion screw. (Spino and Warren[99])

based appliance (Fig. 22). The Hyrax expansion screw has attachment rods oriented parallel to a pair of main body sections which are adapted to the palate and soldered to the orthodontic bands placed on the abutment teeth.

Forster[39] has proposed a variation of the metal framework expansion screw appliance (Fig. 23). Forster claims that due to the small dimension of his expansion screw, it is possible to place it deep in the palatal vault very close to the center of resistance of the maxilla. The guide rods of this expansion screw are equipped with annular grooves to limit axial movement of the main body sections. Kraus and Walter's[62] variation of the metal framework expansion screw appliance permits maximum separation of the screw bodies by virtue of an extended threaded bore in the screw body (Fig. 24). Siatkowski's[97] metal framework palatal expansion screw utilizes a scissors jack design with the expansion screw mounted longitudinally in the palate (Fig. 25). Lateral outwardly movable linkages allow the device to operate in the manner of a scissors jack and thereby permit expansion.

SPRING

Helical compression and helical torsion spring expansion units have been reported to be used in palatal expansion appliance construction.[24,70,80,81,82,100] Probably the best known helical compression spring expansion appliance is the Minne expander.[81,82] Palatal expansion

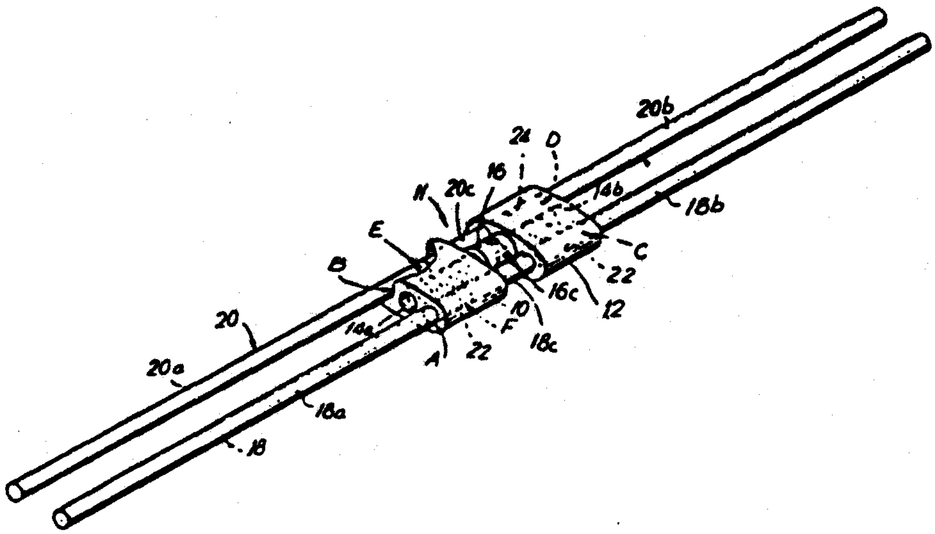


Figure 22. Hyrax expansion screw. (Biederman[13])

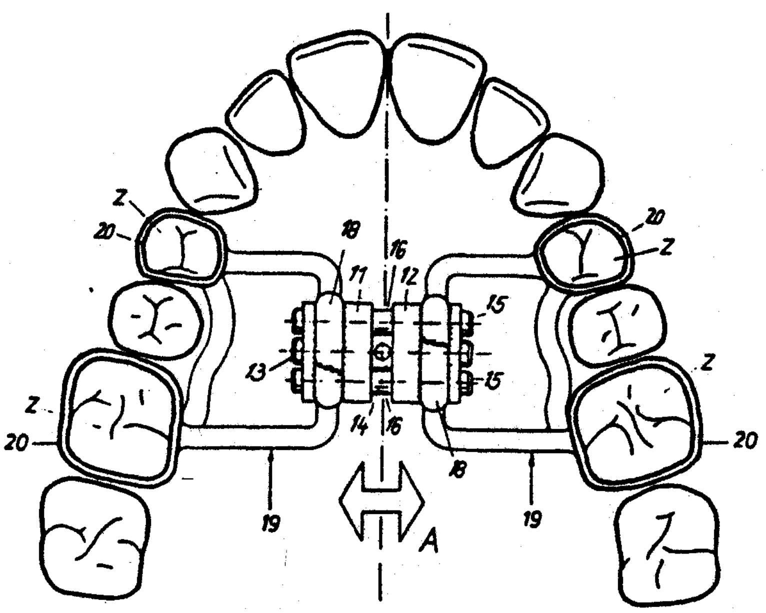


Figure 23. Metal framework expansion screw. (Forster[39])

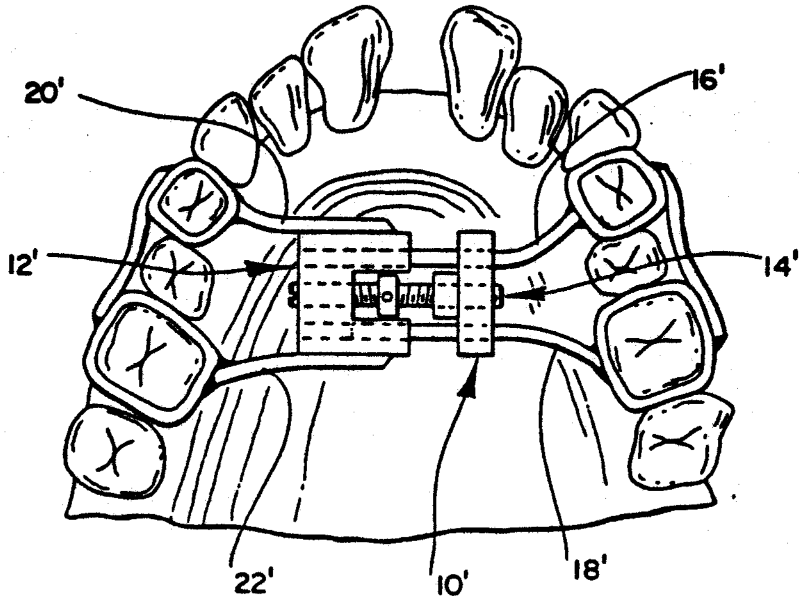


Figure 24. Metal framework expansion screw. (Kraus and Walter[62])

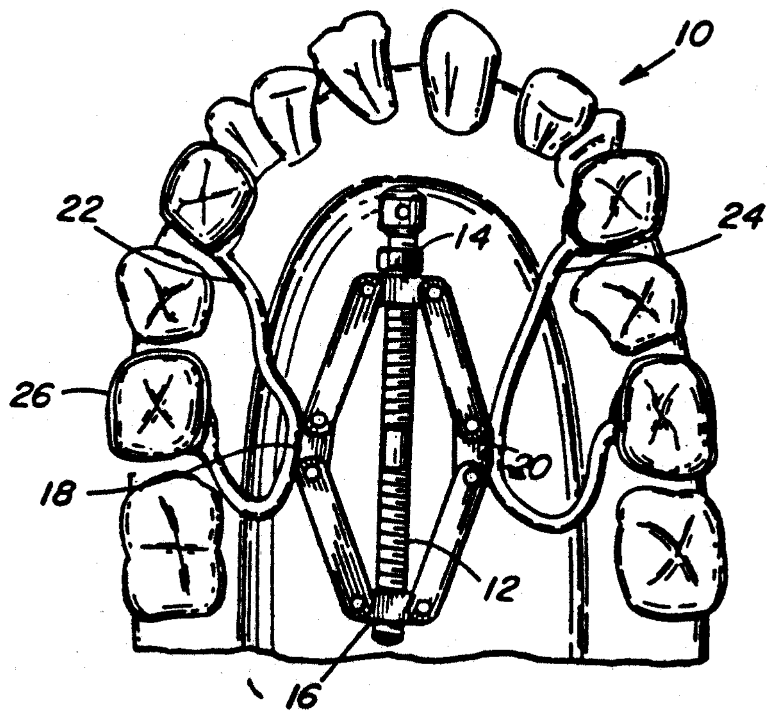


Figure 25. Metal framework expansion screw; scissors jack design. (Siatkowski[97])

with this appliance is achieved by turning an adjustment nut which thereby compresses a transversely mounted coil spring and transmits the load to banded abutment teeth. Chaconas and Caputo[24] have shown that the Minne expander is capable of delivering loads within the orthopedic range.

Nelson[80] has reported incorporating a helical torsion spring expansion unit in a palatal expansion appliance. Nelson's appliance consists of a stationary body and a movable block, each secured to abutment teeth. A helical torsion spring provides the expansile force separating the two main body sections.

McAndrew[70] has proposed a continuous force control expansion arch which utilizes compressed coil spring threaded over an expandable lingual arch wire to provide the expansile force (Fig. 26). Similarly, the Arnold expander[100] provides expansion using compressed coil spring threaded over an expandable lingual arch wire (Fig. 27). The load delivered with these lingual arch wire-coil spring appliances are in the orthodontic range and therefore, only dentoalveolar alterations are expected.

LINGUAL ARCH WIRE

A variety of lingual arch wire appliances have been proposed for palatal expansion.[23,24,41,42,43,57,70,90,91,92,93,100] One of the most widely used lingual arch appliances for palatal expansion is the quad helix (Fig. 28).[90] Chaconas and Caputo[24] have shown that the quad helix is

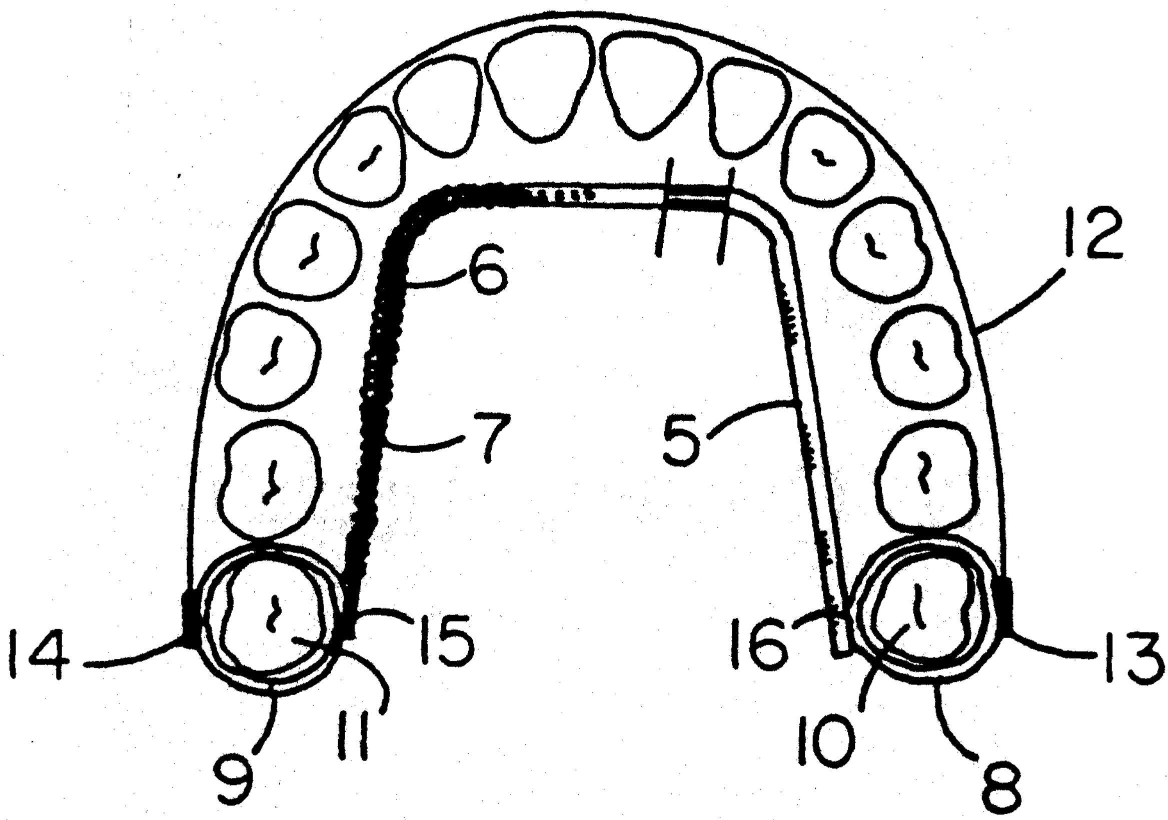


Figure 26. Continuous force control expansion arch. (McAndrew[70])

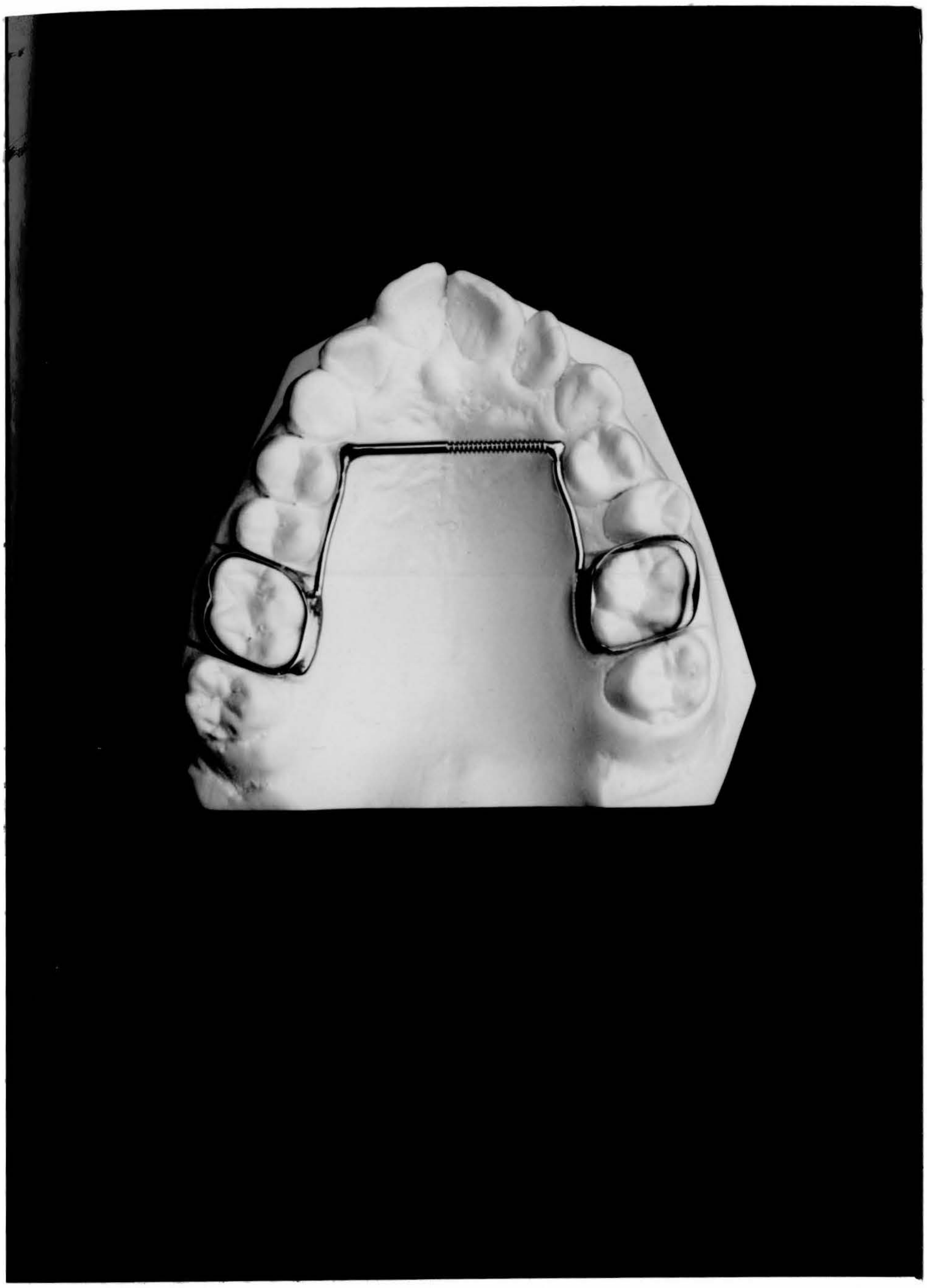


Figure 27. Arnold expander. (Spoylar[100])

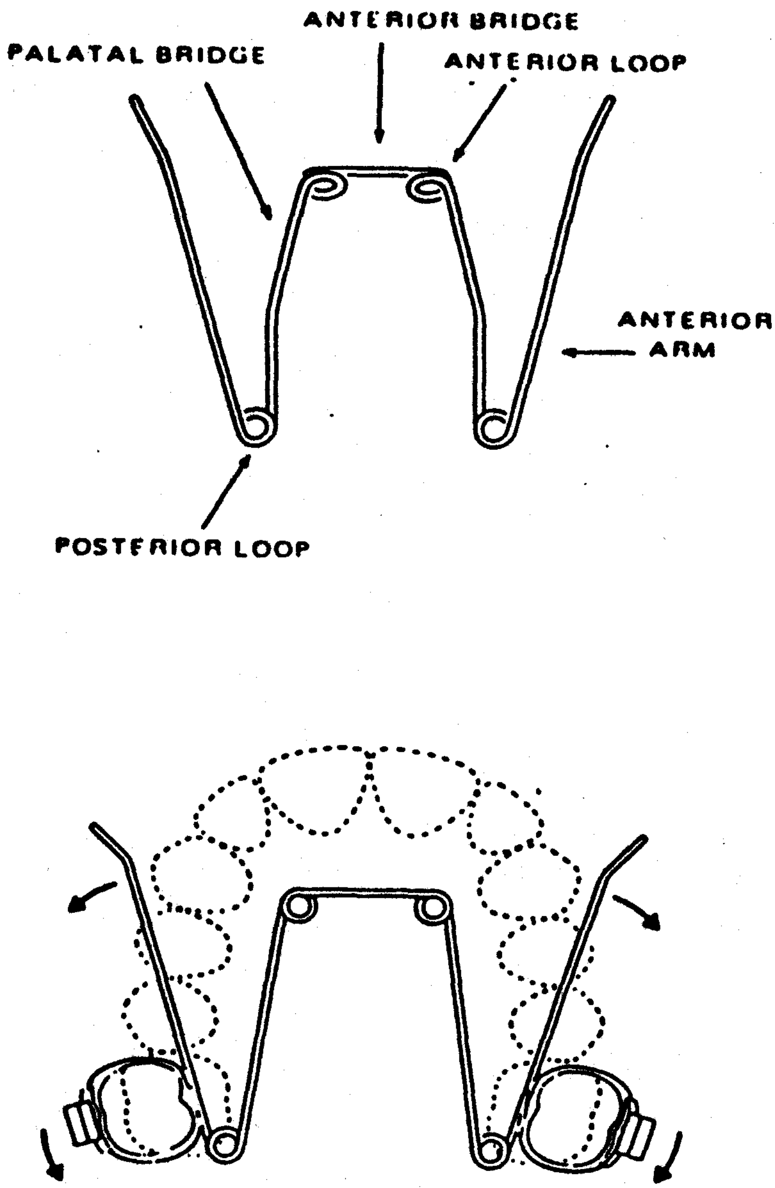


Figure 28. Quad helix appliance. (Ricketts[90])

minimally effective as an orthopedic appliance and exerts its primary influence on the posterior teeth. The lingual arch wire effectiveness as an orthopedic appliance decreases with increasing age and maturity.

Many variations of the lingual arch palatal expansion appliance exist today. Rocky Mountain Orthodontics has introduced a 3D quad helix appliance[91] (Fig. 29), and a 3D palatal appliance[92] (Fig. 30), which in addition to expansion, permit molar control in the other two dimensions of space. Goshgarian[42,43] has designed palatal arch wires which allow three-dimensional molar control similar to the 3D Rocky Mountain appliances.

MAGNET

The use of magnetic force as the expansion unit for palatal expansion appliances was first described by Blechman and Pescatore[17] (Fig. 31). Their appliance incorporates permanent magnets in separate palatal body halves which are arranged in a repulsion mode and oriented to provide the expansile force. Blechman and Pescatore suggest that magnetic reacting fields aid in the reorganization of tissues, accelerate osteogenesis, and insure maintenance of the expansion. Their proposed expansion unit may be fabricated as either a fixed or a removable appliance. Blechman and Pescatore[18] have also proposed a magnetic palatal retention appliance to be used following active expansion.

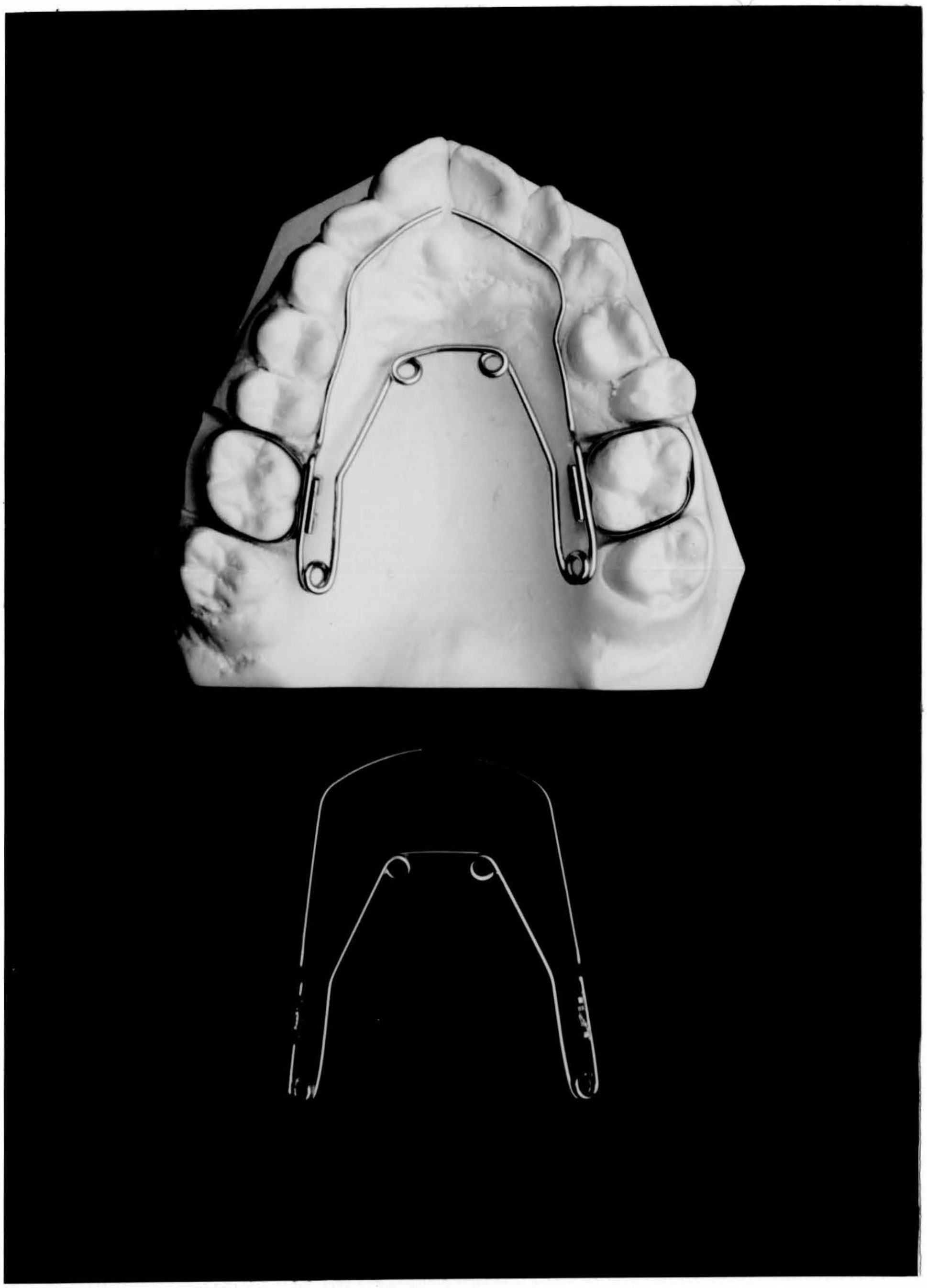


Figure 29. 3D quad helix. (Rocky Mountain Orthodontics[91])

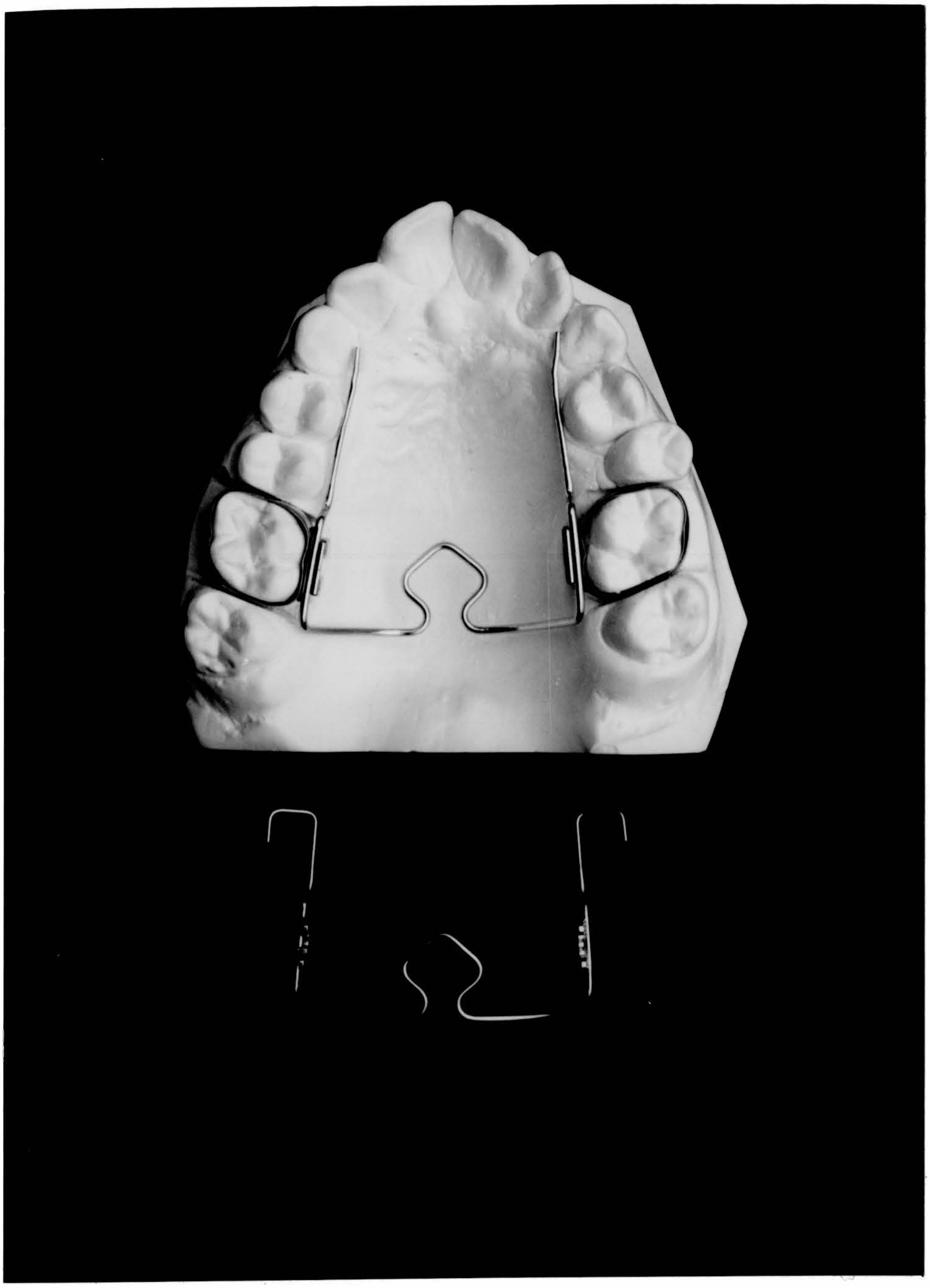


Figure 30. 3D palatal appliance. (Rocky Mountain Orthodontics[92])

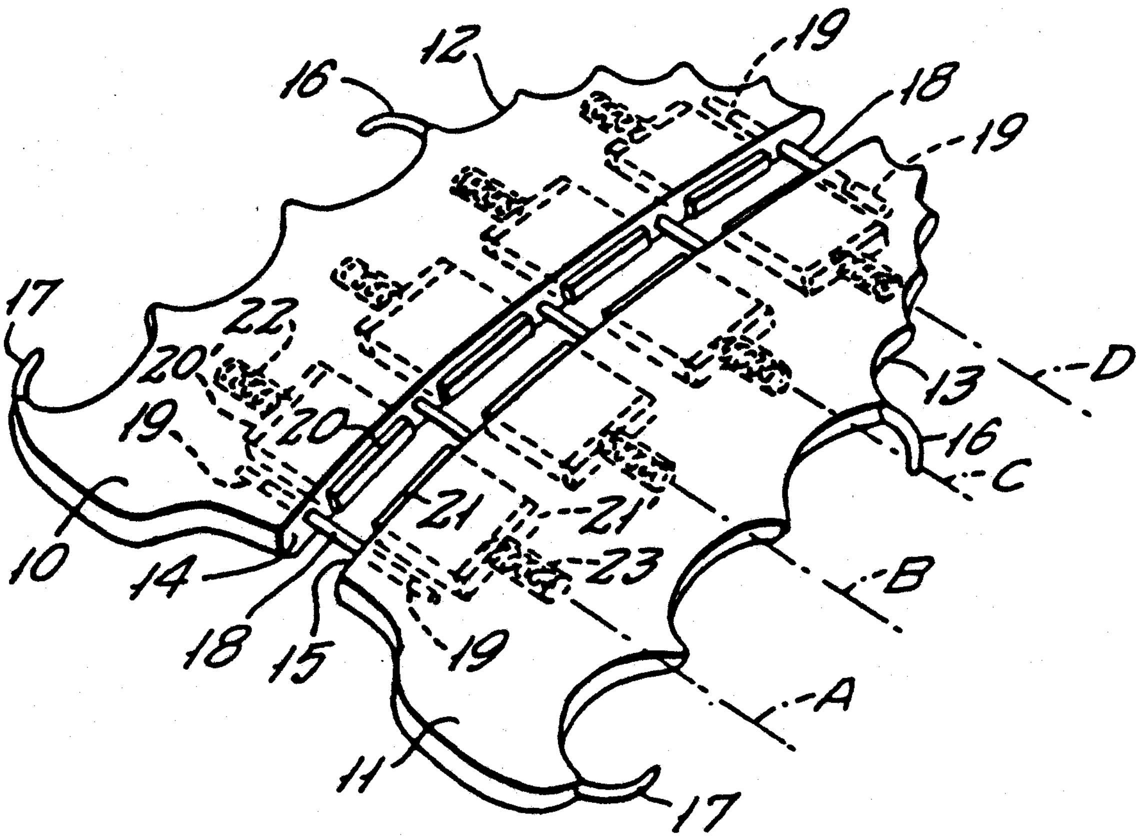


Figure 31. Magnetic palatal expansion appliance. (Blechman and Pescatore[17])

DETAILED PALATAL EXPANSION APPLIANCE DESIGNS

Today, six palatal expansion appliance designs are routinely used in orthodontics:

Haas
Hyrax
Bonded
Minne expander
Removable
Quad helix

HAAS APPLIANCE

The Haas appliance[47,48,49] design is a tissue-borne fixed split acrylic palatal expansion appliance. Figure 32 illustrates a Haas appliance constructed with a skeleton expansion screw;[29] Figure 33, with an encased expansion screw;[30] and Figure 34, with a fan-type expansion screw.[31] This appliance is designed to enhance orthopedic movement and minimize orthodontic movement by strengthening dental anchorage units.

The Haas appliance is fabricated by a direct-indirect technique. Bands are selected for and positioned on the maxillary permanent first molars and either the first premolars or the deciduous first molars. An impression is made, the bands transferred to it, and a stone working model poured. Connecting bars are soldered to the buccal and lingual surfaces of each pair of bands. The connecting bars are placed as close to the gingiva as possible and contoured

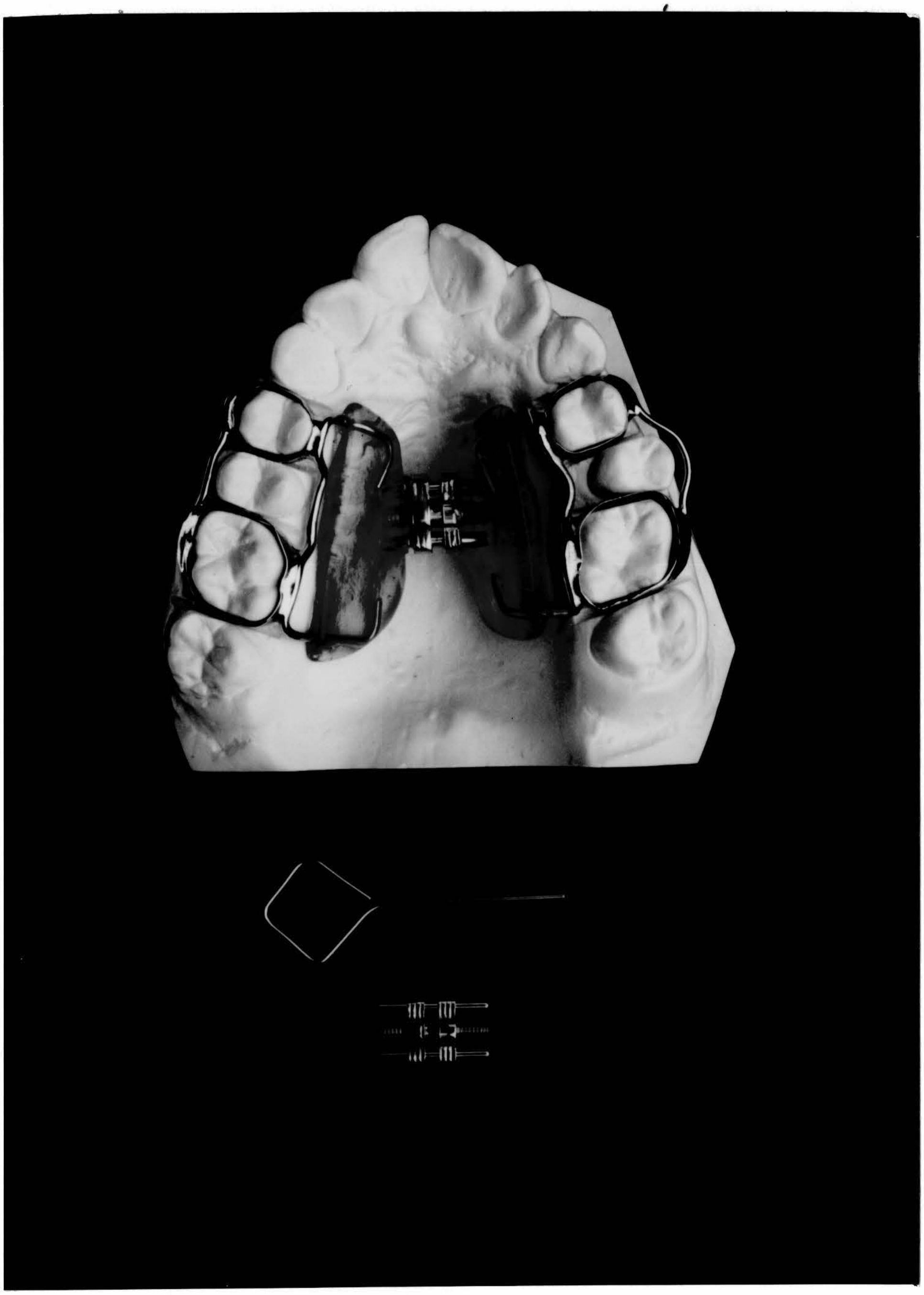


Figure 32. Haas palatal expansion appliance. (Haas[47]) Skeleton expansion screw. (Dentaurum[29])

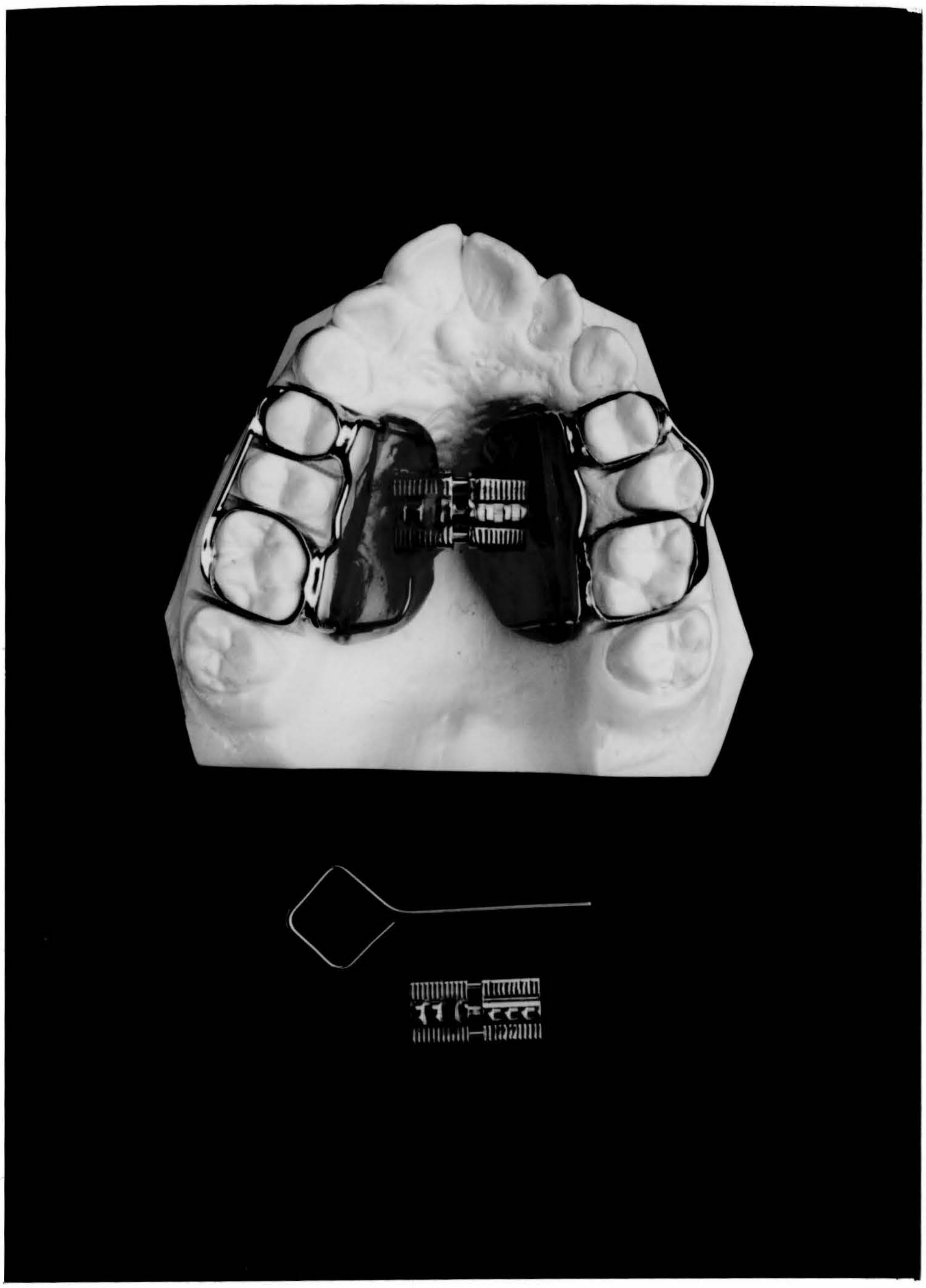


Figure 33. Haas palatal expansion appliance. (Haas[47])
Encased expansion screw. (Dentaurum[30])

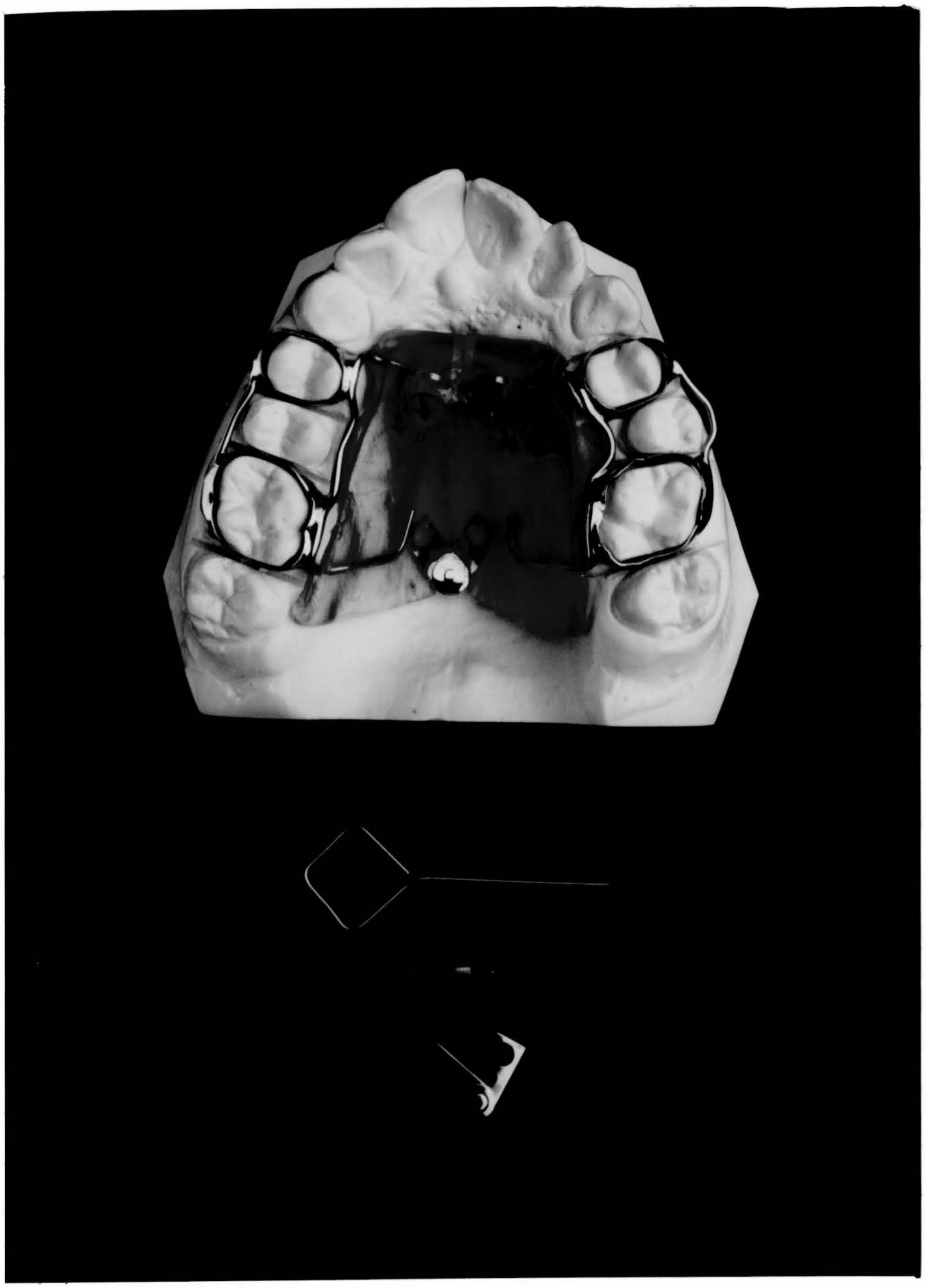


Figure 34. Haas palatal expansion appliance. (Haas[47])
Fan-type expansion screw. (Dentaurum[31])

for maximum contact with the abutment bands and unbanded second premolars. The lingual bars are extended anteriorly and posteriorly. These extensions are directed palatally to act as lugs to anchor the bands and bars to the split acrylic palate.

An expansion screw is mounted on a piece of base plate wax perpendicular to the long axis of the expansion screw. The base plate wax is trimmed to conform to the contour of the palate in order that the center of the expansion screw lies directly over the midline. The lateral margins of the expansion screw are raised 1 mm. from the palate. Elimination of the wax at a later stage provides the needed split in the appliance. Quick cure acrylic is applied incrementally and built up to cover the expansion screw and the anchor lugs of the lingual bars. The appliance is finished, polished, and all corners which are in contact with palatal mucosa are well rounded.

The split acrylic base is designed to avoid impingement on the palatal tissues which possess a rich blood supply: the rugae, the gingival tissue, and the tissue overlying the greater palatine foramina. The resistance units are the individual walls of the palatal vault, the buccal alveolar process, the posterior teeth, and the periodontal fibers. After the appliance has been cemented, the activation rate is empirically determined according to the patient's maturity and comfort. The expansion screw is constructed to expand approximately 0.25 mm. per quarter turn of activation. A key is used to activate the expansion screw assembly by inserting it anteriorly and directing it posteriorly in an arcing motion. To avoid accidental swallowing or aspiration of the key, a string should be attached to it and the parent instructed to wrap the string around the fingers during appliance activation. This procedure, however, has met with some undesirable patient compliance.[79] The patient is observed at weekly intervals to assess the transverse position of the maxillae. When sufficient expansion has been obtained, expansion screw activation is discontinued. Haas[48] suggests overtreatment of the maxillary apical base to allow for subsequent uprighting of tipped buccal teeth and recontouring of the bent alveolar process.

When appliance activation has ceased, the expansion screw is stabilized with .040 wire fastened across the acrylic bases and secured with quick cure resin. Stabilization prevents the expansion screw from reversing its motion under function. The appliance is permitted to remain in place for three months to permit connective tissue reorganization and readaption. At the same time the appliance is removed, an acrylic palate processed from quick cure acrylic is inserted. The acrylic palate is subsequently worn throughout treatment and during retention.

HYRAX APPLIANCE

The Hyrax appliance[12,13,83] is a tooth-borne fixed wire appliance which is key activated by means of a centrally located expansion screw (Fig. 35). Multiple variations of the wire framework expansion screw have been reported.[39,62,65,97,107]

The Hyrax appliance is entirely tooth-borne with a metal construction which may be positioned in the patient's mouth to avoid palatal irritation. The design features a pair of main body sections, each including an oppositely threaded screw bore into which is threadably inserted an adjustment screw having two ends counter-threaded. This allows the main body sections to either move closer together or further apart depending upon the direction of turning. A pair of sectional rods straddle the adjustment screw with each rod being inserted through rod bores running parallel to the threaded screw bore. The sectional construction of the rods enables their action as both slide members as the main body sections are separated and as attachment rods for securing the appliance to the banded maxillary teeth.

Fabrication of the Hyrax appliance utilizes a direct-indirect technique. Bands are selected for and positioned on the maxillary permanent first molars, and either the first premolars or the deciduous first molars. The bands are removed in a relationship impression, and a stone working model is poured. The Hyrax expansion screw

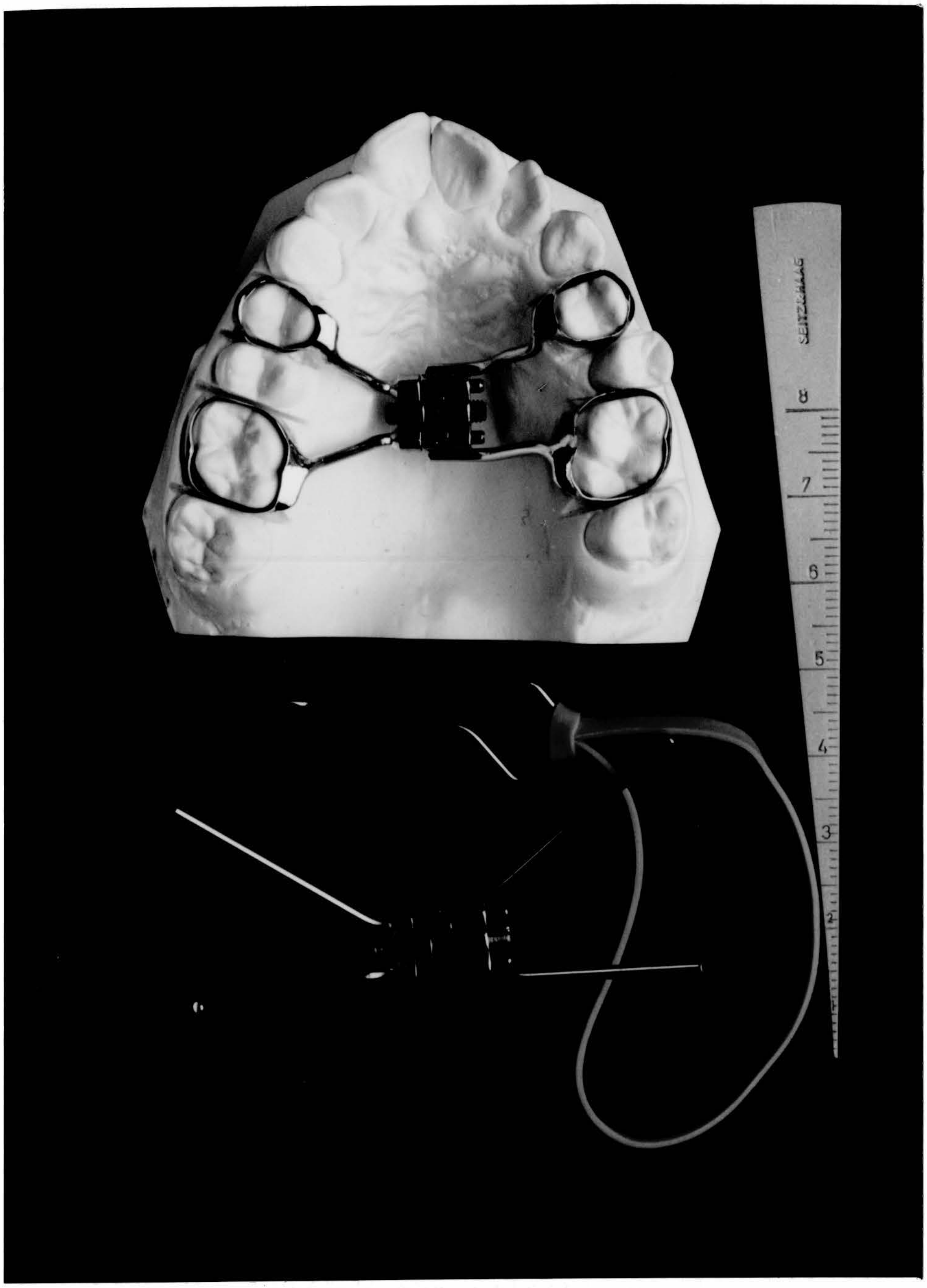


Figure 35. Hyrax palatal expansion appliance. (Orthodontic Int. Services, Inc.[83])

is adapted to clear the palatal tissue and sectional rods contoured to the palatal vault and abutment teeth. Buccal and/or lingual bars may be soldered to the abutment bands simultaneously with the adapted sectional rods. The Hyrax appliance is removed from the working model, cleaned, and polished. Next, the appliance is inserted and cemented in place. After insertion, the adjustment screw is typically rotated twice daily activating the appliance 0.5 mm. per day for a two-week duration. Subsequently, transverse apical base coordination is clinically assessed and necessary adjustments are performed prior to stabilization. A four-month stabilization period is recommended following active expansion. The wedge shaped calibrated gauge accompanying the Hyrax expansion screw is used for measuring openings in the expansion screw. This permits quick estimation of the amount of expansion attained by the expansion screw. Furthermore, a rubber band included with the Hyrax expansion screw is recommended to be attached to the key handle to prevent accidental swallowing or aspiration of the key upon activation.[83]

Haas[49] has noted that employing an all wire framework and eliminating the palatal acrylic base leads to some hazardous consequences. With the entirely tooth-borne all wire framework, the brunt of the expansion screw force is borne by the thin buccal alveolar plate. Haas considers this appliance design to be anchorage deficient, since the only resistance units are the buccal teeth, the periodontal fibers, and the thin buccal alveolar plate. Haas notes that using wire framework appliances on mature individuals with significant resistance to expansion, may result in extreme dental pain and even perforation of the buccal alveolar plate.

BONDED APPLIANCE

The Haas and Hyrax appliances require permanent teeth to be present for band placement in order to gain maximum support and stabilization. An alternative design in the permanent or mixed dentition is the bonded palatal expansion appliance.[57]

Researchers have proposed a variety of bonded appliance designs.[25,33,56,57,75] The bonded expansion appliance is a tooth-borne fixed wire appliance which incorporates a rigid wire framework expansion screw as its active element (Fig. 36).

Huge and others[57] have reported on the design and indirect fabrication of a bonded expansion appliance. A Hyrax[12,13,83] expansion screw is soldered to a .040 wire framework bent around the buccal and lingual surfaces of the posterior teeth. Acrylic is processed over the wire framework on each side and contoured to the gingival margins. The occlusal of all posterior teeth is covered with an acrylic thickness of 1 to 1.5 mm. for strength. Ideally, a lower model is articulated with the constructed appliance

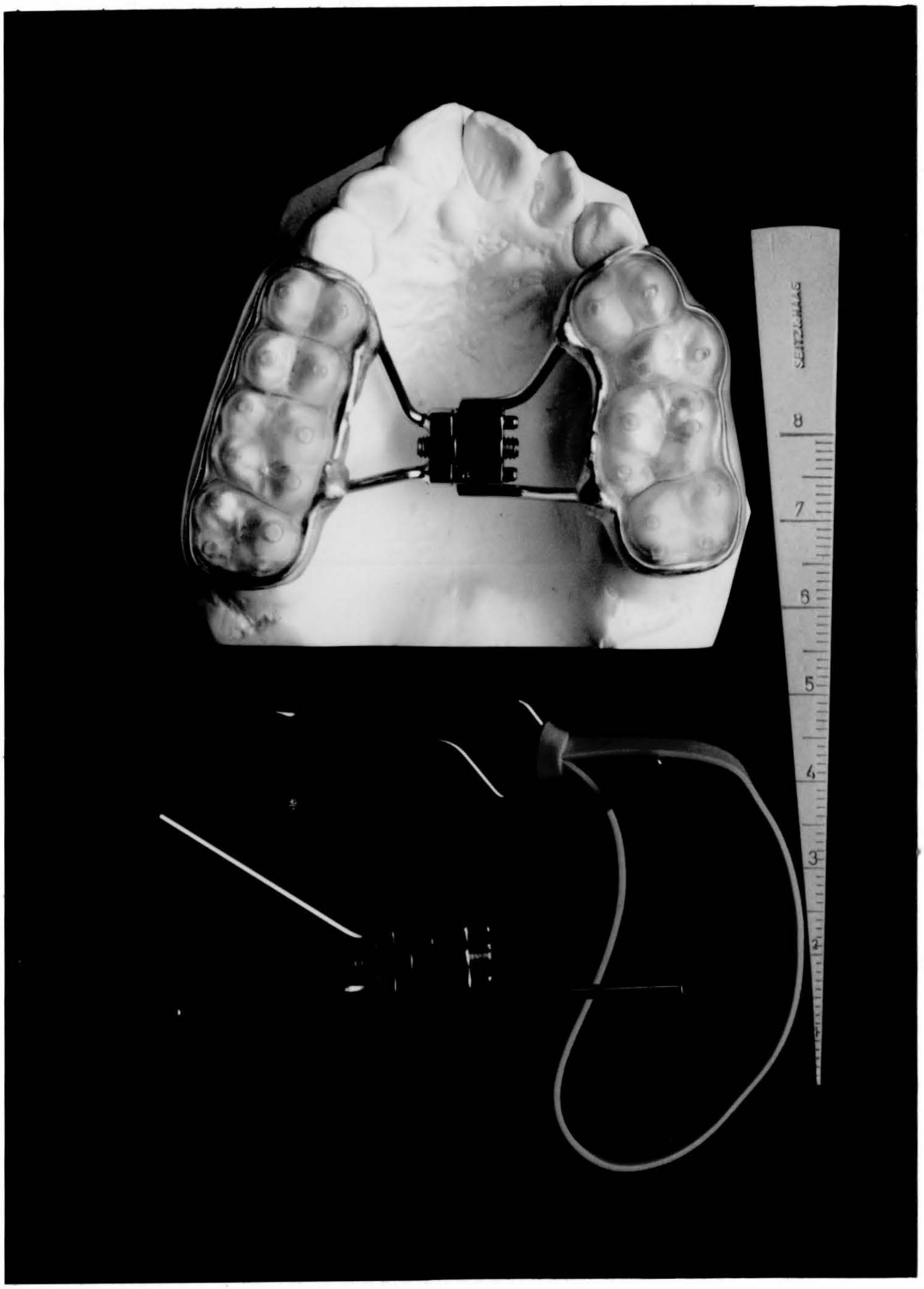


Figure 36. Bonded palatal expansion appliance. (Huge[57])

to minimize occlusal interference upon insertion. Howe's[56] appliance design incorporates a thin collar of acrylic surrounding the buccal segment maintaining interocclusal dental contact which minimizes the bite opening effect observed with occlusal coverage. The entire appliance is bonded to the maxillary teeth using conventional orthodontic adhesives. The recommended adhesive material is one with medium viscosity, a quick gel phase, and maximum strength. The acrylic occlusal areas are vented to facilitate escape of adhesive material during placement. Further modifications of the bonded expansion appliance have been proposed which include palatal coverage and direct fabrication.[33,75]

Spolyar[100] discusses the advantages of using a bonded expansion appliance with occlusal coverage as opposed to other appliances which do not have occlusal coverage. Occlusal coverage permits the mandible to rotate backwards thus clearing the anterior occlusion for crossbite correction and maxillary protraction. Furthermore, unilateral segmental displacement may be achieved in surgical expansion osteotomy cases if differential anchorage is incorporated into the design and fabrication of the appliance.

MINNE EXPANDER APPLIANCE

The Minne expander[81,82] is a tooth-borne fixed helical compression spring expansion appliance (Fig. 37). It is key activated by rotating an adjustment nut which

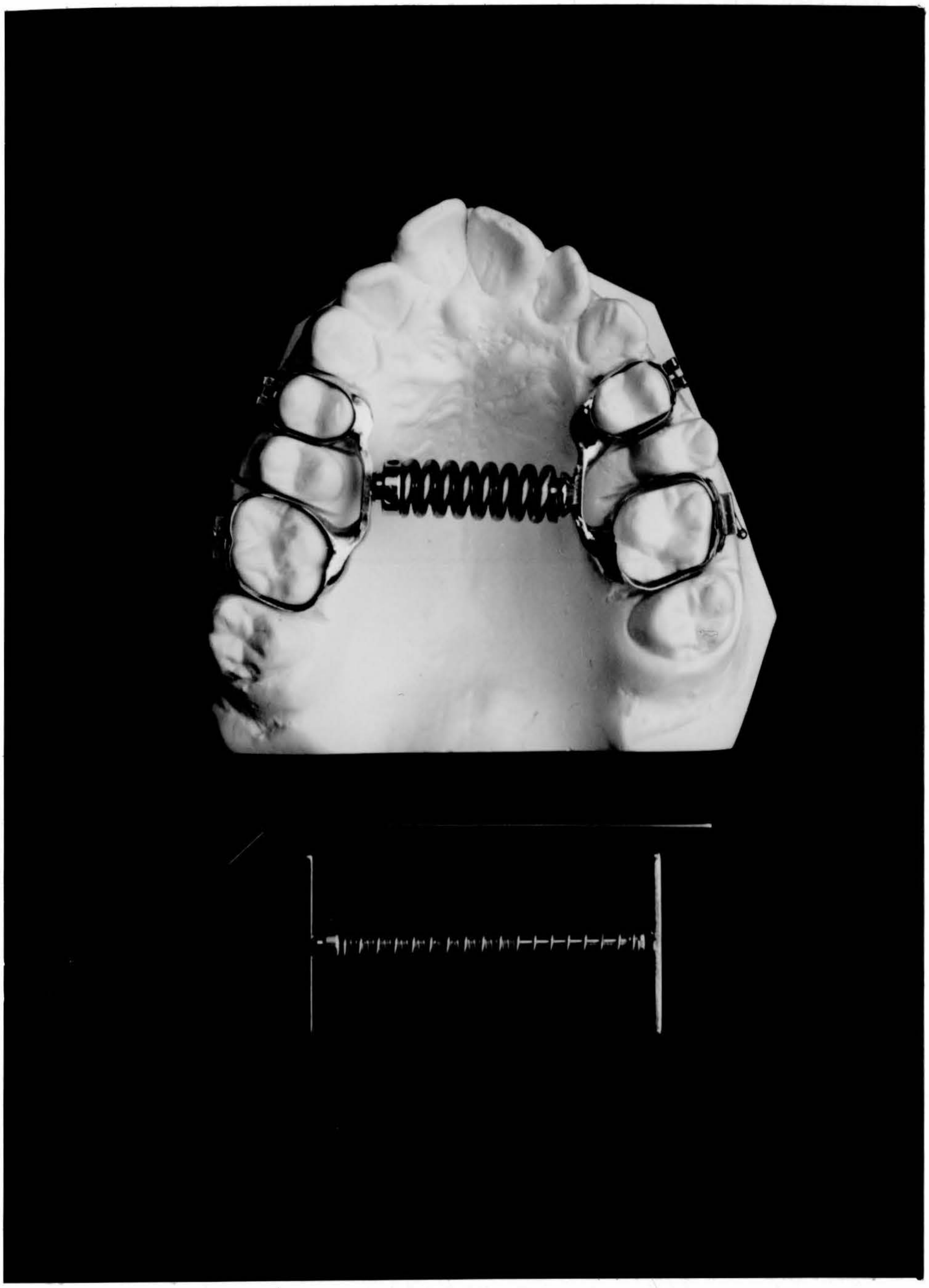


Figure 37. Minne expander. (Ormco[81])

compresses a transversely mounted helical spring and transmits the load to lateral lingual solder bars and abutment teeth. The Minne expander permits clinical awareness of the approximate load present at any point during treatment, what load is produced by any given activation, and the rate of load decay or expansion achieved. The Minne expander is accompanied with a chart (Fig. 38) which plots compression displacement versus number of coil revolutions in the active spring element. Utilizing this chart, the clinician may obtain the approximate load produced for varying degrees of activation. The manufacturer also cautions that unsupervised activation of the appliance can develop loads beyond those reported on the chart.

Fabrication of the Minne expander device employs a direct-indirect technique. Bands are selected for and positioned on two teeth in each maxillary quadrant. The permanent first molars and first premolars are the preferred abutments. If the teeth are not parallel, slightly oversized bands are selected to facilitate seating the appliance. Buccal attachments should be placed on all the bands. The bands are removed in a relationship impression; the lingual surfaces of the bands are waxed in, and a stone working model is poured. The Minne expander lingual bars are adapted to the lingual surfaces of the bands and soldered in place. The appliance is then removed from the working model, cleaned, and polished. Next, the appliance

Figure 38. Minne expander - compression vs. load chart. (Ormco[82])

MINNE EXPANDER

CAUTION: **Unsupervised activation of this appliance is capable of developing very high loads beyond those shown in this chart.**

POUNDS PRESSURE							
COMPRESSION (MM)	4 COIL	5 COIL	6 COIL	7 COIL	8 COIL	9 COIL	(ORIG.) 10 COIL
1/2	1.7	1.7	1.7	1.5	1.5	1.4	1.4
1	4.0	4.0	3.9	3.6	3.3	3.1	3.0
1 1/2	6.3	6.3	6.2	5.6	5.4	4.9	4.9
2	8.6	8.6	8.4	7.7	7.3	6.8	6.7
2 1/2	11.0	11.0	10.7	9.6	9.2	8.5	8.4
3	13.5	13.2	13.0	11.6	11.0	10.3	10.2
3 1/2	16.2	15.6	15.2	13.7	13.0	11.9	11.8
4	19.0	18.0	17.4	15.8	14.8	13.5	13.4
4 1/2	21.6	20.4	19.7	17.9	16.7	15.3	15.1
5	24.2	22.7	22.0	19.7	18.6	17.0	16.9
5 1/2		24.6	24.2	21.6	20.4	18.7	18.6
6				23.7	22.2	20.4	20.3
6 1/2					24.3	22.3	22.1
7						24.1	24.0

In some instances it is necessary to reduce the length of the cylinder, rod and coil in order to fit the appliance into a very narrow arch. The load produced by the original coil and 1 coil increment reductions is shown above.

is inserted and cemented in place. The appliance is constructed permitting activation to be achieved by inserting the key into the adjustment nut anteriorly and directing it posteriorly. The adjustment nut is rotated to achieve the desired compression of the helical spring and load production. A small segment of arch wire is tied into the attachments on the buccal surfaces of the bands to increase stability. After treatment has achieved clinical correction, the appliance is left in place until the load has decreased to resting length of the spring.[82]

Chaconas and Caputo[24] have shown that the Minne expander appliance showed less force with each activation when compared to the Haas and Hyrax appliances. It was also shown that Minne expander produced forces within an orthopedic range.

Developers of the Minne expander appliance suggest the spring allows a gentler force which will remain active over a longer distance than a simple expansion screw. Lite force Minne expanders are modified Minne expanders which produce lighter forces and are designed for slow maxillary expansion.[81]

REMOVABLE APPLIANCE

Removable palatal expansion appliances are tissue-borne split acrylic palate appliances which have a centrally located expansion screw for activation. The removable appliances are commonly used for slow palatal expansion.

One of the routinely employed removable expansion appliances is the Schwartz appliance (Fig. 39).[57] The Schwartz appliance incorporates two midpalatal expansion screws for maximum stability. The anterior expansion screw is placed in the canine area, and the posterior expansion screw is in line with the first molars. Occlusal acrylic coverage is processed over the posterior teeth to disarticulate the arches and provide additional anchorage to minimize the dislodging forces from the active expansion screws. The acrylic lingual to the anterior teeth is scalloped to follow the cingula. The retention of the appliance is usually attained by means of Adams clasps on the molars and ball clasps on the premolars. Activation of the appliances may vary from one-eighth turn every week to one-quarter turn every other day, the former used more commonly in the deciduous dentition. One activation of the expansion screw delivers approximately 0.25 mm. expansion. As with all removable appliances, these require excellent patient cooperation to achieve successful results.

The removable appliances are fabricated indirectly since no banding of abutment teeth is required. An impression is made and a stone working model is poured. The expansion screw and attachments are adapted to the working model and quick cure acrylic is applied. The acrylic body is sectioned in half following the midpalatal suture to permit separation upon activation.

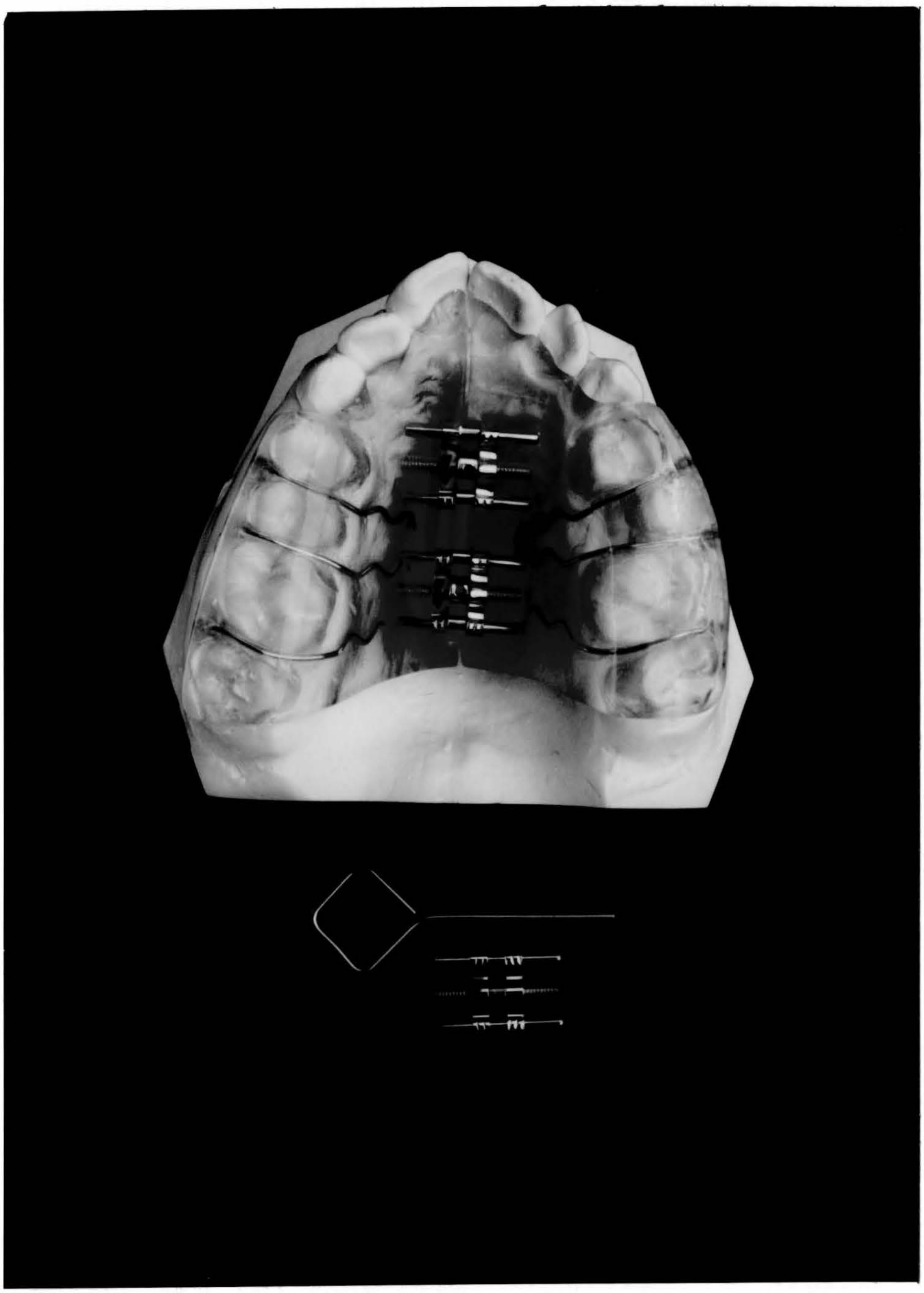


Figure 39. Schwartz palatal expansion appliance. (Huge[57])

Unitek[107,108] has proposed a two-stage removable component system for palatal expansion (Fig. 40). A short first-stage screw, with which the screw body is preassembled, can achieve up to 7 mm. of expansion. To convert the appliance for second-stage application, the screw body is removed from the mouth by retracting the screw and completely freeing it from the anchor legs which are soldered to the banded abutment teeth. The screw body is then disassembled and reassembled using the long screw. Then, the screw assembly is adjusted to be refitted on the anchor legs; therefore, an additional 7 mm. of expansion may be gained by substitution of the long second-stage screw. The chief advantage of this composite appliance is that it permits removal and replacement of the expansion screw without removal of the entire appliance framework. Howard[55] has suggested a similar removable component appliance system for palatal expansion.

Ivanovski[60] has suggested a removable palatal expansion appliance incorporating a centrally located expansion screw in a vacuum formed acrylic split palate base. The indirectly fabricated appliance is maximally adapted to the palate and the dentition; therefore, it distributes force equally to all areas of the mouth, not just to the abutment teeth. Further modifications of removable appliances have been suggested to permit their use in a fixed manner with the acid-etch composite resin technique.[38]

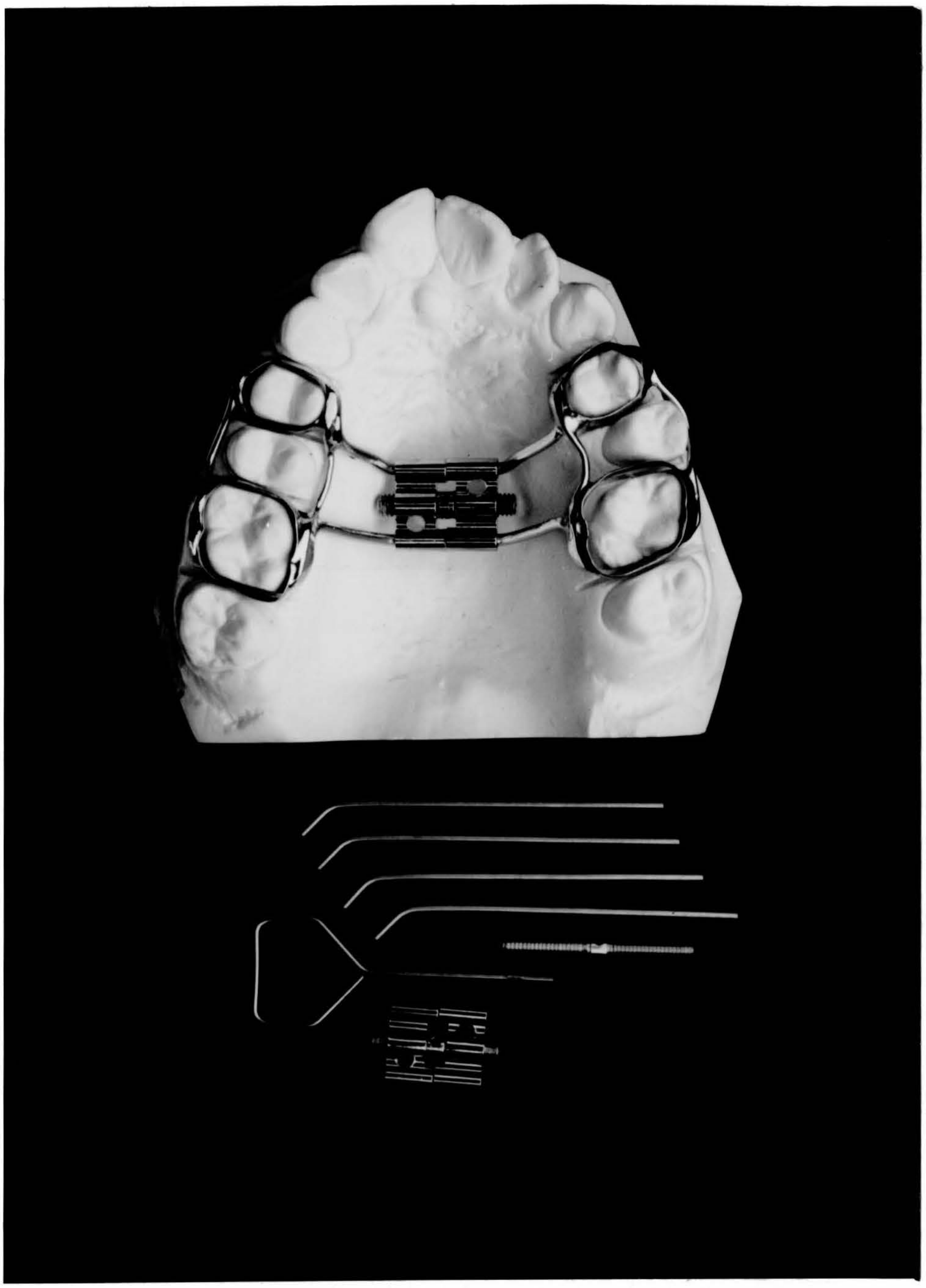


Figure 40. Two-stage palatal expansion screw. (Unitek[107])

QUAD HELIX APPLIANCE

The quad helix[90] is a tooth-borne fixed appliance which is cemented to the maxillary deciduous second molars or permanent first molars (Fig. 41). The quad helix appliance is a lingual expansion arch consisting of four helical loops which are constructed to produce expansion upon activation.

The quad helix is fabricated out of .038 Elgiloy or No. 4 gold wire using a direct-indirect technique. Bands are selected for and positioned on the deciduous second molars or permanent first molars. An impression is made, the bands transferred to it, and a stone working model poured. The quad helix expansion arch is constructed out of one unit piece of wire incorporating four helical loops which when properly activated produce pressure which expands the arch, rotates molar teeth, and orthopedically influences the midpalatal suture. Initiation of the quad helix arch is with the anterior arm at mesial lingual line angle of the canine. The anterior arm is contoured and adapted to the buccal segment and terminates with a posterior helical loop extended distal to the molar band allowing for molar rotation and expansion. Continuing anteriorly off the molar helical loop is a segment of wire called the palatal bridge which terminates in an anterior helical loop at the distal lingual line angle of the canine. Continuing medially off the anterior helical loop is the anterior bridge which

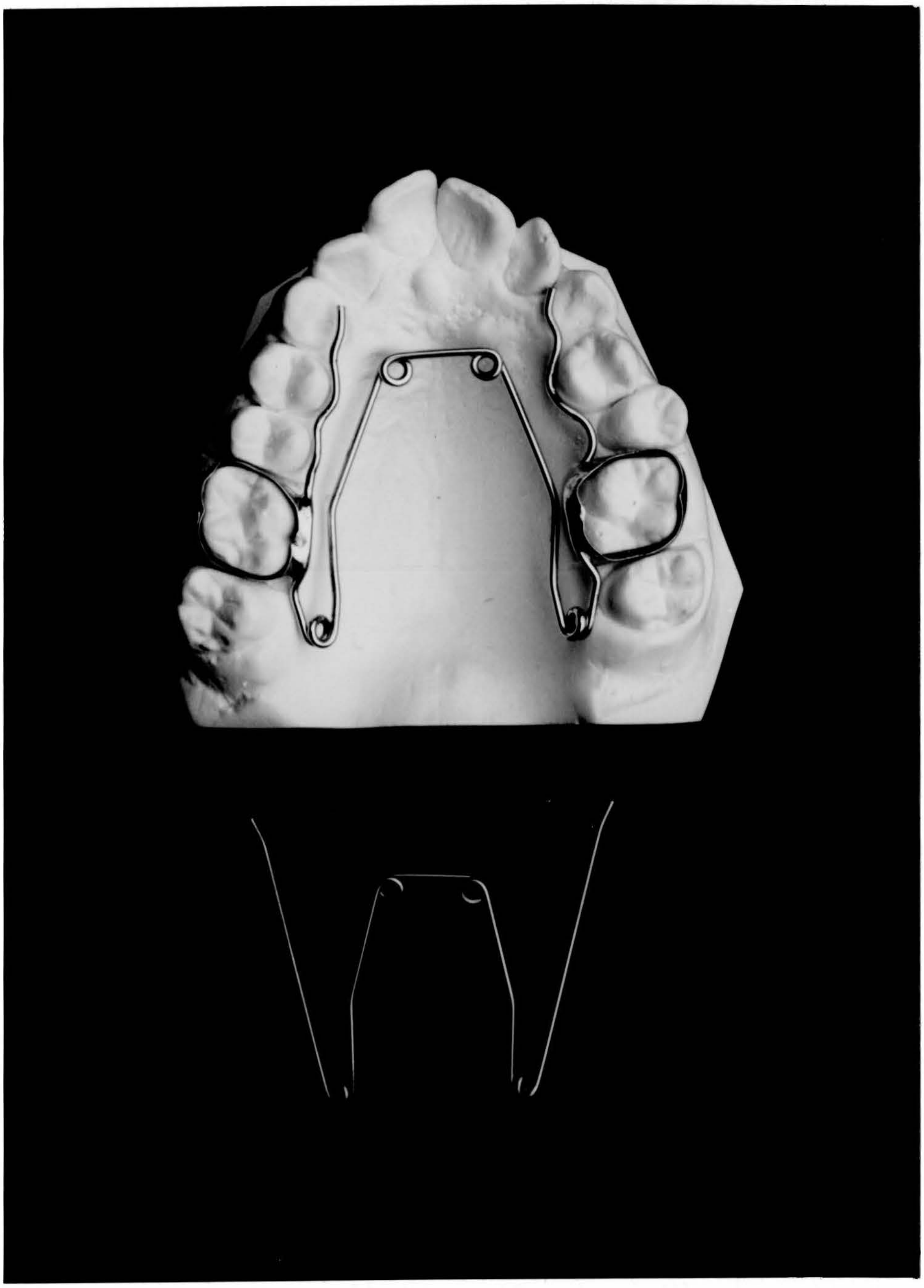


Figure 41. Quad helix expansion appliance. (Ricketts[90])

terminates across the midline into another anterior opening helical loop. The wire fabrication is completed by reversing the aforementioned process on the contralateral side. The anterior arms are soldered bilaterally to the molar bands and polishing completes construction.

Initial activation is derived by expanding the appliance prior to cementation. Intraoral activation of the appliance involves crimping at anterior bridge which produces molar expansion, and crimping at palatal bridges which produce molar rotation and buccal segment expansion.

Modifications of the quad helix appliance to correct thumb sucking or tongue thrusting habits, molar rotation or expansion alone, and anterior and posterior expansion, have also been described.[90] A 3D quad helix has also been proposed by Rocky Mountain Orthodontics which permits three-dimensional molar control in addition to palatal expansion.[91]

SUMMARY

A wide variety of palatal expansion appliances have been presented, each claiming certain advantages. The prototype palatal expansion appliance described in Chapters III and IV maximizes control over the variables encountered with palatal expansion therapy in an attempt to achieve controlled lateral expansion. The prototype palatal expansion appliance which will be presented minimizes patient cooperation factors and permits clinical awareness of the approximate magnitude of force present at any given point in treatment, as well as the rate of force decay. The design of the prototype palatal expansion appliance, permitting greater clinical control over the variables encountered with palatal expansion therapy, provides an alternative to conventional appliance designs and attempts to yield more consistent and beneficial clinical results.

CHAPTER III

METHODS

DESIGN OF THE PROTOTYPE PALATAL EXPANSION APPLIANCE

The proposed prototype palatal expansion appliance is a versatile appliance with the potential of generating orthopedic and/or orthodontic force loads. The prototype expansion unit employs a modular design which is powered by a helical compression spring. The appliance is compatible with rapid or slow palatal expansion therapy. The prototype expansion unit may be fabricated with either an acrylic base or a metal framework. The module assembly consists of the following elements:

Outer housing
Inner housing
Socket
Sleeve
Pin

Energy Source: Helical Compression Spring

Note: All dimensions on the mechanical drawings (Figs. 42-47), and those used in this discussion, are given in inches.

OUTER HOUSING (Fig. 42)

The outer housing represents a slidable component part of the expansion unit. The outer housing element maintains a rounded cylindrical shaft which terminates in a hexagonal base. Within the hexagonal base, a guide pin is inserted to encourage centric travel of the compression spring which powers the device. The inner housing travels within the confines of the outer housing during function. The outer housing possesses two parallel transverse channels which are united by a circumferential channel. One parallel channel provides entry of the inner housing mating piece and therefore, is referred to as an open channel. A circumferential channel is cut into the outer housing 120° from the open channel and terminates into another parallel channel. This parallel channel does not permit escape of the inner housing mating piece and is referred to as a closed channel. It is within this closed channel that the expansion unit will function. This feature provides a bayonet lock assembly which limits the inner housing travel and thereby prevents disengagement of the inner and outer housing assembly.

The base of the outer housing is hexagonal and inserts into the socket (Fig. 44) which is attached to the appliance framework. The hexagonal base permits the outer and inner housing to remain parallel during function and enhance rigidity of the expansion unit. Within the base of the outer housing, a pin is inserted which is mated to the inside diameter of the helical compression spring. This pin will minimize buckling of the compression spring under load and maintain nearly centric spring travel.

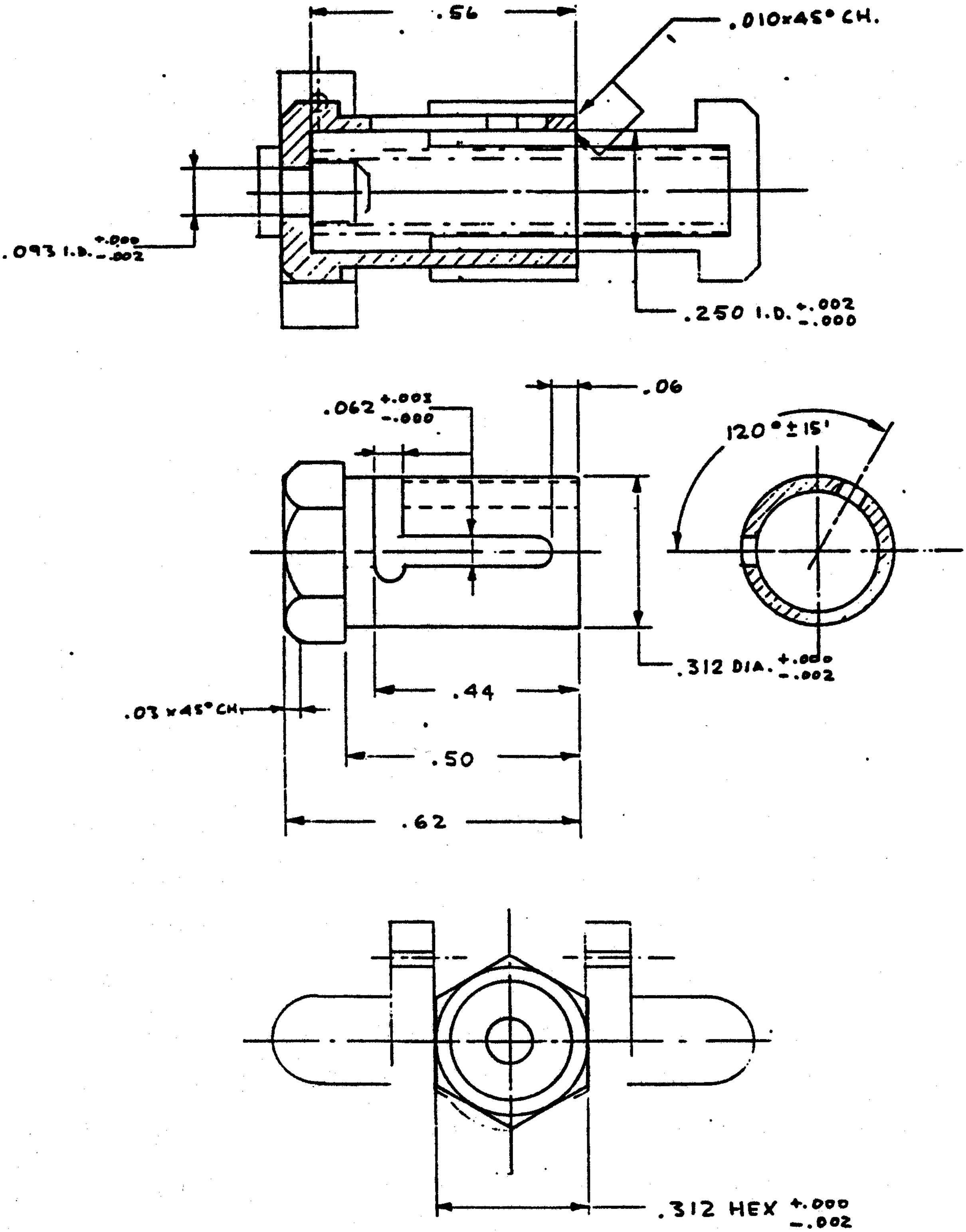


Figure 42. Outer housing of prototype palatal expansion unit. (Dimensions in inches.)

Specifications for the outer housing (Fig. 42):

Overall Dimensions

Total Unit Length	.62
Functional Unit Length	.56

Cylindrical Shaft

Cylinder Length	.50
Outside Diameter	.312
Inside Diameter	.250
Channel Width	.062
Channel Offset	120^{o}
Open Channel Length	.44
Closed Channel Length	.38
Mating Terminal Bevel	.010 x 45^{o} Chamfer

Hexagonal Base

Total Length	.12
Diameter (Hex)	.312
Pin Placement Bore (I.D.)	.093
Hexagonal Head Bevel	.03 x 45^{o} Chamfer

INNER HOUSING (Fig. 43)

The inner housing represents the mating element to the outer housing and with it constitutes the body of the expansion unit. The inner housing element maintains a rounded cylindrical shaft of smaller diameter than the outer housing element and a hexagonal base. The inner housing has a guide tab machined onto its cylindrical shaft which permits insertion into the outer housing's open channel. Rotary action within the circumferential channel will seat the guide tab into its functional position in the closed channel. A hexagonal base represents the terminal attachment of the inner housing similar to the outer housing design.

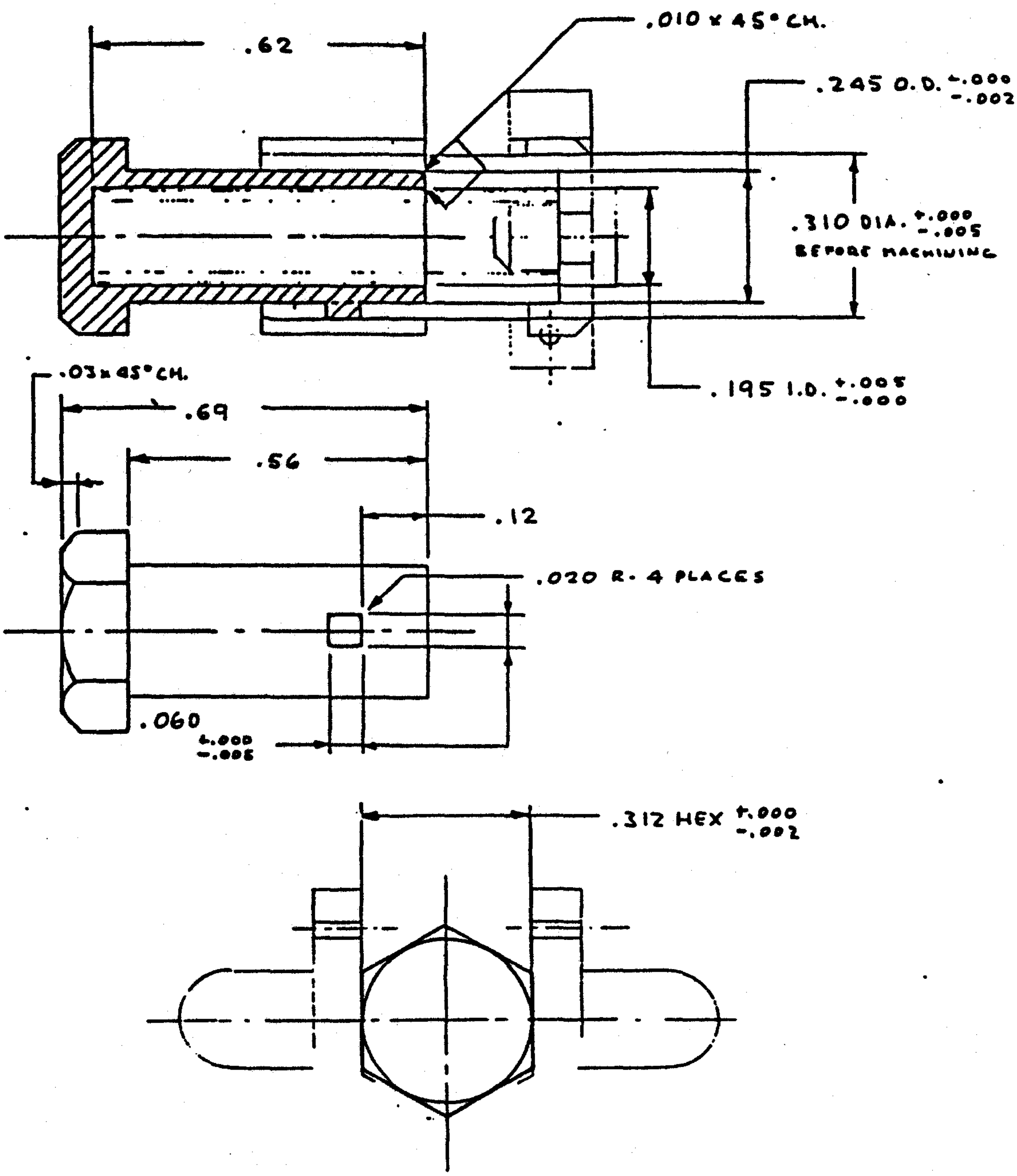


Figure 43. Inner housing of prototype palatal expansion unit. (Dimensions in inches.)

Specifications for the inner housing (Fig. 43):

<u>Overall</u> <u>Dimensions</u>

Total Unit Length	.69
Functional Unit Length	.62

<u>Cylindrical</u> <u>Shaft</u>

Cylinder Length	.56
Outside Diameter	.245
Inside Diameter	.195
Guide Tab Position	.12
Guide Tab Length	.060
Guide Tab Width	.060
Guide Tab Height	.030
Corner Radius	.020
Mating Terminal Bevel	.010 x 45^{o} Chamfer

<u>Hexagonal</u> <u>Base</u>

Total Length	.12
Diameter (Hex)	.312
Hexagonal Head Bevel	.03 x 45^{o} Chamfer

<u>SOCKET</u> (Fig. 44)

Two socket elements are required for this appliance design and are positioned bilaterally in the palate attached to the acrylic base or appliance framework. The socket elements represent the attachment points of the functional unit to the appliance. They are horseshoe shaped receptacles that facilitate attachment of the outer and inner housings' hexagonal bases to the appliance framework. Therefore, the socket elements are mated to the hexagonal bases located at each end of the functional unit. The hexagonal mating of each component part will enhance the rigidity of the expansion unit while securing it against rotation. A mounting base is machined on the socket element to facilitate its attachment to an acrylic

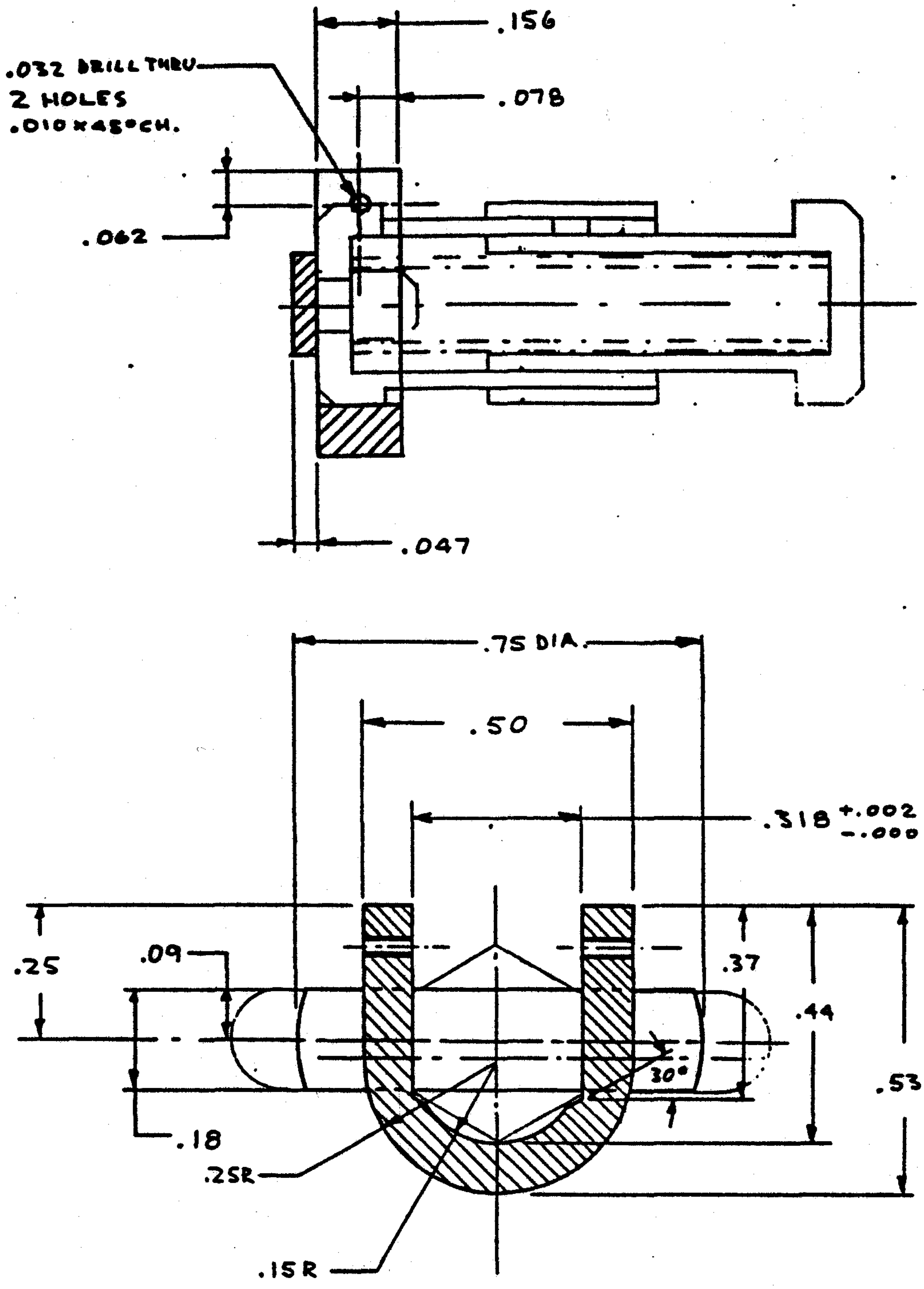


Figure 44. Socket of prototype palatal expansion unit. (Dimensions in inches.)

base or an all metal framework. Two holes are drilled into the socket element to permit module ligation. Securing the expansion unit with orthodontic ligature wire will prevent it from being dislodged from the socket receptacles under function.

Specifications for the socket (Fig. 44):

Mounting Base

Total Length	.75
Total Height	.18
Total Width	.047

Socket

Length (O.D.)	.50
Length (I.D.)	.318
Width	.156
Height (O.D.)	.53
Height (I.D.)	.44
Height (Center Line)	.25
Drop Center	.03
Outside Radius	.25
Inside Radius	.15
Internal Bevel	30^{o}

Drill Holes

Horizontal Position	.078
Vertical Position	.062
Drill Holes (2)	.032
Drill Hole Bevel	.010 x 45^{o} Chamfer

SLEEVE (Fig. 45)

A reinforcing sleeve is wrapped around the outer housing to provide support for the wall. The wall of the outer housing is perforated by three channels and therefore is vulnerable to deformation and/or fracture. The sleeve is brazed to the outer housing element to maintain centric travel of the expansion unit assembly during function.

Specifications for the sleeve (Fig. 45):

Overall Dimensions

Total Length	.310
Outside Diameter	.375
Inside Diameter	.313

PIN (Fig. 46)

A centering guide pin is placed in the hexagonal base of the outer housing to assure centric travel of the helical compression spring. The guide pin also aids in minimizing buckling of the spring under load. The pin acts as a guide by mating to the inside diameter of the helical compression spring.

Specifications for the pin (Fig. 46):

Overall Dimensions

Total Length	.18

Dimensions of Pin: Hex Base

Length of Pin	.06
Pin (O.D.)	.094
Bevel	.010 x 45° Chamfer

Dimensions of Pin: Cylinder

Length of Pin	.12
Pin (O.D.)	.125
Bevel	.020 x 45° Chamfer

MODULE ASSEMBLY (Fig. 47)

Figure 47 represents a composite illustration of the component parts of the prototype palatal expansion unit. The module assembly consists of 5 component parts:

1. Outer Housing
2. Inner Housing
3. Socket
4. Sleeve
5. Pin

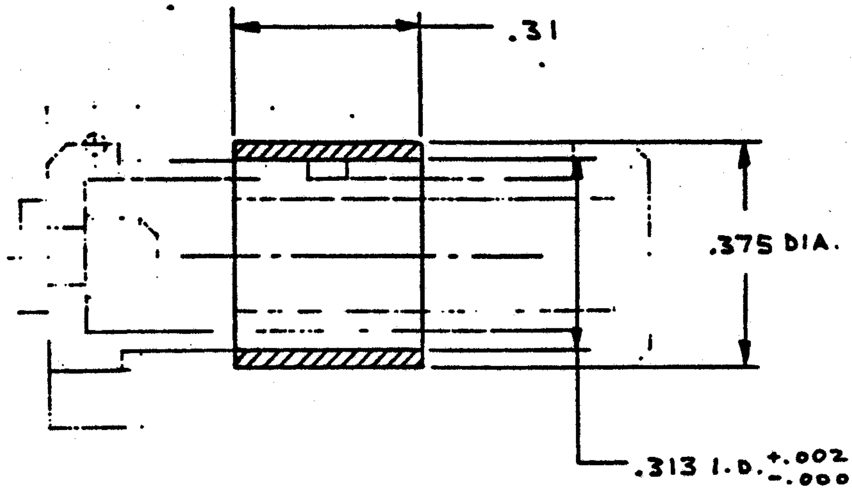


Figure 45. Sleeve of prototype palatal expansion unit. (Dimensions in inches.)

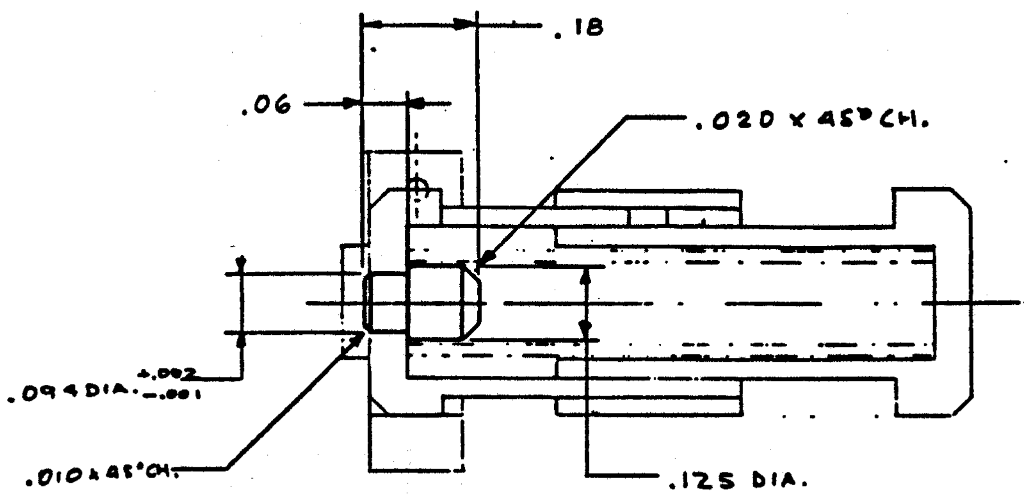


Figure 46. Pin of prototype palatal expansion unit. (Dimensions in inches.)

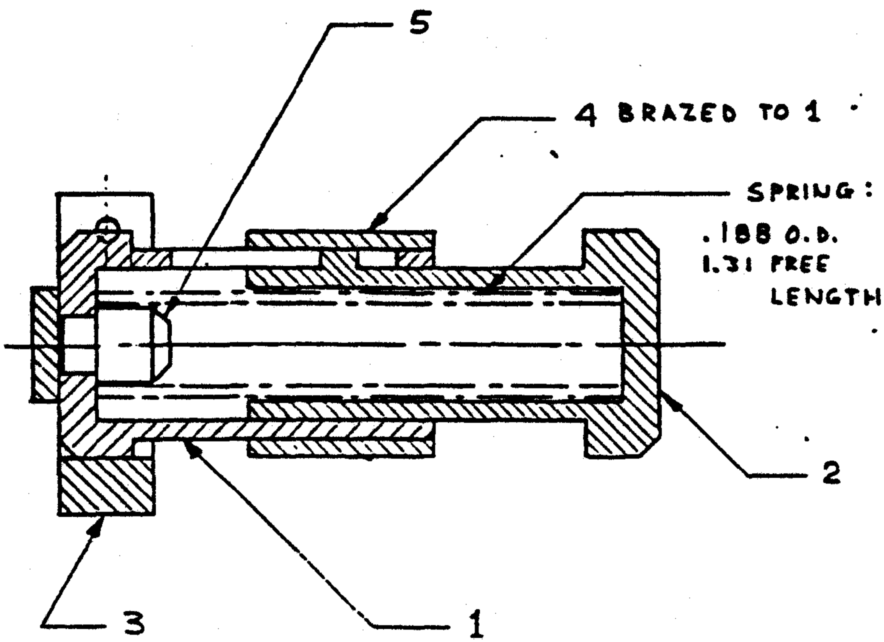


Figure 47. Module assembly of prototype palatal expansion unit. (Dimensions in inches.)

The module assembly is powered by a helical compression spring. The inner housing travels within the confines of the outer housing as the compressed helical spring expresses its stored energy. Rotation of the module assembly is prohibited by two design features:

1. Mating of the hex base with the socket receptacle at each end of the expansion unit.
2. Restricted guide tab movement of the inner housing within the outer housing's closed channel.

ENERGY SOURCE: HELICAL COMPRESSION SPRING

A helical compression spring provides the energy source for the prototype palatal expansion unit. The helical compression spring stores energy in the push mode and therefore, is an ideally suited power source for the expansion unit.

The Barnes group[5,6,7,8] has elaborated on various aspects of spring material selection and described the pertinent features of helical compression spring design. Operating environment is often the single most important consideration for proper spring material selection. For successful application, spring material must be compatible with its surrounding environment and withstand the effects of corrosion and temperature without an excessive loss in spring performance. Corrosion and elevated temperature are two factors which decrease spring reliability.

The material chosen for fabrication of the helical compression spring is AISI type 302 stainless steel.

Stainless steel has been shown to be compatible with the oral environment and corrosion resistant. Furthermore, the effect of the oral cavity temperature on spring performance is considered to be negligible.[5]

Special terminology has evolved in the spring industry to describe the features of helical compression springs and improve communication between the designer and manufacturer. The Barnes group,[5] has described dimensional terminology for helical compression spring design which will be adopted for use in this discussion (Fig. 48).

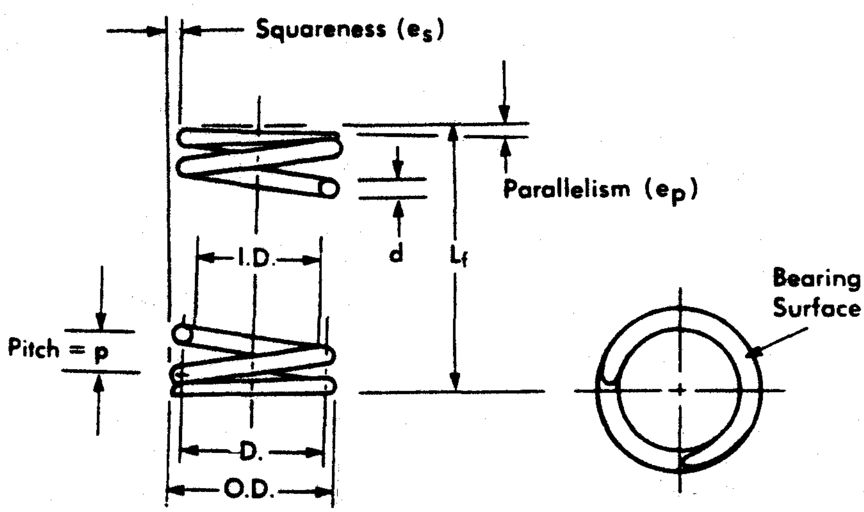


Figure 48. Dimensional terminology for helical compression springs. (Barnes[5])

Specifications for the helical compression spring:

Wire Diameter (d)	.020
Outside Diameter (O.D.)	.188
Inside Diameter (I.D.)	.142
Mean Diameter (D)	.165
Free Length (L_f)	1.31
Pitch (p)	.048
Number of Active Coils (N_a)	16
Solid Height	.36
Type of Ends	Squared ends--Ground
Direction of Coiling	Left Hand
Material	AISI Type 302 Stainless Steel

The wire diameter (d), outside diameter (O.D.), inside diameter (I.D.), and mean diameter (D) are all used to describe helical compression spring dimensions. The wire diameter (d) used in the spring design varies directly with the load produced by compression of the helical spring. The mean diameter (D) is equal to the sum of outside diameter and inside diameter divided by two, and is employed in spring design calculations for stress and deflection. The outside diameter (O.D.) is specified for springs which function within a cavity, while inside diameter (I.D.) is specified for springs which function over a rod. Minimum diametral clearance between the spring and cavity or rod is estimated from the following:

0.05 D when the diameter of the rod or cavity is greater than 0.512".

0.10 D when the diameter of the rod or cavity is less than 0.512".

Spring diameter increases when a spring is compressed. Although the increase in diameter is usually small, it must be considered when minimum clearances are established.

The increase in diameter is a function of initial spring pitch and can be estimated from equation (1) where p = pitch.

$$O.D._{at\ solid} = \sqrt{D^2 + \frac{P^2 - d^2}{\pi^2}} + d \qquad (1)$$

O.D. = Outside Diameter
D = Mean Diameter
d = Wire Diameter

Free length (L_f) is overall spring length in the free or unloaded position (Fig. 48). When definite loads are required of the helical spring, free length is the reference dimension that can be varied to meet these requirements. Pitch (p) is the distance between centers of adjacent coils and is related to free length and number of coils in the spring design.

The type of ends employed in helical compression spring design effects spring activity. The types of ends available are: plain ends, plain ends--ground, squared ends, and squared ends--ground (Fig. 49). To improve squareness and reduce the tendency of buckling under load, a bearing surface of at least 270° at each end is required (Fig. 49). The type of ends employed in the helical compression spring used in the prototype appliance was squared ends--ground.

The total number of coils is usually specified as a reference number when designing a helical compression spring. For springs with squared ends, the total number

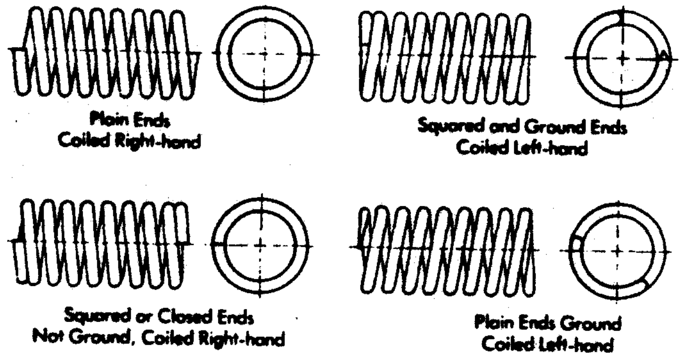


Figure 49. Types of ends for helical compression springs. (Barnes[5])

of coils minus 2 is the number of active coils (N_a) present in the design. There is some activity in end coils; however, during deflection some active material comes in contact with the end coils rendering them inactive.

Solid height is another reference dimension to be considered when designing a helical compression spring. The solid height is the length of the spring with all coils closed. For ground springs, solid height is estimated by multiplying the wire diameter by the number of coils.

A helical compression spring may be fabricated either right or left hand coiled. If the index finger of the right hand can be bent to simulate direction of coil, so that the fingernail and coil tip are approximately at the same angular position, the spring is right-hand wound (Fig. 50). If the index finger of the left hand simulates the coil direction, the spring is left-hand wound.

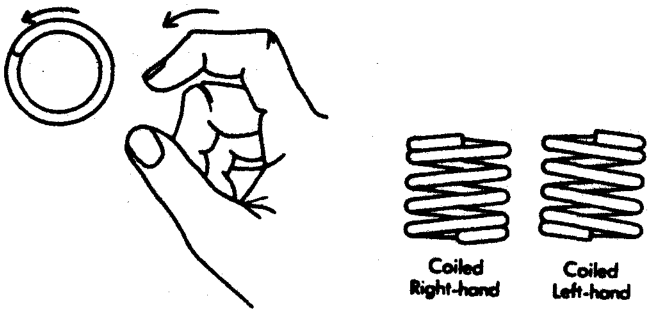


Figure 50. Direction of coiling helical compression springs. (Barnes[5])

Squareness of helical compression springs can be measured by standing the spring on end on a horizontal flat plate and bringing the spring against a straightedge at right angles to the plate. The spring is rotated to produce a maximum out-of-square dimension e_s (Fig. 48).

Parallelism refers to the relationship of the ground ends, and is determined by placing a spring on a flat plate and measuring the maximum difference in free length around the spring circumference e_p (Fig. 48).

Spring rate for helical compression springs is defined as the change in load per unit deflection and is expressed by equation (2).

$$k = \frac{P}{f} = \frac{Gd^4}{8D^3N_a} \qquad (2)$$

k = Spring Rate
P = Load
f = Deflection
G = Shear Modulus
d = Wire Diameter
D = Mean Diameter
N_a = Number of Active Coils

This equation is valid when the pitch angle is less than 15° or deflection per turn is less than D/4. For large deflections per turn, a deflection correction factor should be employed. When deflection is known, loads are determined by multiplying deflection by the spring rate using equation 2.

The load deflection curve for helical compression springs is essentially a straight line up to the elastic limit, provided the amount of active material is constant (Fig. 51). The initial spring rate and the rate as the spring approaches solid frequently deviate from the calculated rate. Therefore, when specifying a spring rate, it is usually specified between two test heights which lie between 15 to 85% full deflection range.

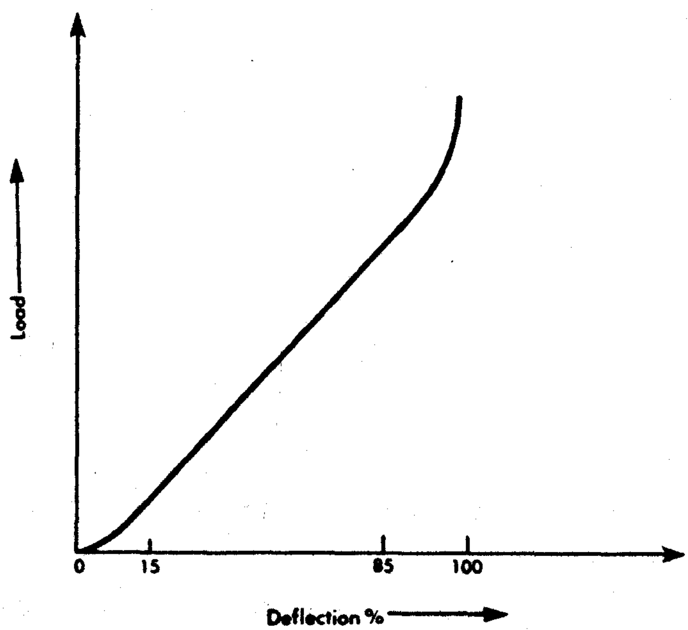


Figure 51. Typical load deflection curve for helical compression springs. (Barnes[5])

Wire in a helical compression spring is stressed in torsion. Torsion stress is derived using equation (3).

$$S = \frac{8PD}{\pi d^3} K_w \qquad (3)$$

S = Stress
P = Load
D = Mean Diameter
d = Wire Diameter
K_w = Stress Correction Factor for Helical Springs

When stresses are known or assumed, loads are determined from equation (3). Bending stresses are present but can be ignored except when the pitch angle is greater than 15^o and deflection of each coil greater than D/4. Under elastic conditions, torsional stress is not uniform around the wire cross section due to coil curvature and a direct shear load. Maximum stress occurs at the inner surfaces of the spring and is computed using a stress correction factor, K_{w1} attributed to Wahl, equation (4).

$$K_{w1} = \frac{4C - 1}{4C - 4} + \frac{0.615}{C} \qquad (4)$$

C = Spring Index D/d
K_{w1} = Stress Correction Factor for Helical Springs

In some instances after yielding occurs, resultant stresses are distributed more uniformly around the cross section. Then, a stress correction factor K_{w2} which accounts only for the direct shear component is used and is calculated from equation (5).

$$K_{w2} = 1 + \frac{0.5}{C} \qquad (5)$$

C = Spring Index D/d
K_{w2} = Stress Correction Factor for Helical Springs

Compression springs that have lengths greater than four times the spring diameter can buckle. If properly guided, either in a cavity or over a rod, buckling can be minimized. However, friction between the spring and tube or rod will affect the loads, especially when the aspect ratio (L_f/D) is high.

Infinite numbers of variations of helical compression spring designs are possible. Therefore, spring design engineers use reference tables for quick estimation of approximate spring dimensions, such as: outside diameter, wire diameter, free length, load at specific compressed lengths, and spring rate. Figure 52 represents tabular data obtained from Barnes,[9] illustrating the dimensional variables in helical compression spring design. The spring selected for the prototype appliance has an approximate spring rate of 3.0 lb/in. This force range is considered to be within the orthopedic range. By varying the wire diameter to .014, a spring rate of approximately 1.0 lb/in. is generated. This force range is within the

Outside Diameter		Wire Diameter		Free Length, L		Load, P		Length, L_1		Spring Rate, R	
in	mm	in	mm	in	mm	lb†	N†	in	mm	lb/in†	N/mm†
				0.25	6.35			0.116	2.95	6.2	1.086
				0.31	7.87			0.139	3.53	4.9	0.858
				0.38	9.65			0.167	4.24	3.9	0.683
				0.44	11.18			0.190	4.83	3.4	0.595
				0.50	12.70			0.214	5.44	2.9	0.508
				0.56	14.22			0.238	6.05	2.6	0.455
		0.014	0.36	0.62	15.75	0.84	3.74	0.261	6.63	2.3	0.403
				0.69	17.53			0.289	7.34	2.1	0.368
				0.75	19.05			0.313	7.95	1.9	0.333
				0.88	22.35			0.364	9.25	1.6	0.280
				1.00	25.40			0.411	10.44	1.4	0.245
				1.25	31.75			0.510	12.95	1.1	0.193
				1.38	35.05			0.561	14.25	1.0	0.175
				1.50	38.10			0.608	15.44	0.9	0.158
0.180	4.57			0.25	6.35			0.109	2.77	8.9	1.559
				0.31	7.87			0.143	3.63	7.5	1.313
				0.38	9.65			0.169	4.29	5.9	1.033
				0.44	11.18			0.187	4.75	4.9	0.858
				0.50	12.70			0.205	5.21	4.2	0.736
				0.56	14.22			0.223	5.66	3.7	0.648
		0.016	0.41	0.62	15.75	1.25	5.56	0.254	6.45	3.4	0.595
				0.69	17.53			0.283	7.19	3.1	0.543
				0.75	19.05			0.300	7.62	2.8	0.490
				0.88	22.35			0.389	9.88	2.5	0.438
				1.00	25.40			0.440	11.18	2.2	0.385
				1.25	31.75			0.545	13.84	1.7	0.298
				1.38	35.05			0.600	15.24	1.6	0.280
				1.50	38.10			0.651	16.54	1.4	0.245
				1.75	44.45			0.756	19.20	1.2	0.210
				0.25	6.35			0.120	3.05	13.5	2.36
		0.018	0.46	0.31	7.87	1.76	7.83	0.156	3.96	11.4	2.00
				0.38	9.65			0.190	4.83	9.3	1.629
				0.44	11.18			0.215	5.46	7.8	1.366
				0.50	12.70			0.239	6.07	6.7	1.173
				0.56	14.22			0.252	6.40	5.7	.998
				0.62	15.75			0.276	7.01	5.1	0.893
				0.69	17.53			0.310	7.87	4.6	0.806
				0.75	19.05			0.323	8.20	4.1	0.718
				0.88	22.35			0.417	10.59	3.7	0.648
				1.00	25.40			0.471	11.96	3.2	0.560
		0.018	0.46	1.25	31.75	1.76	7.83	0.584	14.83	2.6	0.455
				1.38	35.05			0.643	16.33	2.3	0.403
				1.50	38.10			0.697	17.70	2.1	0.368
				1.75	44.45			0.810	20.57	1.8	0.315
				0.25	6.35			0.142	3.61	21.2	3.71
				0.31	7.87			0.171	4.34	16.5	2.89
				0.38	9.65			0.205	5.21	13.1	2.29
				0.44	11.18			0.234	5.94	11.1	1.944
				0.50	12.70			0.263	6.68	9.7	1.699
				0.56	14.22			0.292	7.42	8.6	1.506
		0.020	0.51	0.62	15.75	2.29	10.19	0.321	8.15	7.7	1.348
				0.69	17.53			0.355	9.02	6.8	1.191
				0.75	19.05			0.384	9.75	6.3	1.103
				0.88	22.35			0.447	11.35	5.3	0.928
				1.00	25.40			0.505	12.83	4.6	0.806
				1.25	31.75			0.626	15.90	3.7	0.648
				1.38	35.05			0.689	17.50	3.3	0.578
				1.50	38.10			0.747	18.97	3.0	0.525
				1.75	44.45			0.868	22.05	2.6	0.455

Figure 52. Helical compression spring design, dimensional data. (Barnes[9])

orthodontic range. Therefore, during treatment, the expansion unit assembly will remain constant, but the energy source which is inserted into the assembly will change according to the desired type of movement (orthopedic vs. orthodontic) and the desired expansion rate.

CHAPTER IV

RESULTS

PROTOTYPE PALATAL EXPANSION APPLIANCE FUNCTION

The prototype palatal expansion unit is designed to function quite differently from conventional palatal expansion units. The principal difference is related to the method of appliance activation. Conventional methods of appliance activation require the patient to insert a key into the expansion unit and activate it at designated intervals. The prototype palatal expansion appliance does not rely on patient cooperation for expansion unit activation.

The prototype palatal expansion unit is inserted in the active compressed state and relies on the travel of the helical compression spring within the module assembly to provide the expansile force. A discussion of the functioning component parts of the module assembly will follow:

<u>MODULE ASSEMBLY</u> (Fig. 53)

The module assembly as described in Chapter III consists of the following elements:

Outer housing
Inner housing
Socket
Sleeve
Pin

Energy source: Helical compression spring

These elements are assembled in a series of steps. The helical compression spring is inserted in the inner housing and fully seated to its hexagonal base. The inner housing inside diameter confines the helical spring and minimizes buckling of the spring under compression force. The free end of the helical compression spring is then directed inside the outer housing and threaded over the outer housing's guide pin located in the hexagonal base. The guide pin mates with the inside diameter of the helical spring and thereby maintains centric travel of the spring. The outer housing's guide pin minimizes buckling of spring due to compression loading as it travels within its larger diameter cylindrical shaft. Next, the guide tab is located on the inner housing cylindrical shaft and rotated to align with the open channel located on the outer housing cylindrical shaft inside the reinforcing sleeve. The unit is compressed allowing the guide tab to slide down the open channel to full engagement. The inner housing is then rotated 60° in the circumferential channel to lock the assembly together under compression. The guide tab has a square shape with .020 radius corners to minimize frictional binding of the tab within the functional channels.

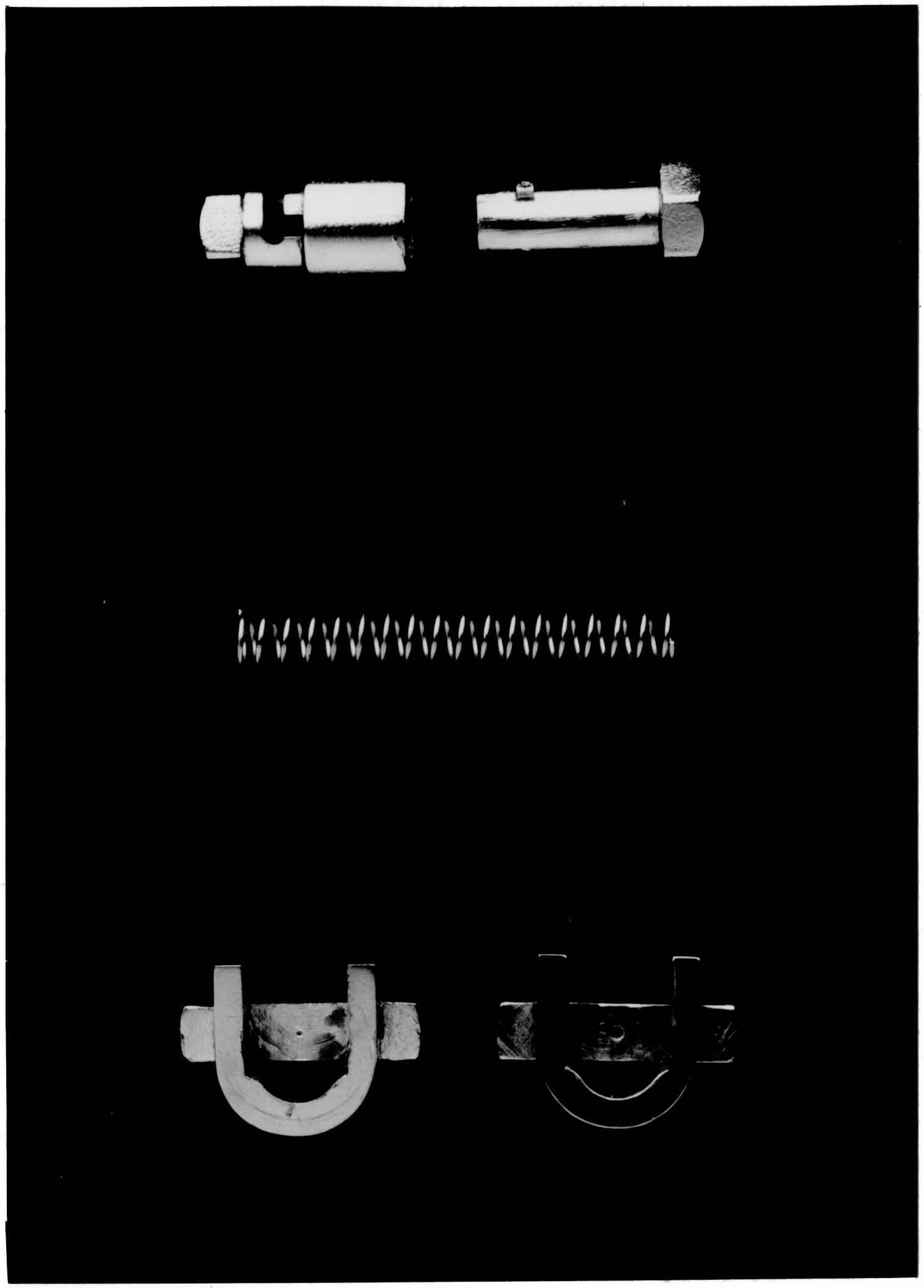


Figure 53. Module assembly of prototype palatal expansion unit.

The module now represents a single unit of stored energy which is ready for insertion into the sockets bilaterally attached to the appliance framework.

The prototype palatal expansion appliance may be constructed either embedded in an acrylic resin base (Fig. 54) or soldered to a metal framework (Fig. 55). The mounting bases which are machined on the socket elements facilitate their attachment. The mounting bases are positioned parallel within the palatal vault using the inactive compressed module assembly to facilitate socket attachment to the appliance acrylic base/framework and abutment teeth.

MODULE INSERTION

The module is inserted into the sockets which are attached to the appliance framework in a sequential manner. The inner housing hex base is aligned within the socket and allowed to seat fully. The socket design features a drop center radius and a 30° internal bevel which permits seating to the flat surfaces on the hexagonal base. This reduces any stresses which may be localized at the corners of the hexagonal base. The unit is inserted and oriented to permit visualization of the guide tab travel within the circumferential channel. Next, the outer housing is rotated 60° to permit the guide tab to enter the closed channel and the outer housing hex base to align parallel with inner housing hex base and seat into

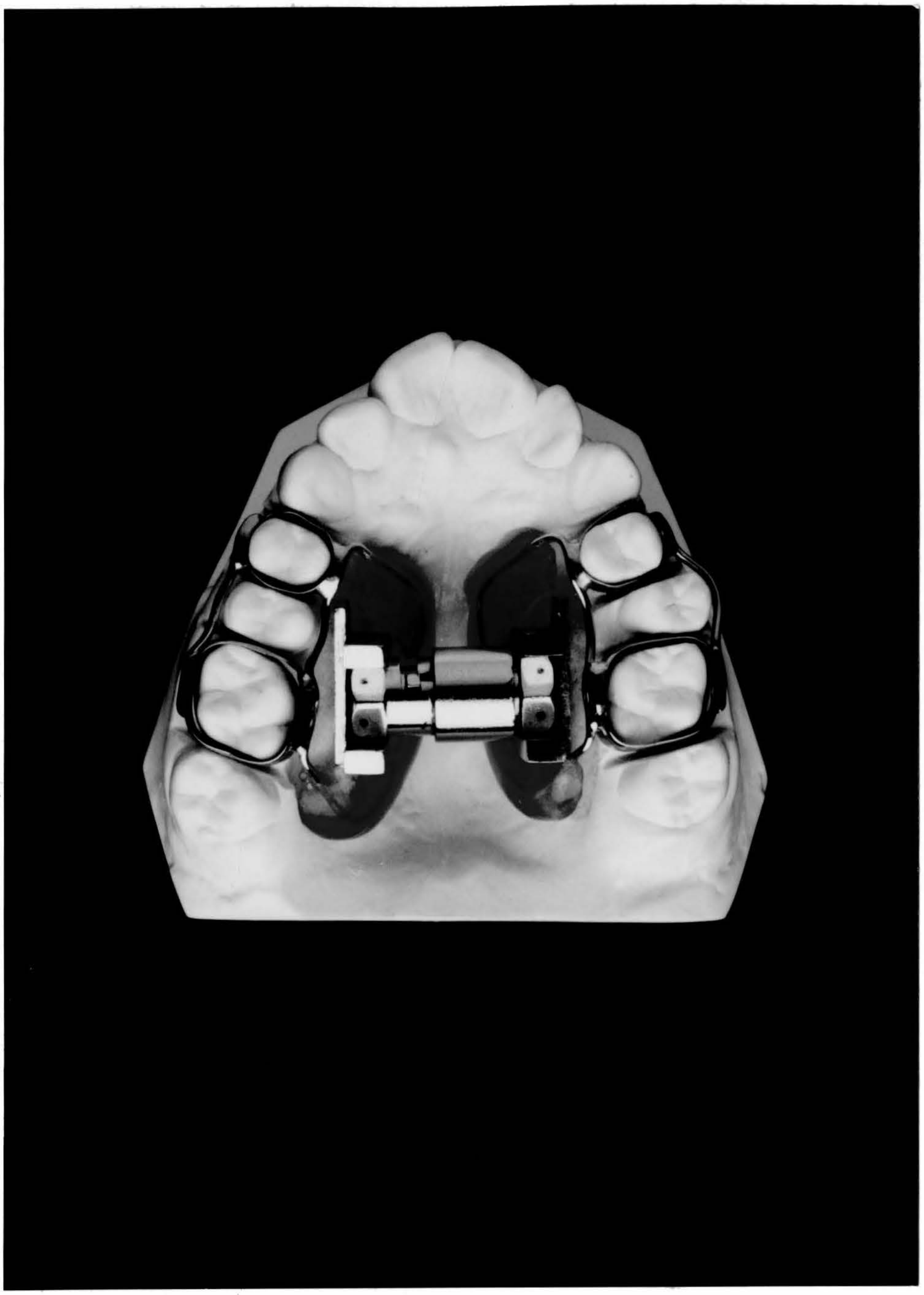


Figure 54. Prototype palatal expansion appliance. Acrylic base design.

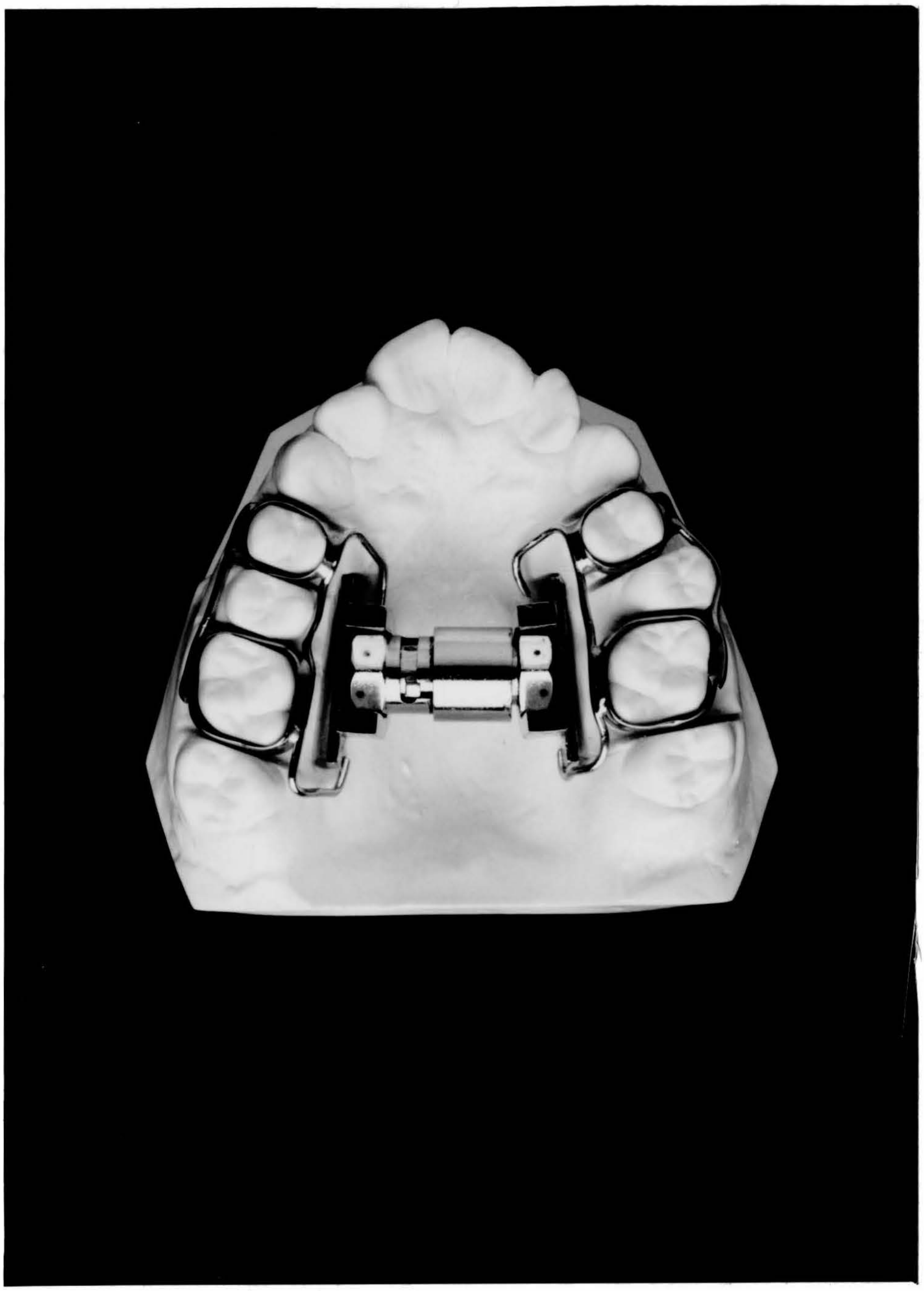


Figure 55. Prototype palatal expansion appliance. Metal framework design.

the opposing socket. The unit is then ligated in place with orthodontic ligature wire through the drill holes in the socket receptacle. This prevents assembly disengagement during function. The terminal ends of each respective housing are chamfered to reduce friction between the two housing elements during functional movement.

MODULE REMOVAL

Removal of assembly is facilitated by reversing the aforementioned process. The reinforcing sleeve stabilizes the wall of the outer module assembly and permits a point of plier application to facilitate assembly removal. The assembly is compressed and the module is removed after the restraining ligature wires have been removed.

CHAPTER V

DISCUSSION

The proposed prototype palatal expansion appliance theoretical model presents specific advantages over conventional palatal expansion appliances. The advantages of the prototype palatal expansion appliance design are:

1. minimizing patient cooperation factors;
2. capability of developing orthopedic or orthodontic force loads;
3. clinical awareness of the load present during active expansion;
4. appliance compatibility with slow and/or rapid expansion rates;
5. expansion unit compatible with construction of either an acrylic base or an all wire framework.

The prototype palatal expansion appliance minimizes patient cooperation factors. The prototype expansion unit is inserted in the active state and does not require daily activation by the patient as is required by the majority of expansion appliances. This permits greater clinical control over the expansion procedure. More consistent clinical results may be obtained if irregular appliance activation schedules which may be seen with the conventional appliances are eliminated. Furthermore, the side effects of accidental swallowing or of aspiration of the conventional appliance keys will be eliminated by this design.[79] The prototype appliance design also requires minimal additional clinical chair time to remove the assembly and insert a new active element within the module.

The capability of varying the force loads is also possible with this appliance design. By altering the wire size diameter, pitch, and free length of the helical compression spring, the spring will be capable of generating loads in either the orthopedic or the orthodontic range.

Clinical awareness of the load present at any time is possible using equation (2) when the deflection is known. The Minne expander[82] has this information tabulated on a chart (Fig. 38). A similar chart could be developed for the prototype appliance. Furthermore, the outer housing of the module assembly could be calibrated to permit visualization and quick estimation of the magnitude of displacement and thus the load present.

The prototype palatal expansion appliance resists rotation by two unique design features:

1. Mating of the hex base with the socket receptacle;

2. Restricted guide tab movement of the inner housing.

This appliance will allow orthopedic loads to be transferred to the maxillae and possess significant rigidity to prevent structural damage. At the maximum expansion allowable by the module assembly, the minimum overlap exists between inner and outer housing assemblies. Therefore, a sleeve was added to bolster the support of the outer housing's wall.

The prototype appliance is compatible with slow or rapid expansion procedures. Selecting a different helical compression spring energy source will allow alterations in the rate of expansion. The clinician may choose initially to start the expansion with a rapid rate which is subsequently followed by a slow rate prior to stabilization. These alterations would be possible by removing the module assembly and inserting a different active element.

Altering the rate of expansion is dependent on altering the spring rate (equation 2). The spring rate varies directly with shear modulus and the diameter of the wire. Therefore, the clinician can alter the expansion rate by altering the diameter of wire incorporated in the active element. The spring rate varies inversely with the mean diameter of the spring and the number of active coils in the helical compression spring. A series of color coded helical compression springs could accompany the module assembly with spring rate being laboratory determined, whereby the clinician could judge the expansion rate.

The socket receptacle was designed to be compatible with an acrylic base or a wire framework. The socket element has a mounting bracket which can be adapted for soldering to a metal framework or embedded in an acrylic base. This versatility enables the appliance to be used as a hygienic appliance similar to the Hyrax, or as an acrylic based appliance, similar to the Haas appliance. The teeth utilized for attachment purposes are the permanent first molars and first premolars. Fixed abutment units are required to secure the removable module assembly.

The primary objective of palatal expansion is controlled lateral expansion. The prototype palatal expansion appliance minimizes some of the variables encountered with the palatal expansion technique and therefore, more consistent clinical results may be obtained. The prototype appliance provides clinician controlled expansion which may help to achieve more predictable and stable results.

The appliance design represents only one variable encountered in palatal expansion therapy. It is necessary to understand the interaction of all of the variables encountered with palatal expansion therapy in order to select the appropriate power source for the module. If skeletal alterations are desired, an orthopedic force module is selected; if dental alterations are desired, an orthodontic force module is selected.

In summary, the prototype expansion unit is a versatile appliance. Clinical trials will be necessary to assess its utility in the orthodontic field. The theoretical model provides significant advantages over the conventional appliances. Its adaptability to a variety of clinical situations should permit its eventual use in orthodontic therapy.

Many variations of the prototype appliance design are possible. Designing a series of modules, accommodating to the various palatal vault morphologies, may present a possible avenue for second and third generation appliance design. Arranging multiple modules in parallel within the appliance body may permit even greater control over the expansion process. It may even be possible to design a plier which would facilitate module insertion and removal. Furthermore, modifications of the socket receptacles to be compatible with the acid etch composite resin system, may be possible. Every answer asks new questions; it is up to further research to unlock these mysteries.

SUMMARY

Palatal expansion therapy is a very useful clinical treatment modality for the correction of posterior crossbite. Beneficial effects have been observed both anatomical and physiological when the maxillary apical base is widened and harmonized with the mandibular apical base. In order to properly utilize this treatment modality, however, it is necessary to understand the treatment variables as they relate to palatal expansion therapy.

The relative amount of skeletal vs. dental alterations observed with palatal expansion therapy is primarily related to the following treatment variables:

patient's age
rate of expansion
magnitude of applied transverse force
retention protocol
appliance design

Maximizing control over these variables and altering them to obtain the best clinical advantage allows for more predictable and stable results. The proposed palatal expansion appliance design minimizes patient cooperation factors and yields additional control over the other variables encountered with the procedure. By minimizing patient cooperation factors, it is possible to achieve more consistent clinical results.

The proposed palatal expansion appliance is very versatile. Its versatility is primarily due to its modular design. A different helical compression spring energy source may be selected to provide the desired orthopedic and/or orthodontic movement. The appliance is rigid enough to prevent rotation under heavy orthopedic load. The proposed palatal expansion appliance is compatible with slow or rapid therapy. Each component of the appliance functions harmoniously in an effort to achieve the ultimate goal of palatal expansion therapy, "controlled lateral expansion".

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The final copies have been examined by the director of the thesis and the signature which appears below verifies the fact that any necessary changes have been incorporated and that the thesis is now given final approval by the Committee with reference to content and form.

The thesis is therefore accepted in partial fulfillment of the requirements for the degree of Master of Science.

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