Forces Produced By Rapid Maxillary Expansion

I. Design of the Force Measuring System

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Introduction

The clinical use of rapid mechanical expansion screw appliances was first described over a century ago. Since the procedure was apparently contradictory to the most widely accepted orthodontic principles however, it was not generally accepted. New interest has been shown in this procedure in the last decade. Nevertheless, despite the awareness of controlled force levels in orthodontics today, no data has been reported to even approximate the magnitude and duration of the forces associated with rapid expansion techniques. In order to most efficiently and safely employ these procedures it is imperative that these forces and the biologic responses they invoke be disinterestedly investigated and clearly described.

This report is one portion of a program undertaken at the School of Dentistry of the University of Minnesota to evaluate rapid expansion procedures. The study reported in this paper describes the design, construction and calibration of a force measuring system which was developed to accurately measure the forces produced by rapid expansion techniques. Subsequent papers will describe the forces measured by this instrument in clinical patients during the periods of active treatment and retention.

Theoretical Considerations

Dental structures are frequently subjected to a wide variety of pressure or loads. Some loads tend to push an object and these are commonly referred to as forces. Other loads tend to rotate objects and these are commonly referred to as couples or moments. Often these loads are highly complex and any attempt to measure them must necessarily be based on principles of mechanics.

In mechanics, complex loads acting in arbitrary directions are resolved into components along three perpendicular axes. The components along each axis are then summed to produce one equivalent component. In Figure 1 the x-axis component is vertical and the superior direction is taken as positive. The y-axis component is perpendicular to the x-axis and the distal direction is taken as positive. The z-axis component is perpendicular to both of the previously described axes and has a positive lingual direction completing a right handed orthogonal triad.

The loads exerted by expansion screw appliances may also be resolved into these component forces and moments. However, some of the components are

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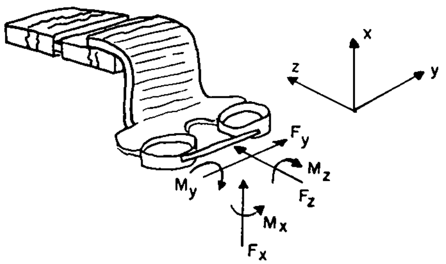

Figure 1 Component loads potentially capable of acting on the expansion-screw appliance.

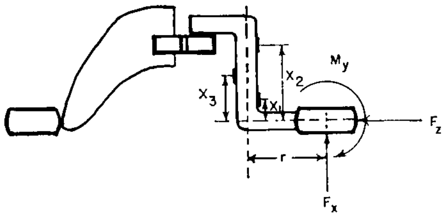

Figure 2 Design of the expansion-screw appliance showing modification to incorporate the dynamometer.

more important than others. F_z is clearly the most important since it is oriented against the direction that the appliance tends to expand. Similarly, the load F_x is probably important since it is oriented against the direction of tooth extrusion and it has been demonstrated that teeth can extrude during treatment. Since it is not possible for orthodontic tooth movement to result in any significant amount of lateral tipping of the teeth during the relatively short duration of treatment, the maxilla must be the source of a large resisting moment. Therefore, M_y is also probably an important load. On the other hand, the loads F_y, M_x, and M_z, are probably relatively less important and, consequently, these three loads were taken as equal to zero in the analysis that follows.

DESIGN OF THE SYSTEM

In order to measure the loads F_z, F_x, and M_y the appliance shown in Figure 2 was designed. One half of a centrally positioned expansion screw was embedded in acrylic in the usual manner. The other half of the expansion screw housing was soldered to one end of a stainless steel beam having two right angle bends. The other end of the beam was soldered to the bands on the teeth. Therefore, activation of the expansion screw in the mouth is accompanied by deformation of the metal. When recordings of these deformations are compared with deformations produced by known loads, the magnitude of the appliance loads in the mouth can be ascertained.

SENSING ELEMENT

The deformation of the beam produced by the various loads was measured using bonded filament strain gauges. A strain gauge is a small grid of wire or foil which can be bonded to the surface of a deformable object. When a load is applied to the surface of an object, its dimensions are changed and it becomes strained. If a strain gauge is properly bonded to the surface of the object, its dimensions will be changed in a similar fashion and any such change will alter the electrical resistance of the wire grid. Therefore, if an electric current is passed through the gauge, it is possible to measure this resistance change in the strain gauge and thereby record the strain on the surface of the object at that point. The system composed of the deformable object and the attached strain gauges is referred to as a dynamometer.

ANALYSIS OF DEFORMATION

The loads F_x, F_z, and M_y each affect the strain at every point of the beam in some way. Moreover, the total strain at each point is equal to the sum of the strains produced by each load separately. Since there are three unknown loads, the total strain at three points must be measured in order to determine the loads. In Figure 2, gauge 1 is located distance x_1 from the occlusal bend, gauge 2 distance x_2 on the same side of the beam, and gauge 3 distance x_3 on the opposite side of the beam. The strain at each of these locations due to each of the loads is derived in the following manner.

It is generally assumed that an axial load, such as F_x, is uniformly distributed over any cross section. Hence the strain (load per unit area) at every point resulting from the axial load F_x is $\sigma = \frac{-F_x}{A}$ where F_x is given in pounds, A in square inches and σ in pounds per square inch. Notice that the stress in the beam is compressive when F_x is positive, hence the minus sign.

Similarly, it is generally assumed that for a pure bending moment such as M_y, the stress is the same in every cross section. Moreover, the stress distribution is such that one half of the cross section is subjected to tensile stresses and the other half to compressive stresses. The two regions are separated by a neutral plane or plane of zero stress. The stress at any point in the cross section due to the pure bending moment M_y is $\sigma = \frac{-M_y z}{I}$ where z is the distance of the point from the neutral plane in inches. The variable z may assume any value from $-d/2$ on the buccal surface of the beam to $+d/2$ on the lingual surface of the beam. The "moment of inertia," I, of a cross section is a measure of the ability of a given cross section to withstand bending moments. If the moment is held constant, the stress decreases as I increases, i.e., as the cross section gets stiffer. For a rectangular cross section $I = 1/12\ bd^3$ where b is the width and d is the thickness in inches.

Account must also be taken of the fact that F_x acts along a line of action set at a distance *r* from the neutral plane (Fig. 2). Hence, in addition to an axial stress, F_x also gives rise to a bending moment rF_x which is the same for every cross section. The effect of the moment M_y and the effect of the moment rF_x can be combined to give one equivalent movement M_0 as

$$M_0 = M_y + (-rF_x) = M_y - rF_x$$

The negative sign is introduced because rF_x acts in an opposite direction to the direction defined as positive for M_y.

Finally, since the load F_z acts perpendicular to the long axis of the beam, it tends to bend the beam. In this instance, unlike the case of the pure bending moment M_y, the amount of bending at any cross section depends on the distance of the section from the line of action of F_z and is given as $M = xF_z$ where x is the distance of a cross section from the line of action in inches. Therefore, the stress due to F_z at any point of any cross section is

$$\sigma = \frac{-(xF_z)z}{I} = \frac{-xzF_z}{I}$$

Based on the fact that stress and strain are related by Hooke's Law, $\sigma = E\varepsilon$ (or $\varepsilon = \frac{\sigma}{E}$) where E is Young's modulus, the total strain at the location of each of the three strain gauges can be obtained by dividing the total stress by E. The total stress at each gauge is the sum of the stresses produced by F_x, M_0, and F_z. Hence,

$$\varepsilon_1 = -\frac{F_x}{AE} + \frac{d\,M_0}{2\,EI} + \frac{d\,x_1\,F_z}{2\,EI}$$

$$\varepsilon_2 = -\frac{F_x}{AE} + \frac{d\,M_0}{2\,EI} + \frac{d\,x_2\,F_z}{2\,EI}$$

$$\varepsilon_3 = -\frac{F_x}{AE} - \frac{d\,M_0}{2\,EI} - \frac{d\,x_3\,F_z}{2\,EI}$$

Notice that z has the value $-d/2$ at locations 1 and 2 and $+d/2$ at location 3. These three equations contain the three unknowns F_x, M_0, and F_z and can be solved for F_z to obtain

$$F_z = \frac{2\,EI}{d} \frac{(\varepsilon_1 - \varepsilon_2)}{(x_1 - x_2)} = K\,(\varepsilon_1 - \varepsilon_2)$$

where $K = \dfrac{2\,EI}{d\,(x_1 - x_2)}$

The symbol K is a constant describing the dimensions and properties of the beam and the location of the gauges. Notice that the load F_z can be determined from only two strain readings if they are both taken from the same side of the beam.

DETERMINATION OF BEAM DIMENSIONS

The location of the strain gauges was limited by the size of the gauges. Since the smallest available gauges were approximately ¼ inch wide, the beam was made about ⅜ inches wide. The vertical dimension, L, between the two right angle bends was limited by the available intraoral space and consequently the beam was made approximately 5/16 inches long.

Based on the assumption that the strain due to the load F_x is small relative to the loads F_z and M_y, the following equation was derived and used to select the thickness of the beam:

$$d = \sqrt{\frac{3\,F_z\,L}{b\,E\,\varepsilon_{max}}}$$

Where ε_{max} is the strain corresponding to the proportional limit of the metal. Substituting an anticipated value of F_z and known values of L, b, E and ε_{max}, an acceptable value of d is 0.037 inches. Thus the beam was constructed from 18-8 stainless steel .038 inches thick with an ε_{max} of 2000 microinches per inch. Since the value of ε_{max} can potentially be altered by the heat produced during soldering, it must be determined for each dynamometer during calibration. The fact should be stressed that the dynamometer cannot be subjected to strains in excess of ε_{max} nor can the bends in the metal be any other than right angle bends or the previously derived force-deformation relations will not be valid.

CALIBRATION OF THE APPLIANCE

In order to calibrate the dynamometer, the appliance bands were embedded in stone and the stone trimmed parallel to the expansion screw and beam. The entire assembly was placed in series with a force gauge between the jaws of a vise as shown in Figure 3. When the jaws of the vise were closed a load was applied to the dynamometer as measured by the force gauge. After the strain gauges were wired into the indicating circuit, the strain indicating meter always returned to zero upon unloading the appliance if the gauges were properly bonded to the beam. The quantity ε_{max} was found by loading the appliance until the strain continued to increase without any increase in load.

The appliance was also subjected to a force F_z in increasing one pound increments and the strain in each gauge was recorded for each load. The quantities were plotted against F_z for several different combinations of F_x and M_y (Fig. 4). If the graph of $\varepsilon_1 - \varepsilon_2$ for all sets of data was the same straight line, the system was accepted for use. The slope of this line yielded a value of K. The appliance was also waterproofed and submerged in tap water for nine hours. If the zero load strain readings

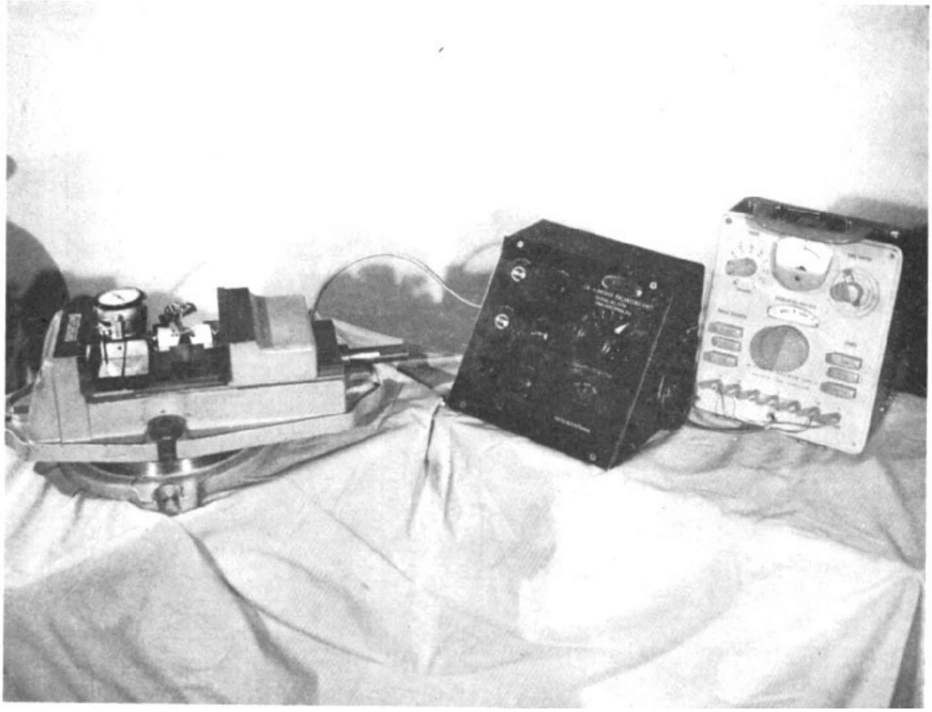

Figure 3 Appliance calibration unit with vise and force gauge, Baldwin bridge balancing unit and strain indicator.

did not change after this time the appliance containing the dynamometer was considered ready for clinical use (Fig. 5).

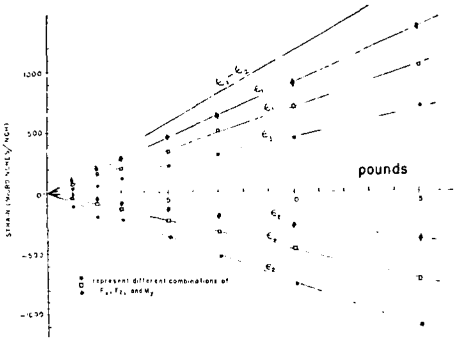

Figure 4 Typical calibration curve for this force measuring system.

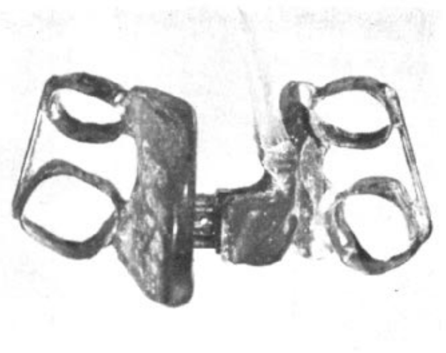

Figure 5 Completed appliance showing waterproofed strain gauges in the dynamometer contained in the right quadrant.

II. Forces Present During Treatment

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Rapid mechanical maxillary expansion procedures have been increasingly employed in recent years. Conclusive radiographic and microscopic evidence of midpalatal suture separation has been reported by numerous investigators.[1-5, 7-10] More recently cephalometric studies utilizing metallic implants have offered good evidence that expansion screw appliances also expand the basal facial skeletal structures.[6-8] The expansion of the dental arches in every case, however, has appeared to be significantly greater than the expansion of the underlying skeletal structures. Moreover, it has also been reported that the response of the buccal quadrants to rapid expansion forces may differ between patients and between the left and right quadrants of the same patient.[6]

The apparent growing acceptance of this technique as a clinical procedure, however, has resulted in an increasing availability of a puzzling plethora of expansion screw designs. Fixed and removable rapid expansion appliances for the maxilla and mandible as well as for single teeth have also been described recently. Nevertheless, neither the mechanism of action nor the biologic responses evoked by this procedure have been completely described.

Therefore, this study was designed to accurately measure the forces produced by rapid mechanical maxillary expansion appliances during several types of activation schedules. While it is well accepted that the inclined planes of a screw force produce a relatively high load deflection rate, no estimates of the forces or decay rates produced by rapid expansion appliances have been reported.

Methods and Materials

This study was conducted on five patients ranging from eight years six months to fifteen years six months of age selected from the Orthodontic Division of the University of Minnesota School of Dentistry. Four of the patients were females and all patients demonstrated bilateral crossbites with some degree of maxillary constriction.

The expansion screw appliances consisted of (1) orthodontic bands placed on selected maxillary teeth, (2) a midline expansion screw, (3) acrylic processed against the alveolar process and palate on one side of the mouth and (4) a force-measuring dynamometer connecting the expansion screw and the bands on the other side of the mouth (Fig. 1).

Oversized orthodontic bands were selected for the maxillary first permanent molars and first bicuspids (or stable deciduous molar) and transferred to a working model via an alginate impression. Round stainless steel .040

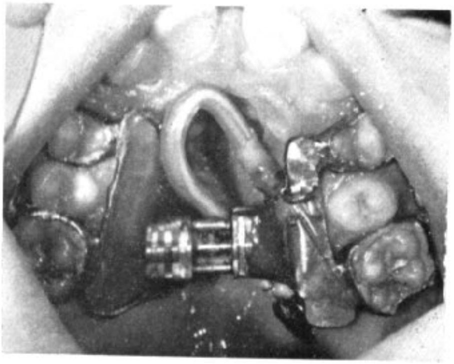

Fig. 1 Expansion appliance in place. Note the dynamometer on the left side with the lead wires tied above the expansion screw.

inch wire was soldered to the buccal surface of the bands in both quadrants for stabilization. In one quadrant round .060 inch wire was soldered to the lingual surface of the bands and palatally extending retention lugs were embedded in acrylic together with one half of the expansion screw. The expansion screw opened .8 mm for each complete revolution of the screw and was constructed to permit only one-fourth of a revolution (0.2 mm) per activation.

In the other maxillary quadrant a force-measuring dynamometer was constructed from .038 inch 18-8 stainless steel. The dynamometer beam was constructed as previously described and was positioned parallel to the long axes of the posterior teeth and carefully soldered with low heat to the bands and to the other half of the expansion screw. Two strain gauges were cemented to the palatal surface of the beam and lead wires were soldered to the gauges and covered with one-sixteenth inch polyethylene tubing. The tubing containing the lead wires was passed through an .040 inch hook soldered to the anterior portion of the beam and stabilized there with acrylic. A waterproofing protective coating was applied to the beam and gauges to prevent absorbed moisture from producing dimensional changes in the gauges. The appliance was calibrated in a ten inch vise incorporated with a force gauge to apply known static loads.

Recordings were obtained by soldering the appliance leads to a terminal block connected into two channels of a bridge balancing unit connected to a Baldwin strain indicator. During experimental clinical procedures the terminal block was stabilized on the face by a head strap. Following the recording of force values the lead wires were unsoldered from the terminal block, coated with sticky wax and stabilized on the palatal side of the expansion screw with ligature wire.

At the time of permanent cementation of the appliance verbal instructions were given to the parent and patient on the maintenance and activation of the appliance. It was cautioned that a string should be attached to the activation key and to the wrist of the person activating the appliance to prevent accidental swallowing of the key.[5] At least one of the initial activations was completed by the parent at this time also. The activation schedules varied between the several patients and are shown in Figures 2, 3, 4 and 5.

RESULTS

First Day of Treatment

The forces produced and the decay rates resulting from the various activation schedules employed during the first day of treatment are shown in Figures 2 and 3. The magnitude of the forces indicated refers to the forces measured by the dynamometer. An equal and oppositely directed force may be assumed to have existed in the opposite quadrant.

In patient *A*, an 8:6 year old female, the zero load of the appliance was not established until after cementation of the appliance in the mouth. Therefore, the forces produced by the appliance as a result of cementation were not known. The first activation, however, produced an increase of 3.7 pounds of expansion force. Within one minute 0.2 pounds of this force decayed. A second activation, one and one-half minutes after the first activation, produced 2.5 pounds of force resulting in a net total of 6.0 pounds of force produced. Within one minute this force decayed 0.3 pounds. A third activation of the appliance, three and one-half minutes after the initial activation, produced 2.4 pounds of force resulting in a total of 8.1 pounds of expansion force

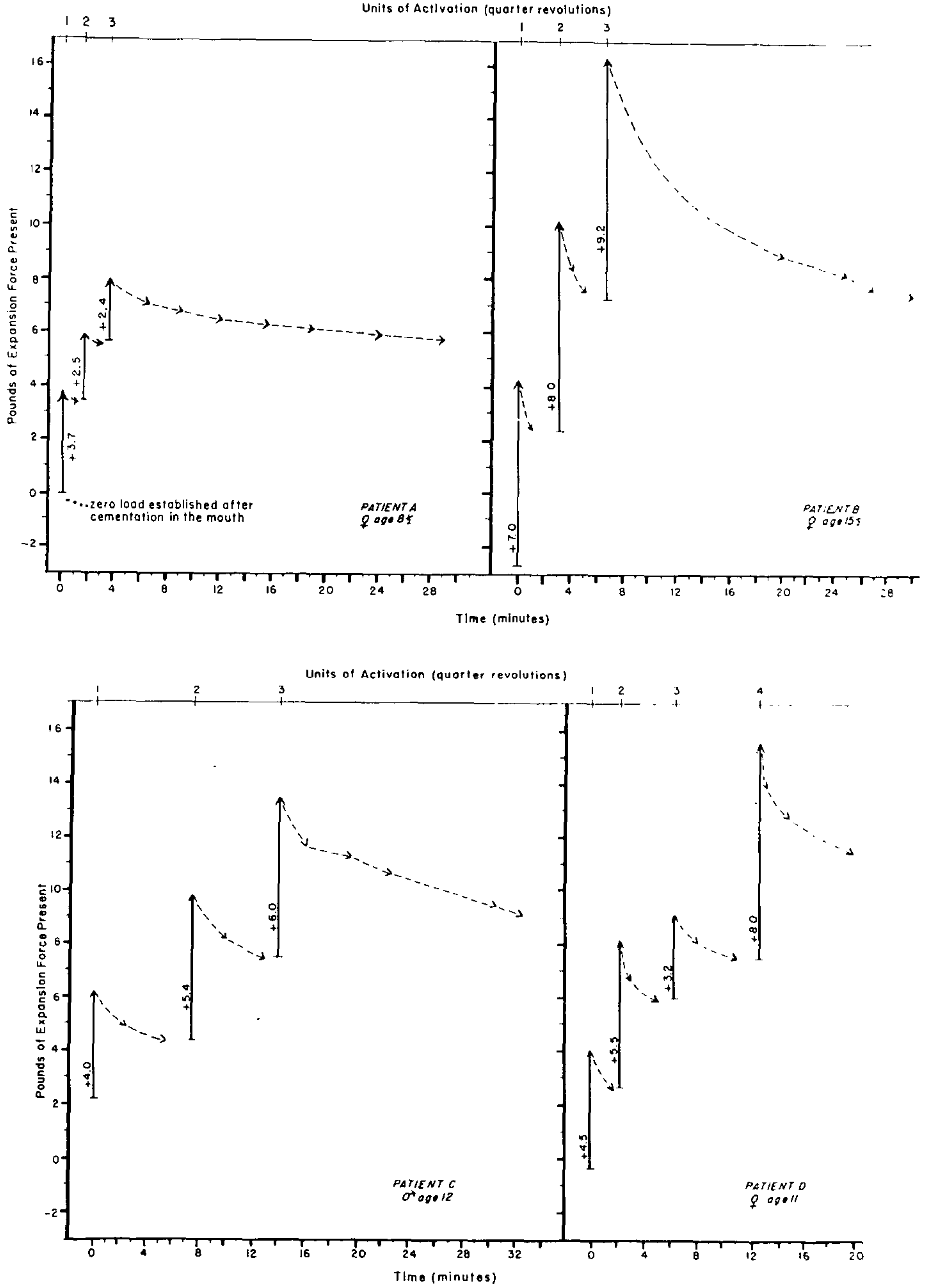

Fig. 2 Graphic representations of the forces recorded during the first day of activation and their decay rates for patients A, B, C and D. Every arrowhead represents a recorded reading.

present. This force decayed 2.2 pounds over the course of the next twenty-five and one-half minutes. Thus a total of 5.9 pounds of expansion force was produced by three activations given over a twenty-nine minute period. It should be pointed out, however, that since in this patient the zero load of the appliance was not established prior to cementation, these values are only precise relative to each other. Based on the experience gained in the cementation of subsequent appliances, it is apparent that the distortion of the appliance produced by cementation can produce significant amounts of constriction or expansion force. In all subsequent cases the zero load strain values were recorded prior to cementation.

In patient *B*, a 15:6 year old female, cementation of the appliance produced a constriction force of 2.8 pounds. The first activation produced an increase of 7.0 pounds of force resulting in a net expansion force of 4.2 pounds. This force decayed 2.0 pounds in three minutes. A second activation, three minutes after the first activation, produced 8.0 pounds of force resulting in a net expansion force of 10.2 pounds. This force decayed 3.0 pounds in three and one-half minutes. A third activation, six and one-half minutes after the initial one, produced 9.2 pounds of force resulting in a net expansion force of 16.4 pounds. This force decayed 9.1 pounds over the next twenty-three minutes. Therefore, a net expansion force of 7.3 pounds remained following three activations given over a thirty minute period.

Cementation of the appliance in patient *C*, a 12 year old male, resulted in an expansion force of 2.2 pounds. The first activation produced 4.0 pounds of force resulting in a net expansion force of 6.2 pounds. This force decayed 1.8 pounds in five and one-half minutes. A second activation, seven and one-half minutes after the first activation, produced 5.4 pounds of force resulting in a net expansion force of 9.8 pounds. In five and one-half minutes this force decayed 2.3 pounds. A third activation, fourteen minutes after the initial activation, produced 6.0 pounds of force resulting in a net expansion force of 13.5 pounds. This force decayed 4.4 pounds over the next eighteen and one-half minutes. Therefore, a net expansion force of 9.1 pounds remained following three activations given over a thirty-two and one-half minute period.

In patient *D*, an 11 year old female, 0.4 pounds of constriction force were produced by cementation of the appliance. The first activation produced 4.5 pounds of force resulting in a net expansion force of 4.1 pounds. This force decayed 1.4 pounds in two minutes. A second activation, two and one-quarter minutes after the first activation, produced 5.5 pounds of force resulting in a net expansion force of 8.2 pounds. In two and three-fourths minutes this force decayed 2.2 pounds. A third activation, six and one-half minutes after the first activation, produced 3.2 pounds of force resulting in a net expansion force of 9.2 pounds. This force decayed 1.7 pounds in four and one-half minutes. Because the third activation appeared to produce a relatively smaller net force increase, a fourth activation was given twelve and one-half minutes after the first activation. This activation produced 8.0 pounds of force resulting in a net expansion force of 15.5 pounds. In seven and one-half minutes this force decayed 4.0 pounds. Therefore, a net expansion force of 11.5 pounds remained following four activations given over a twenty minute period.

Cementation of the appliance in patient *E*, a 15:6 year old female, resulted in an expansion force of 0.2 pounds. One half of one activation, or one-eighth revolution of the expansion screw, produced 3.6 pounds of force

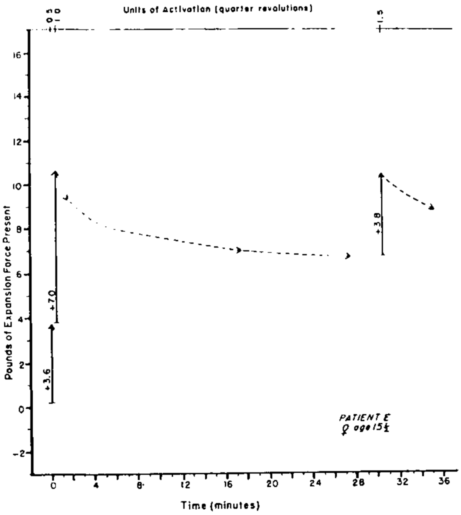

Fig. 3 Graphic representation of the force recorded during the first day of activation and the decay rate for patient E. Every arrowhead represents a recorded reading.

resulting in a net expansion force of 3.8 pounds. Completion of the first activation or another one-eighth revolution of the expansion screw one-half minute later produced 7.0 pounds of force resulting in a net expansion force of 10.8 pounds. In twenty-seven minutes this force decayed 4.1 pounds. Another one-half activation or one-eighth revolution of the expansion screw thirty and one-half minutes after the initial activation produced 3.8 pounds of force resulting in a net expansion force of 10.5 pounds. This force decayed 1.7 pounds in five minutes. Therefore, a net expansion force of 8.8 pounds remained following one and one-half activations given over a thirty-five and one-half minute period.

Subsequent Days of Treatment

The dynamometer constructed for patient *A* was relatively highly sensitive and was calibrated as linear up to a force of 7 pounds. On the second and third days of treatment, however, large strain values were recorded that failed to subsequently decrease. Thus it was assumed that permanent deformation of the dynamometer beam had occurred and continuing data relative to the net forces present or their decay rates could not be recorded. Changes in forces could be noted, however, and these changes indicated that less than 5 pounds of force was produced by each subsequent activation. The dynamometer in all subsequent patients was calibrated as linear up to a force of 30 pounds to avoid the recurrence of this problem.

In patient *B* another problem arose which precluded the collection of continuing data. When this girl returned to the clinic the second day, one strain gauge was completely inoperative. Therefore, no data regarding the forces present and their decay rate on subsequent days of treatment were recorded for this patient.

The data recorded for patients *C, D* and *E* during treatment subsequent to the first day are shown in Figures 4 and 5. In patient *C,* all activations were made in the clinic and no regular schedule was followed. Instead, the appliance was activated daily as much as possible while still attempting to keep the maximum force values below an arbitrary selected figure of 10 pounds. On the fifth day an unusual decrease in forces was noted which was later shown to be the result of a backing off of the expansion screw either by masticatory function or by the patient manipulating the appliance. Consequently the screw was locked in position with brass ligature wire thereafter. Excluding the data from the fifth day when this event occurred, it is apparent that a single activation produced from 2.4 to 6.2 pounds of force in every instance. In the first few minutes following an activation these forces decayed rapidly, but the rate of decay also

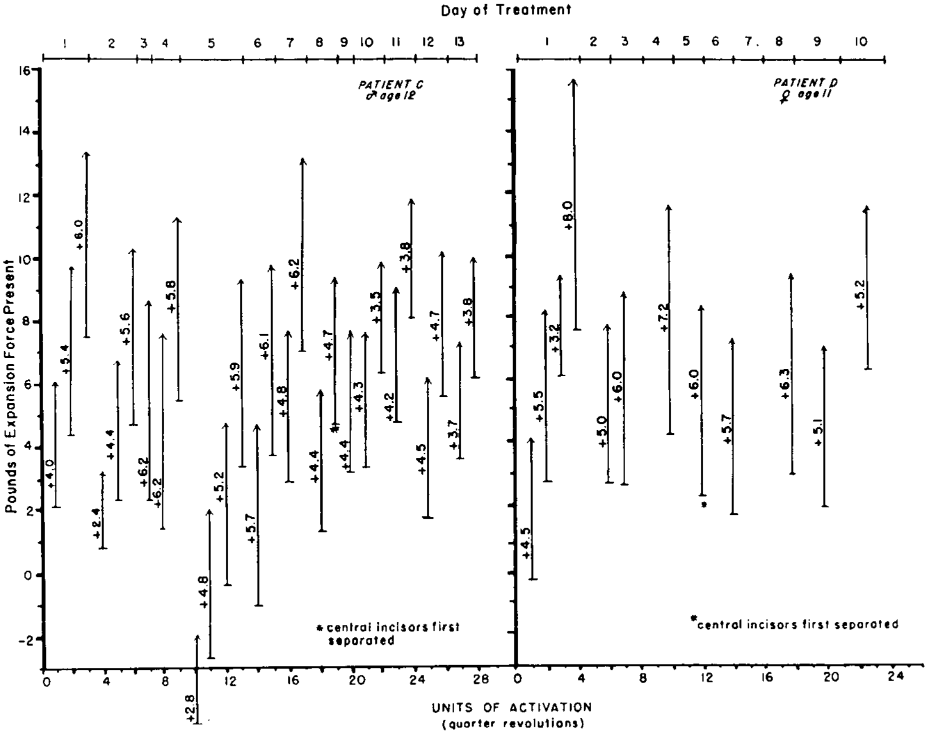

Fig. 4 Graphic representations of the forces recorded during the period of treatment of patients C and D.

rapidly decreased and residual forces were always present. With one or two activations per day, residual forces ranging from 1 pound to almost 5 pounds were present at all times. Thus it might be conjectured that in this patient the usual activation schedule of two quarter-turns (or 0.4 millimeters of expansion) per day maintained a constant expansion force on the facial skeleton from about 1 to 13 pounds.

The force values in patient *D* were recorded at intervals also throughout almost the entire treatment. A constant activation schedule of one quarter turn of the screw (0.2 millimeters of expansion) every morning and every evening was followed and about one half of the activations were done at home by the patient where strain values were not recorded. It may be noted in Figure 4 that a single recorded activation of the screw produced from 3.2 to 8.0 pounds of force. It was also noted that this force decayed rapidly in the minutes immediately following an activation, but that the rate of decay rapidly decreased. Moreover, residual forces of from about 1 to 6 pounds were always present. Thus, it is highly likely that in this patient an activation schedule of two quarter-turns per day of the expansion screw maintained a constant expansion force on the facial skeleton ranging from 1.5 to 11.5 pounds.

In patient *E* it was first decided to attempt to keep the expansion force again below 10 pounds. However, attempts to utilize half activations (or one-eighth revolutions of the screw) proved too difficult for the patient and therefore the usual schedule of one

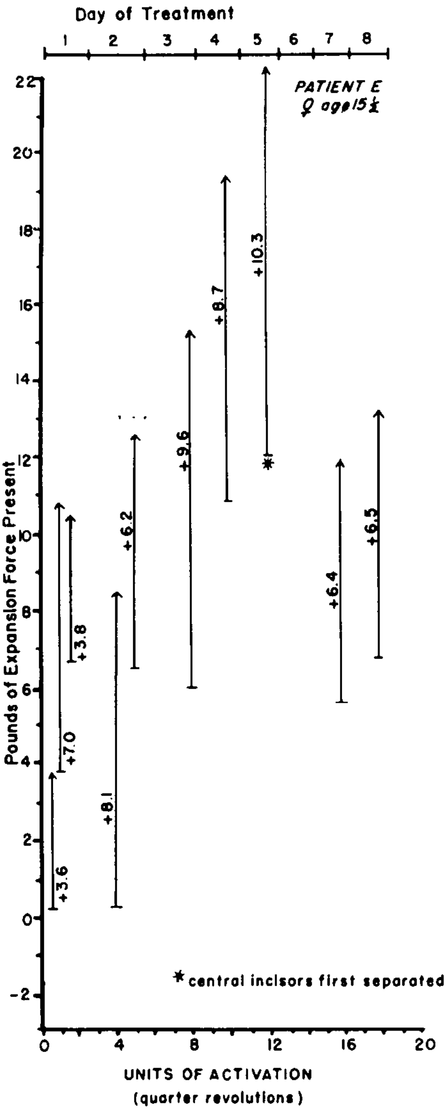

Fig. 5 Graphic representation of the force recorded during the period of treatment of patient E.

activation every morning and every evening was followed for the remainder of the treatment. The data shown in Figure 5 are recorded only to the eighth day of treatment since one of the gauges was no longer considered accurate after this point due to the absorption of moisture. It is significant to note, however, that after the second day of treatment the force increases produced by each activation ranged from 6.2 to 10.3 pounds and residual forces never dropped below 5.5 pounds. Moreover, an expansion force as high as 22.5 pounds was recorded in this 15:6 year old girl.

Discussion

One significant finding in this study is the magnitude and consistency of the forces exerted by the expansion-screw appliance. It is apparent from the illustrations that, in the patients studied, a single activation of the expansion screw produced from about 3 to 10 pounds of force. Moreover, as a general pattern there is also the suggestion that a smaller load was produced per activation in the younger patient as compared with the more mature patients. Since the force values recorded represent an indication of the resistance of the facial skeleton to expansion, this finding suggests that the facial skeleton increases its resistance to expansion significantly with increasing maturity and age. On the other hand, the presence of lower load values indicates only that the facial skeleton yielded to the expansion more readily and does not necessarily indicate that this is the optimal rate at which the expansion procedures should be carried out. It could be hypothesized that the total expansion might become physiologically stable in a shorter net treatment time with expansion procedures carried out at lower forces with slower activation schedules or less expansion per activation.

Most of the previous reports in the literature have stressed the action of the midpalatal suture during rapid expansion procedures. However, no significant changes in the force values present during the time the suture opened were apparent in this study.

Thus, it must be concluded that the major resistance to rapid maxillary expansion apparently is not the midpalatal suture but the remainder of the maxillary articulations. This finding is in complete agreement with a recent report of the failure of an expansion screw to expand the basal structures of a twenty-two year old male cleft lip and cleft palate patient. Therefore, the retention of rapid maxillary expansion cases probably does not necessarily depend on the presence of bone in the opened midpalatal suture. Rather, the retention of these cases more probably relies on the creation of a stable relationship at the articulations of the maxilla and the other bones of the facial skeleton. Even the deposition of new bone in the midpalatal suture does not necessarily insure the permanency of the treatment as long as forces are present at adjacent maxillary articulations for it is reasonable that relapse forces can cause the resorption of this bone just as expansion forces caused its deposition. Moreover, retention of these cases based on holding the teeth alone does not appear to be a rational approach. For example, if a lingual arch was soldered to bands on the teeth to hold the expansion, forces present in the facial skeleton could conceivably cause the basal structures to relapse while the teeth were held at a constant width. The net result of this occurrence would be no better than if a dental arch had been expanded by conventional orthodontic procedures. It should be noted that in the present study it was necessary to remove the appliances for recalibration immediately upon completion of expansion procedures. Measurements of the dental arch width before and immediately after removal of the expansion appliance showed relapses of as much as twenty per cent of the expansion achieved. Further studies of the magnitude and the duration of relapse forces are in progress.

The rate of force-decay and the residual forces present are also indicated in Figures 2, 3, 4 and 5. The limited data in this study strongly suggest that the decay immediately following an activation is rapid, but that the rate of decay rapidly decreases within several minutes. Therefore, it would appear that little advantage is gained by allowing more than approximately five minutes between several activations given on the first day of treatment. On the other hand, the nearly constant presence of residual forces and the apparent cumulative nature of these forces suggest the possibility that the forces produced by the third or fourth activation on the first day of treatment are probably greater than the forces present later in treatment. Thus, based on the hypothesis that a constant force level produces the optimal biological response and also on safety considerations, it would appear that two activations on the first day of treatment would produce maximum forces more closely approximating the maximum forces produced by two daily activations during the remainder of treatment.

A discussion of the force values produced during activation and the residual forces present raises the obvious question of what is the optimal force value. Is it necessary to employ 10 pounds of force and over to successfully expand the maxilla? Based on the present data, it would appear that lower loads may well be capable of producing equally successful clinical results. Slower activation schedules or expansion screws with less expansion per activation should be tested. It is quite possible that a constant acting force with a low load deflection rate may be the most ideal procedure. Thus, efforts should be directed toward developing a spring force capable of delivering, for example, only a few pounds of force over 6 or 8 millimeters of distance. Such a force might even be effective at significantly lower levels. Most importantly, work needs to be done on the effect of large forces on the sutures of the facial skeleton to determine the optimal range of forces required to produce the desired physiologic responses in these articulations. It is only when stability has been developed at these unions that the stability of the maxillary expansion procedure can be assured.

Several other important conclusions can be made based on the present findings. First, it is apparent that forces of this magnitude will readily displace a removable expansion screw appliance. Thus, while it is certainly possible that lower load values may produce satisfactory expansion, it must be assumed for the present that removable appliances are not indicated for this type of procedure. Second, compared with what is currently accepted as optimal force values for tooth movement, it must be concluded that inclined plane forces derived from screws are undesirable for producing single tooth movement. Therefore, the incorporation of screws into expansion appliances to move individual teeth also appears to be contraindicated. Third, the high level of forces encountered during activation procedures plus the presence of high levels of residual forces between activations makes the value of expansion screw appliances incorporating a spring-loaded expansion screw exceedingly doubtful. Since the total expansion potential of this type of expansion screw is measured with the spring unloaded and since the load values encountered would, in most instances, produce total compression of the spring, the use of these screws appears to offer no real advantage. On the contrary, in our experience the use of spring-loaded screws served only to reduce the total expansion capabilities of the appliance and necessitate more frequently remaking the appliance to achieve the total expansion desired.

The fundamental differences between rapid mechanical facial orthopedic procedures and the more common orthodontic procedures should also be emphasized. Present-day orthodontic mechanics are commonly designed to produce constant gram loads over long ranges of action in an attempt to produce, as nearly as possible, physiologic responses in the bone and periodontal membrane. Rapid mechanical expansion procedures, on the other hand, produce heavy forces and are designed to produce minimal tooth movement and maximal bone repositioning. The physiologic response to forces such as those found in this study is at present incompletely described in the literature. It has been reported that microscopic examination of the midpalatal suture following expansion procedures has revealed traumatic changes.[2] Such findings underscore again the need for more information regarding the biologic response of sutures in the facial skeleton to relatively heavy forces similar to those found in this study.

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