Some Observations Pertaining
to the
Activation of Spring-Pins

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DEDICATION

This thesis is dedicated to my wife, Patricia, whose love and encouragement made this thesis and, indeed, the last two years of study possible; to my children, Bronwyn and Andrew Cameron, and to my parents, a source of unceasing support.

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INTRODUCTION

The use of auxiliaries for the correction of mesiodistal axial inclinations in the third stage of the Begg technique was first described by Dr P.R. Begg in an article entitled the "Light Arch Wire Technique", which was published in 1961. Canine teeth were uprighted by what Begg referred to as "torquing wires", and this type of auxiliary, described in Chapter One, would appear to have been a forerunner to the modern day helical-coil type uprighting auxiliary.

Modifications have included the introduction of the spring pin, Begg and Kesling(1977) which negates the need to ligate the base arch wire into the bracket.

Although these helical-coil type auxiliaries are of similar design, differences in the diameter of the wire, number and size of the coils within the helix, and the type of wire from which they are manufactured can all effect their clinical performance.

It is proposed in this thesis to investigate some of the mechanical properties, under load, of a range of uprighting spring pins (TP Laboratories). Individual groups of spring pins were selected from the same batch, to eliminate as far as possible variations arising from the manufacture of different batches.

From these findings, an attempt will be made to relate the force values, produced, with those that have been reported as producing what has been termed "optimal physiological tooth movement."

REVIEW OF LITERATURE

CHAPTER ONE: History of the Begg Differential Force Technique.

(1.1) An Overview of the Development of the Begg Technique

Dr P.R. Begg first introduced his concepts of orthodontics, in a series of articles in 1954. (A,B, and C) These three articles basically dealt with his philosophy of "anatomically correct occlusion."

The author emphasised that anatomically correct occlusion is not a static condition and is characterised by continuous migration, in both the horizontal and vertical directions, throughout life.

In a fourth article, in 1954(D), Begg described a treatment technique for controlled universal tooth movement. This technique utilised a round, heat-treated, 0.018 inch diameter stainless steel arch wire. Vertical spurs were incorporated into the arch, to produce buccolingual and labiolingual bodily tooth movement. A modified Angle ribbon arch bracket was used in conjunction with the above arch configuration.

Spurs were soldered to the bands, to prevent mesial and distal tipping of the teeth and to gain additional leverage on the arch, in order to produce mesiodistal bodily movement.

Begg conjectured that these modifications resulted in a reduction of force levels, by half, and allowed a greater working range, when compared to existing techniques.

Begg(1956) further elaborated on this differential force technique, emphasising the use of what he termed "optimum forces." He contrasted these with the levels of force, exerted by rectangular arch wire, which he considered to be excessive.

One case, discussed by Begg, made no mention of the vertical spurs, referred to above, and, in fact, described the tipping of the upper anterior teeth into the extraction spaces, under the influence of light class II intermaxillary elastics.

This would appear to have been a prelude to the next stage of development of the technique, which was described in an article entitled "Light Arch Wire Technique." (Begg 1961). The author stated: "The crowns of the anterior teeth are allowed to tip back, instead of being moved back bodily, because their bodily movement would so strain the molar anchorage, that the molars would be moved too far mesially."

This article (Begg 1961) underlined the fact, that the technique consists of three distinct stages. "It is of vital importance that the three stages are kept separate."

Begg, also, elaborated on the concept of differential force. "In this technique, advantage is taken of the principle, that, for moving teeth with a small root-surface area, relatively light arch wire and rubber ligature forces produce the most rapid movement, with the least disturbance to tooth investing tissues. These light forces leave the larger-rooted posterior anchor teeth almost stationary. Conversely, relatively large forces cause the anterior teeth to resist pressure."

Begg(1962) noted that the free tipping of crowns of all teeth, mesial to the anchor molars, was mandatory, with this technique. If this is not permitted to occur, the higher force values, that must be resorted to, will tend to move the posterior teeth, mesially, largely negating the purpose of orthodontic extraction.

The crowns of the second premolars are allowed to tip freely, during the first two stages, as their uprighting, during the third stage, helps to augment molar anchorage.

Sims(1962) pointed out that, whereas edgewise arches are shaped to an ideal arch form, the arch wires, employed in the Begg technique, are designed to overmove the teeth.

Development of the technique has continued, right up to the present day and in the second section of this chapter, it is proposed to describe, more fully, the development of uprighting auxiliaries, utilised in Stage Three.

(1.2) The Development of Begg Uprighting Auxiliaries

The first description of the correction of mesiodistal axial inclinations, in the Begg technique, was set out in an article by Begg(1961) entitled the "Light Arch Wire Technique."

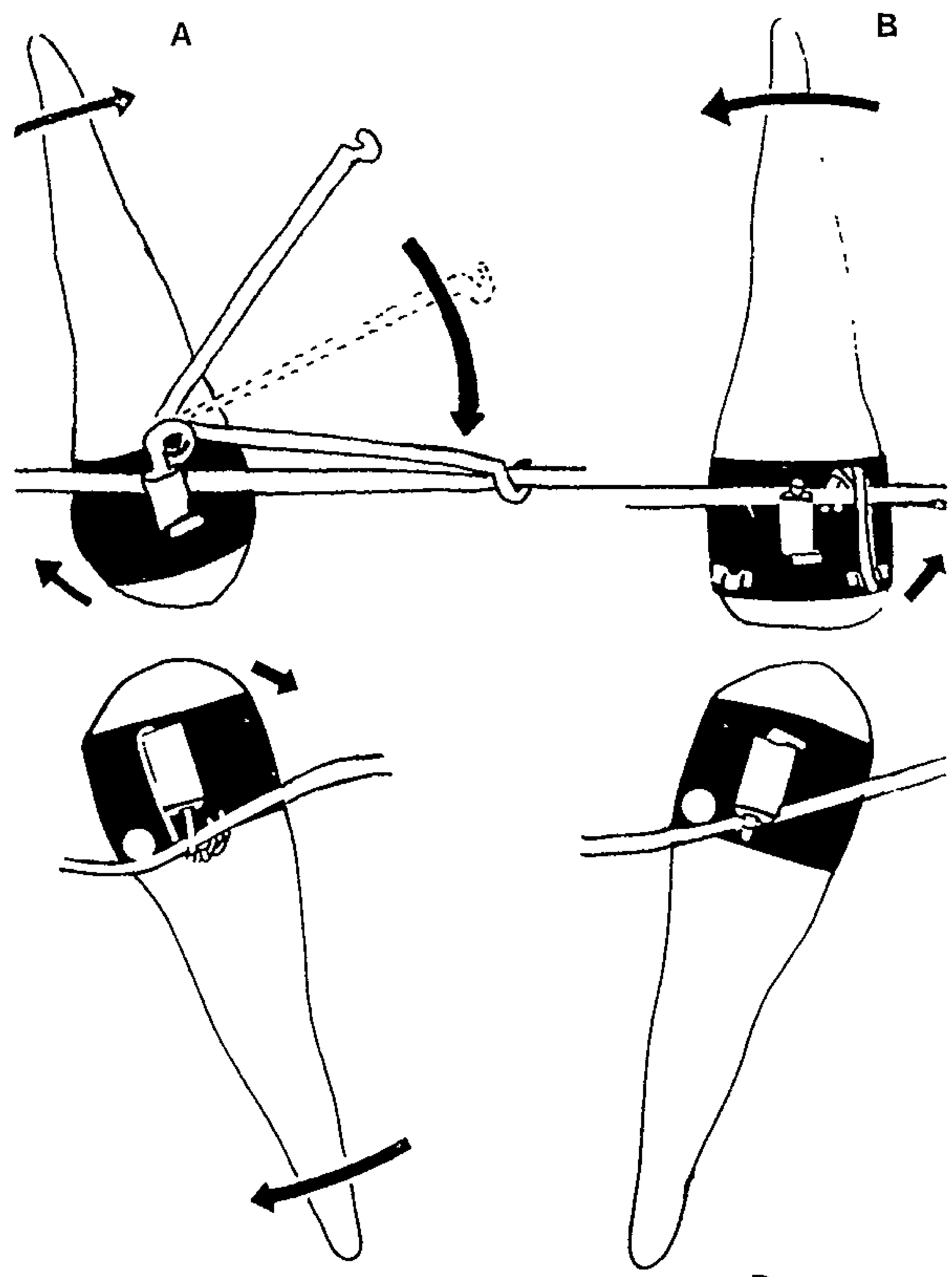
This was the first article, which emphasised the free tipping of the crowns of teeth, other than the anchor molars, in the first two stages. This may be contrasted with earlier articles, Begg(1954D) and Begg(1956), where the mechanics of the vertical spurs used, produced a more bodily form of movement.

Uprighting auxiliaries described by Begg(1961) for the correction of axial inclinations in Stage Three are illustrated in (Figure 1), see over.

These consisted of:

(i) An uprighting spring, which Begg referred to as "torquing wires" which "move teeth to their correct mesiodistal axial relations, without having to be reactivated." These would appear

Figure 1



Methods used for uprighting incisor, canine and premolar teeth. Begg(1961)

to have been used basically for uprighting canines. (Figure 1A)

(ii) "the mesiodistal axial relations of the incisors were corrected, where necessary, by threading ligature wires, through the eyelets and extending these ligatures around the arch wires and periodically tightening the ligatures." (Figure 1B)

(iii) Horizontal band spurs were also used "for torquing tooth roots, mesially and distally. (Figure 1C and 1D)

Begg(1961) also explained that where upper and lower incisors were inclined only slightly lingually at the end of the second stage; "these incisors are made to incline labially entirely as a result of the action of the spring wires used to torque the roots of the canines distally."

Brandt(1962) corrected the mesiodistal axial inclination of canines, using a combination of both eyelets and uprighting springs, which were fabricated from wire of between 0.012 inch and 0.016 inch diameter.

Barrer(1963) advocated the use of a helical coil auxiliary spring made from 0.014 inch wire, with two coils of 0.030 inch internal diameter. The two arms of the spring were at an angle of 180° to one another.

Swain(1975) also described a paralleling auxiliary which had an angle between stem and active arm of 180°, but this could be reduced to 160°, in the author's opinion.

Von der Heydt(1965) summed up the development of uprighting auxiliaries to that time with the statement, "the most efficient root paralleling device, yet introduced, is the helical coil paralleling spring. Usually they are constructed from 0.014 inch diameter wire, but their size and shape can be altered to produce the exact degree of pressure, that is required."

The reason for the progression towards a helical coil type uprighting auxiliary was explained by Begg(1965). In reference to the use of horizontal band spurs together with a progressively tightened ligature, the author observed that the excessive force, produced, caused the crown of the canine to be brought mesially whilst the roots were not moved far enough distally, which resulted in the whole arch moving too far forwards. The reason for this was that the roots of the canines resisted the high forces produced. In contrast, the light forces exerted by the helical coil type auxiliary moved the roots far enough distally, whilst hardly moving the crowns of the canines forward.

The uprighting auxiliaries favoured by Begg(1965) had long activating arms which bypassed one another along the base arch wire.

A further transition in the development of uprighting auxiliaries can be observed in an article by Miller(1969). "In more recent procedures, springs with smaller helices and shorter arms, which do not overlap, have been utilised. The shorter arms leave enough space for the hooks to move towards each other, as the teeth upright."

The longer arms, which were previously used could cause undesirable molar expansion, if they bound where they crossed. (Swain 1975)

Miller(1969) also discussed the use of a single spring unit, to upright the canine and second premolar simultaneously. "It is a combination of springs, whose free arms are encompassed in a round tube running horizontally between the cuspid and premolar. The force application of each spring can be controlled by adjusting the vertical arm of the spring, that is inserted in the vertical slot of the attachment."

In the same article, Miller(1969) also described a molar root-tipping spring, which can be used when anchorage needs to be reinforced or for axial correction. "One arm of the molar spring is inserted through the 0.036 inch buccal tube with the helix at the distal end of the tube, while the other arm is hooked over the main arch mesial to the buccal tube. The extension of the spring arm protruding through the mesial of the buccal tube is bent occlusally and lingually to rest against the buccal surface of the molar to prevent the natural tendency of the spring to roll around the buccal tube."

Fine(1969) mentioned a number of uprighting springs, then in vogue in Begg, Stage Three. "The standard springs, the instant springs, the double spring with a sleeve, the double spring with a central helix and others." He also described an uprighting spring which incorporated built-in rotational control. "A bent loop is utilised in the fabrication of the spring, which effectively fills the box of the Begg bracket and, spatially, positions the helix. "This directs the engaging arm either bucally or lingually, according to the demands of the rotation."

A further development of the Begg uprighting auxiliary came with the use of larger coils, within the helix. Begg and Kesling(1971) stated: "It has been found that the newer, shorter lever-armed springs with larger, more resilient coils will upright teeth, just as effectively as the original spring. The advantage of the shorter springs is that they are self-retaining and, being short, they do not interfere with springs on adjacent teeth."

Begg and Kesling also demonstrated what may be considered to be the forerunner of today's spring-pin. They stated: "A recent modification in the uprighting spring has resulted in a spring, that also acts as a lock pin to retain the arch wire. The leg of the spring (0.014") is passed through the coils, then bent occlusally. This creates a "lock pin" effect, with the coils of the spring reinforcing the bend in the leg. When properly utilised, this spring pin combination eliminates the need for ligating the arch wires to the brackets in Stage Three." The helix, in this uprighting spring modification contained three coils.

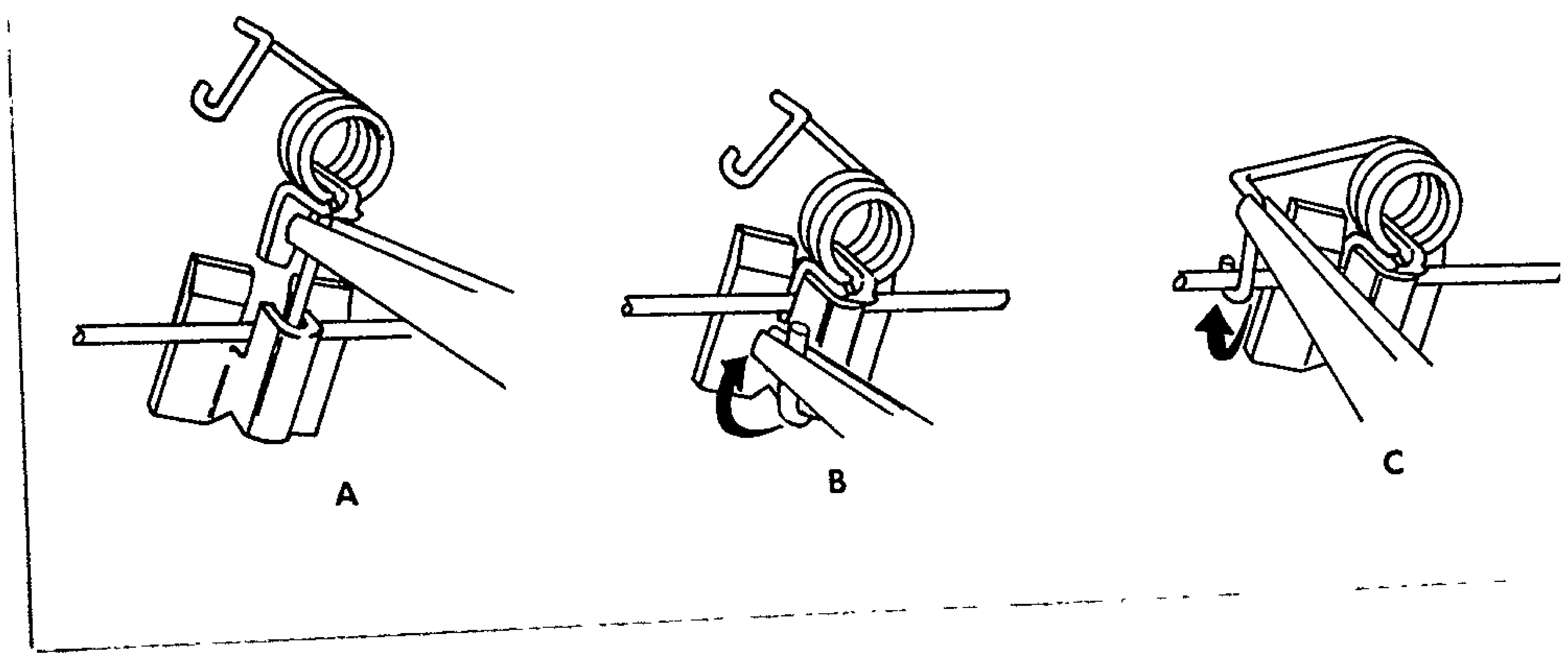
These advances are mirrored in a journal interview, given in that same year by Kesling and Rocke(1971). In reply to a question, Peter Kesling said, "We are personally using three coils, as the lever arm may be activated over a longer range, without distortion of the spring. Also, this delivers a more gentle force." In general, they believed that the length of the lever arm is not really important for effective uprighting and found the shorter lever arm to be neater and less of a food trap.

Cadman(1975A) had observed that, when the mesiodistal crown diameters of the canines and second premolars are small, the short arm type of uprighting spring may be inappropriate and should be replaced with a spring incorporating a longer arm, so that the arms by-pass one another.

Even at this stage of development, it can be seen that no one type of uprighting auxiliary, will be adequate to meet every clinical situation.

To overcome the adverse clinical effects of the reciprocal forces, produced by the uprighting auxiliary, if the arch wire is not fully ligated into the bracket, the spring pin was developed.

Begg and Kesling(1977) stated: "This is a combination of a lock pin and an uprighting spring, which has the desirable qualities of each. The leg of the pin portion passes lingual to the archwire and the tail of the spring fits labial to the archwire, in the space in the bracket that normally accepts the lock pin." (See Figure 2, below)



Spring-pin type uprighting auxiliary as introduced by Begg and Kesling(1977).

Begg and Kesling emphasised the importance of the springs, or spring-pins, being constructed from the "hardest Australian wire possible."

The authors listed the type of springs, or spring-pins, which, they considered, delivered the correct amounts of force in a four first premolar extraction case:

- upper and lower canines - 0.016 inch or 0.018 inch two coil.
- upper and lower second premolars - 0.016 inch two coil.

- upper lateral incisors - 0.014 inch two coil.
- lower lateral incisors - 0.014 inch three coil.

Many authors, prior to 1977, had, however, recommended, the use of uprighting springs, utilising a wire of smaller diameter, than that which Begg and Kesling (1977) selected for canines and premolars.

Halliday(1969) considered that the uprighting of canines and second premolars could be easily accomplished by the use of uprighting springs of 0.014 inch diameter.

Rodesano(1972) advocated the use of 0.012 inch, or 0.014 inch, uprighting springs for all teeth.

Brouwer(1973) recommended the use of 0.014 inch uprighting springs, for premolars and canines and 0.012 inch springs for lateral incisors, delivering a force range of between 50 and 75 grams.

However, direct comparison between these articles and the work of Begg and Kesling(1977) is difficult. The last three authors gave no indication, as to the number of coils, or type of wire, used in the fabrication of the uprighting auxiliaries. These are but two of the many variables that can affect the force values, produced.

As far back as Begg(1965) the importance of the need to use a highly resilient wire had been recognized.

Démogé(1966) made the point that it is just as important to use the high tensile wire, developed by Wilcock, for uprighting springs, as it is for archwire fabrication.

Recent trends, in the development of uprighting springs and spring pins, have seen, both the reduction of the diameter, of the wire, along with the incorporation of more coils in the helix.

Lebsack, Weimer and Hanna(1980), in a study of force decay, concluded that "the ideal uprighting spring should be fabricated from 0.014 inch Australian wire, with a three coil helix."

Fletcher(1981) believed that uprighting springs should be prefabricated from 0.012 inch or 0.014 inch hard stainless steel wire, with three full coils, wound around a core of 1 millimetre wire.

How these variations in the design of Begg uprighting auxiliaries, can affect force delivery will be discussed in a later chapter.

CHAPTER TWO:

The Present Day Begg Uprighting Auxiliary

(2.1) Nomenclature

Lebsack, Weimer and Hanna(1980) noted that Begg uprighting auxiliaries have also been referred to as:

- individual root springs
- root paralleling devices
- mesiodistal uprighting springs
- paralleling auxiliaries

(2.2) Uses of Begg uprighting auxiliaries in Stage Three

In broad terms, Barbieri and Barbieri(1972) observed that "the paralleling auxiliary .... is used to perform root movements or to create resistence to crown movements."

These auxiliaries, and modifications of them, can be utilized throughout all three stages of the Begg technique, in situations, ranging from the derotation of teeth to "braking", in conjunction with the use of differential force.

Is is proposed to limit the discussion of their uses to the Third Stage only:

2.2.1 The correction of mesiodistal axial inclinations of teeth.

Booy(1966) stated: "We also want to correct the mesiodistal inclination of the laterals, canines and premolars which have taken the way of least resistence and have tipped into the extraction space."

To perceive the amount of correction, that may be necessary, Brouwer(1973) recommended that four intraoral radiographs, as well as a lateral cephalogram, be taken at the beginning of Stage Three.

Huckaba(1976) considered that the Stage Three models should be examined, to determine which teeth require uprighting and to what degree.

(a) <u>The need for overcorrection of axial inclinations</u>

Some controversy is found in the literature regarding the amount of overcorrection necessary when correcting the mesiodistal axial inclinations of teeth in the Third Stage.

Begg(1977) states categorically: "The axial relations - labiolingually, buccolingually and mesiodistally - of all upper and lower teeth are simultaneously overcorrected in this final stage."

Thompson(1969) reported that inadequate uprighting and overcorrection "make the denture more apt to collapse."

Thomas(1972), when examining overparalleling, as a factor in stability, found that canines and second premolars, when overcorrected, proved to be more stable.

The need for overcorrection arises, Cadman(1975B), because:

a) a certain amount of rebound usually occurs, as a result of the tendency of the root of the tooth to return slightly in the direction of its original position.

b) the closure of band spaces is by movements opposite to those achieved by the uprighting auxiliaries during Stage Three.

These views may be contrasted with that of Von der Heydt (1982). "I find there is little or no self correction of an overparalleled canine or premolar adjacent to an extraction site."

The concensus of opinion certainly favours a degree of overcorrection but with the introduction of bonding, the need may be somewhat lessened as closure of band spaces is not a factor.

When anterior banding is utilised, Huckaba(1976) observed that the first teeth, to be uprighted to an over-corrected position, have an inbuilt period of retention, after the auxiliaries are made passive. "As it is desirable to place the patient in retention as soon as possible, it is desirable to overcorrect the last few teeth to a greater extent than the other teeth, thus guarding against relapse when the bands are removed."

Having taken the need to overcorrect mesiodistal axial inclinations into account in this last stage of the Begg technique, we must consider the relationship of these uprighted teeth to the other teeth within the dental arches.

Swain(1975) pointed out that these auxiliaries are used not only to parallel teeth in the buccal segment, but also to bring them to a position, at right angles to the occlusal plane.

Fine(1969) observed that the canine and second premolar should almost parallel other teeth in the buccal segment. "We accept the premise that the teeth should be parallel but sometimes overlook the fact that the canine is not uprighted and the second bicuspid has been over uprighted."

Williams(1982) with special reference to lower incisor crowding, post-treatment, stated, "Third, it is very important in both extraction and nonextraction treatment, that the apices of the lower incisors be spaced out distally. Fourth, that the apex of the lower cuspid is distal to its crown."

The results of the failure to achieve longer term paralleling in the buccal segments were summed up by

Strang(1957) who reported that, if the canines and premolars, in extraction cases, were left without full axial inclination correction, any readjustment, to the lines of masticatory force, would be by crown movement, rather than root movement, causing spaces to open.

(b) <u>The variation in the amount of mesiodistal axial correction required</u>

The amount of uprighting required in the final stage of treatment will vary according to :

a) the choice of treatment plan,

b) the mechanics employed during the first two stages, and

c) the distance between apices of teeth.

When a comparison is made between the amount of mesiodistal axial correction needed for the upper versus lower canines and second premolars, the increased anatomical distance between the apices of the lower canines and second premolars becomes significant. During the free crown tipping of the first two stages of the Begg technique (extraction case), less tipping is generally required to close extraction spaces in the upper arch and as a consequence, uprighting in the upper arch, for these teeth, involves less axial correction. Typically, upper canine uprighting is completed before lower, and torque before both. (Swain 1975)

Begg and Kesling(1977) listed the following groups of teeth, in descending order of need for mesiodistal axial inclination correction, in a four first premolar extraction case:

a) lower canines,

b) upper canines,

c) lower second premolars,

d) upper second premolars,

e) upper lateral incisors,

f) lower lateral incisors

The variation, in the degree of mesiodistal axial inclination correction needed, can be adjusted by the selection of Begg uprighting auxiliaries with differing characteristics. Careful clinical monitoring of clinical progress is essential and teeth which reach their over-corrected positions may be held there by passivating the uprighting springs or using "T" pins. (TP Laboratories)

Swain(1975) recommended the taking of an O.P.G., when uprighting appears to be nearing completion, and, if one or more apices were falling behind, to utilise an 0.016 inch or 0.018 inch diameter paralleling auxiliary to expedite axial correction.

In the estimation of the correct mesiodistal axial inclinations for a patient, it is interesting to speculate on the work of Burns(1969). "This study indicated that persons may show a large variation in the mesiodistal axial inclinations of the teeth and still have 'normal occlusion'. The observed difference varied from a maximum of eleven degrees for the maxillary third molar, to a minimum of three point four degrees for the maxillary canine."

2.2.2 <u>The correction of centre-line discrepancies and occlusion</u>

The correction of centre lines ideally should be accomplished in the first two stages of treatment.

However, Fletcher(1981) observed. "It is a safe policy to fit springs in matching pairs, unless a deliberate shift of the centre line is intended."

Cadman(1975A) in commenting on the interaction of reciprocal forces between paired auxiliaries noted that, occasionally the adjacent auxiliary is left off for a desired lateral shifting of teeth, to correct a midline or the buccal occlusion.

2.2.3 <u>The enhancement of anchorage</u>

Begg(1965) explained that second premolars are allowed to crown tip mesially in the first two stages of treatment. This aids in the free sliding of the arch wire and is not detrimental to molar anchorage potential. In the third stage, the uprighting of second premolars is used to increase the resistance of anchor molars to forward movement.

Many authors, including Miller(1969) Barbieri and Barbieri(1972) and Fletcher(1981), have advocated the use of almost passive uprighting auxiliaries on teeth providing anchorage, in first molar and second premolar extraction cases.

Fletcher(1981) stated that passive uprighting springs on second molars, after uprighting, will help to conserve anchorage as they become increasingly active, should the arches be drawn anteriorly.

2.2.4 For the correction of minor rotations

As touched upon previously, one author, Fine(1969), described a modification of the basic uprighting auxiliary to allow a degree of rotational control of teeth in Stage Three. A flattened loop was incorporated which effectively filled the box of the Begg bracket and spatially positioned the helix. He stated: "The most frequent application of this is in the lower second bicuspids which frequently require distolingual rotation when the case is approaching completion."

However, the Begg technique stipulates that rotations should be overcorrected, prior to the end of the second stage of treatment.

(2.3) The design of the Begg uprighting auxiliary

Barbieri and Barbieri(1972) observed that, in general terms, the uprighting auxiliary is a helical spring, with a stem to engage the pin channel of the light wire bracket and an activating arm, which attaches over the base arch wire. The authors described a number of features in the design of the auxiliary, some of which may influence clinical performance. These are:

a) the length and offset of the channel arm,

b) the offset of the hook,

c) the length of the activating arm,

d) the size of the helix,

e) the number of coils in the helix,

f) the diameter of the wire.

Lebsack, Weimer and Hanna(1980) considered that further variables, in the design, of clinical importance were:

a) the type of wire used,

b) the angle of activation.

The last six factors, mentioned above, will be considered in a later chapter, in relation to the levels of force produced by the uprighting auxiliary.

It is proposed, at this point, only to examine the first two design variables, as listed by Barbieri and Barbieri(1972).

2.3.1 The length and offset of the channel arm

Miller(1969) considered that the helices and arms of the spring should be in the same plane, as the long axis of the tooth and the archwire. To achieve this aim, there should be an offset, where the stem enters the coil of the helix. Miller concluded that incorrect positioning of the helix creates undesirable forces, that will rotate the teeth or tip their roots, too far to the buccal or lingual.

The length of the stem arm, according to Fletcher(1981), may be simply the length of the bracket channel, as the spring, once engaged, is self retentive. However, he observed that it may be better policy to leave the stem long enough, to enable it to be turned around the bracket, in the manner of a locking pin.

2.3.2 The offset of the hook portion of the activating arm

Both Barbieri and Barbieri(1972) and Cadman(1975A) agreed that the engaging hook should be offset buccally to avoid the incorporation of a rotational moment. This ensures that the arm of the auxiliary remains parallel to the arch wire, when viewed from the occlusal.

Barbieri and Barbieri(1972), also, observed that when the hook on the activating arm was not offset, the two adjacent arms, when viewed from the buccal, may not appear to be touching, but, in reality, they could be contacting at their free ends, just lingual to the base arch.

2.3.3 Length of the hook portion

Cadman(1975A) and Fletcher(1981) noted that the length of the hook portion should be slightly greater than the diameter of the helix, so that, when activated, the arm is parallel to the base arch.

Barbieri and Barbieri(1972) considered that the return portion of the hook should be kept quite short, in order to avoid the need to use excessive force, when activating the auxiliary.

Cadman(1975A) observed that if the engagement forces were excessively high, there was a danger of flattening and closing the coils of the helix, due to distortion, thereby decreasing the force and, more importantly, the range of the orthodontic spring.

(2.4) Clinical factors in the use of uprighting auxiliaries

2.4.1 Reciprocal effects produced by the auxiliary

Sims(1966) stated that the use of uprighting auxiliaries during the third stage of treatment ideally requires reciprocal, balancing forces in the buccal segments.

To this end, Barbieri and Barbieri(1972) considered that the Stage Three arch wire should lie passively and fully seated in the bracket pocket, or buccal tube. (Vertical considerations were met by anchor bends, reversed curves of Spee etc). Their rationale was that the activating arms, on the canine and second premolar, when adjusted to the same angle, produced approximately equal forces, resulting in no mesial movement of the buccal segments.

Swain(1975) maintained, however, that, as "reciprocal" had a meaning of "both equal and opposite", it was best understood in a figurative, rather than a literal sense. Even in a first premolar extraction case, there was a nett mesial force, attributable to the uprighting auxiliary, on the upper lateral incisor, which, when combined with the effect of the upper torquing auxiliary, resulted in a forward movement of the upper arch, during the Third Stage. The only force, to counter this, was the distal vector of force, produced by Class II elastics.

In the lower arch, a nett forward movement is produced by the unbalanced forces, of the lower lateral uprighting auxiliary, combined with the mesial force vector of the Class II elastics, which is resisted, by the lower anchor bends.

When the uprighting auxiliaries are considered alone, the "inequality", in reciprocity, increases from a to c. (Swain 1975):

a) First premolar extraction cases.

b) Second premolar extraction cases.

c) First molar extraction cases.

When these forces and those produced by the torquing auxiliary are taken together, we can appreciate the findings of Hurd and Nikolai(1977), who showed, in a group of Class II, div 1 cases, treated with the extraction of four first premolars, that the horizontal displacement of the maxillary first molar, in Stage Three, was four times that observed in the first two stages.

The effect of the reciprocal forces produced by the Begg uprighting springs, on the crown of the tooth being uprighted, as distinct from the effect of the interaction of auxiliaries on the whole arch must also be considered.

Fletcher(1981) noted that crown movements were relatively low resistance in nature when compared to movements of the root apices.

In order to prevent the creation of spaces, the ends of the arch wire are bent around the distal of the molar tubes. (Begg 1977)

Other authors recommend the use of lingual ligatures to preserve arch length during Stage Three.

The Begg uprighting auxiliary can cause extrusion and lingual displacement of a tooth being uprighted, if the base arch is not securely pinned or ligated into the bracket slot, due to the action of the activating arm and coil, respectively. (Sims 1968)

The Begg uprighting auxiliaries also have an effect on the base arch, in spite of the use of heavier 0.020 inch or 0.018 inch arches in this last stage of treatment.

Wakamatsu(1974) used a "dentition model" to examine the effects of uprighting auxiliaries on the displacement and loading of the base arch. The author varied the diameter of the base arch, as well as the uprighting spring's diameter, arm length, coil diameter and degree of angulation of the activating arm.

Wakamatsu found that the uprighting springs produced load and gingival displacement to the base arch for all diameters of wires, studied (0.016 inch, 0.018 inch, 0.020 inch). The amount of displacement decreased as the diameter of the wire increased. The difference was statistically significant for all diameters of base archs studied.

Of the four factors listed above, which were thought to influence force production by an uprighting spring, the degree of angulation of the activation arm, prior to engagement, was found to have the greatest influence on the displacement and loading of the base arch.

Canine bayonet bends are placed, so as to produce an intrusive force on the incisors, to counteract the effect of the torquing auxiliary, and an extrusive force on the canines and premolars, thereby lessening the tendency towards an open bite developing in the buccal segments during Stage Three. (Cadman 1975A)

Chan(1972) considered, however, that although the tip back bend between the canine and second premolar was mechanically effective in first premolar extraction cases, its position would hinder uprighting in second premolar and first molar extraction cases.

Although, as noted above, there are some reciprocal effects from uprighting auxiliaries even on a heavier base arch, Begg and Kesling(1977) contend that, in general terms, "the separation of tooth moving forces from the arch wire permits control over the duration, direction and magnitude of forces applied to each tooth." They contrast this with techniques which rely on the fit between arch wires and brackets to create and deliver forces.

To take advantage of the interaction of these reciprocal forces produced by auxiliaries in Stage Three, all auxiliaries are activated simultaneously. (Begg 1965)

2.4.2 Causes of failure in uprighting teeth

Cadman(1975A) listed some of the causes which prevented teeth from attaining their correct mesiodistal axial inclination.

a) Ligatures tied on the wrong side of the bracket:
The ligature which secures the base arch in the vertical slot, should be on the side of the bracket towards which the crown will move. Thus it will tend to slightly loosen during uprighting, avoiding any frictional binding in this area.

b) Overclosure of extraction spaces:
Care must be taken in the Second Stage that the distal aspect of the canine band is not caught under the mesial contour of the second premolar, or even

under the gingival margin of the mesial section of the band on that tooth.

c) Lingual ligatures:

Lingual ligatures, when used, should not be too tight and care must be taken to ensure that the lingual attachments are at the same height.

d) Interference to the hook of the auxiliary:

The hook on the activating arm should be free to slide along the arch wire without interference from any other auxiliaries, canine circles, molar offsets etc.

e) Distortion of uprighting auxiliaries.

f) Binding of the base arch in the bracket.

g) Incorrect placement of uprighting springs.

Begg(1965) pointed out that when the crowns of the upper and lower anterior teeth are tipped distally at the end of Stage Two, they collectively occupy less space, mesiodistally, than will be required, when their axial inclinations have been corrected.

Cadman(1975A), as a consequence of this observation, warned that, if the canine circles were hard up against the brackets at the beginning of the Third Stage, anterior spacing would occur. Uprighting would also be impeded with the danger of causing mesiolingual rotation of the canine.

CHAPTER THREE:

The Range of Orthodontic Forces For Optimal Physiological Tooth Movement.

It is proposed, in this chapter, to firstly define what is termed "optimal orthodontic force", to, then, examine the limits of the range of forces which has been proposed by various authors as producing optimal physiological tooth movements and, finally, to seek to relate levels of force found to be appropriate, to those produced by the uprighting auxiliaries, in the Third Stage of the Begg technique.

(3.1) Definition of optimal orthodontic force

From a histological viewpoint, Burstone(1975) defined an optimal force as one which produced a stress level in the periodontal membrane, that:

(a) basically maintains the vitality of the membrane throughout its length,

(b) at the same time, initiates a maximum cellular response.

A more clinical definition was given by Nikolai(1975), who stated, "the optimum orthodontic force has been defined as that which produces a maximum desirable biological response with minimum tissue damage, resulting in rapid tooth movement with little or no clinical discomfort."

However, as Halderson, Johns and Moyers(1953) have noted, "In truth there is little evidence that any appliance can correct a malocclusion, solely by physiologic tooth movements. The great majority of tooth movements are made possible by pathologic tissue response. It is our task to minimise and control the pathology."

(3.2) The range of orthodontic force.

3.2.1 Studies investigating the concepts of optimal force and its range.

As Nikolai(1975) has pointed out, "light and heavy are largely indicative of the technique and appliances employed by the clinician in treating a case, and are actually more descriptive of the range of force magnitude rather than specific force sizes. For a number of reasons, including variations in tooth size and number of teeth affected by a given force there can be no specific boundary value between light and heavy force ranges."

Schwartz(1932), in an investigation of orthodontic springs, concluded that, biologically, the most favourable levels of force were those that did not exceed the arterial pressure of the blood capillaries (20-26 gms/cm^2).

Storey and Smith(1952) investigated the concept of optimal force in an experiment, involving the distal crown tipping of canines, by means of calibrated orthodontic springs.

Light forces, less than 175gms, were effective in moving the canines rapidly. However, forces greater than 350gms resulted in the movement of anchor teeth. Once such high forces diminished to the optimal range for canine movement, these teeth began to crown tip. The authors considered that the behaviour of the anchor teeth was consistent with that of the canines, "since the ratio of the area of contact of the teeth, with the bone in the cuspid and anchor units is approximately 3:8."

However, as Burstone(1975) has pointed out, it is dangerous to use the rate of tooth movement alone as a measure of optimal force, as Storey and Smith did. "Rate is deceptive as both heavy and light forces have the ability to move teeth quickly."

Lee(1965) continued along lines of research, similar to those commenced by Storey and Smith. He noted that they had not attempted to relate the levels of force, used, to the varying types of tooth movement initiated. He considered that their results related to tipping movement of the lower canine, as opposed to bodily movement within the anchor segment. The author conducted clinical experiments, involving the distal movement of upper canines. One side was retracted by tipping and the other, by bodily movement. By relating forces, to the projected areas of the roots of the teeth, being moved, he arrived at an optimal pressure range of

170-190gms/cm^2, for both types of movements. However, the maximum rate of movement for tipping was between 40% and 80% higher. Bodily movement began at a higher force level, whereas tipping continued at lower levels of force, after bodily movement had ceased.

Storey(1973), perhaps, best summed up the experimental data, derived from these studies. He stated: "All experimental work to date strengthens the hypothesis that there is an optimal range of force which will induce a maximum rate of tooth movement ..... This range can have no precise limits .... For a constant force the optimum range can be expected to vary with the surface area of the tooth root, so that the pressure of the tooth/bone interface becomes of prime clinical importance."

Heavier forces were advocated by Hixon, Atikian, Callow, McDonald and Tacy(1969), from the results of experiments, designed to test the validity of the optimal force theory. For the bodily retraction of canines, the authors found that forces, three and four times greater than those proposed by this theory, were successful in moving teeth. They concluded that "there is no data to support the theory of optimal force. The logical derivative of this theory, differential force as it is currently employed, could not be substantiated."

Hixon, Aasen, Arango, Clark, Klosterman, Miller and Odom(1970), using data from the previous year, stated: "the other important observations of this study were the large differences between patients with regard to root area, time of beginning of tooth movement and rate of movement. The magnitude of variation of each of these factors (none of which can be controlled by the orthodontist) are far more important than the differences in magnitude of force (above 100gm). That the higher forces produce more rapid movement, than lighter ones, is generally valid within an individual patient, although the contribution of this difference is small, in relation to the metabolic variation between patients."

Boester and Johnston(1974) constructed an experiment to test a broad range of forces to retract canines, within individual patients. The levels of force, utilised, ranged from 60gms up through those proposed by Storey and Smith to 350gms, as advocated by Hixon et.al. Calibrated Ricketts retraction springs were randomly assigned to each of the four quadrants.

Significantly, it was found that forces from 150gms and probably less, up to the upper limit of 350gms, produced a similar rate of space closure. At the lower levels of force, tested, the authors felt that the force itself was the rate-limiting factor.

Several authors including Smith and Storey(1952) and Burstone(1975) have concluded that optimal forces are associated with a frontal resorption pattern, within the alveolar bone, adjacent to the teeth, being moved.

Heavy force, on the other hand, "conforms to that which would be expected, according to the theories of 'undermining resorption' as presented by Sandstedt" (Smith and Storey,1975)

The work of Reitan(1975) has demonstrated that, when an orthodontic force is applied to a tooth, there is an initial phase of rapid tooth movement.

The initial phase of tooth mobility corresponds to an intra-alveolar displacement of the root "associated with a preparation of the alveolo-dental fibres on the tension side for function action." (Mühlemann. 1954)

This is followed by a second phase, termed "the lag period", in which there is no perceptible change in tooth position, due to hyalinization of the periodontal ligament, because of compression of this structure. (Reitan, 1975)

Reitan considered that it was important to apply forces in such a way that excessive cell-free zones are avoided, as the rate of resorption is more or less proportional to the extent of these hyalinized zones. Excessive force will also lead to zones of secondary hyalinization.

The author, also, observed that the length of the second phase is dependent on the pattern of resorption in the alveolar bone. With excessive forces, a rear-resorption pattern is seen. As a consequence, the alveolar plate of bone, which resists tooth displacement is the last section of bone to be resorbed. Following an extended 'lag' phase, the tooth moves rapidly over a relatively large distance, during the third stage.

Gianelly and Goldman(1971) considered that the tooth movement, following this initial three phase period, has similar characteristics. In general terms, they believe that, if light forces are continued, further hyalinization of the periodontal ligament is minimised. With forces above this level, the rapid movement of the third stage, associated with an undermining pattern of resorption, will again cause compression of the periodontal ligament and renewed extensive zones of hyalinization.

The relatively smooth continuous movement resulting from a pattern of frontal resorption, produced by forces within the lower range of those proposed would thus appear to be more biologically acceptable.

With special reference to the forces produced by uprighting auxiliaries in the Third Stage of the Begg technique, as previously noted, Begg(1965) observed that heavy forces will result in the roots of the teeth resisting movement and lead to an undesirable reciprocal crown movement.

3.2.2 Factors that may influence this range of force.

Nikolai(1975) considered that, in examining the optimal force range, the influence of four factors must be taken into account:

(a) Individual biology,

(b) Type of tooth movement desired,

(c) Tooth root surface area and shape,

(d) Magnitude time pattern (continuous or intermittent).

(a) Individual biology

Many authors have commented on the variation, in individual response, to similar orthodontic forces.

Reitan(1964) observed that the tissue response may depend on the anatomical environment and, especially, on the existing variations of the alveolar bone and fibrous tissue.

Storey(1970) noted that, with similar forces, systemic factors such as age, diet and hormonal state influenced both the rate of tooth movement and bony changes.

(b) Type of tooth movement desired

As can be seen from Table I, the optimal levels of force for crown tipping, other factors being equal, are considerably lower than for bodily movement or controlled root movement.

Table I

Quantitatively, some experimentally determined "optimum" forces are as follows:

a. tipping	a small tooth such as an incisor (20–30 gm) large tooth—canine—	50–75 gm.
b. controlled root movement (root torque)	small tooth	(50 gm.)
	large tooth	(120–150 gm.)
c. bodily movement	small tooth	(40–50 gm.)
	large tooth	(150 gm.)
d. extrusion		(25–30 gm.)
e. intrusion		(15–50 gm.)

A range of forces for optimal physiological tooth movement as advocated by Gianelly and Goldman(1971)

(c) Tooth root-surface area and shape

Burstone(1975) observed that the total forces are distributed through the periodontal membrane, in a manner which depends on the root

(i) length

(ii) diameter

(iii) contour

Nikolai(1975), however, has noted that "Yet to be determined quantitatively is whether the effect of root surface area on optimum forces is the same for multiple-rooted as for single-rooted teeth."

(d) Magnitude - time pattern (continuous or intermittent)

The forces in the Begg technique may ideally be described as light and continuous in nature, except when heavy differential force is utilised for specific clinical purposes.

(3.3) Optimal forces as related to the Begg uprighting auxiliary.

3.3.1 Levels of force

A broad range of forces have been proposed by various authors for the correction of mesiodistal axial inclinations in Stage Three.

Newman(1963) considered that, for uprighting of canines and premolars, an initial force of between 120-180gms should be used.

Perlow(1968) believed that the level of force should be less than 90gms.

Fine(1969) recommended that a frequent check be made of all forces and that 50gms be considered the safe limit. The author when commenting on light forces, used in the first two stages, spoke of the Third Stage as simply a change in objectives, where the same forces should be used, with an altered time factor.

Both Perlow(1968) and Fine(1969) pointed out that the rate of tooth movement was time dependent.

Cadman(1979A) expressed this consideration qualitatively in the following equation:

$$\text{Tooth movement} = \frac{\text{Force x time}}{\text{Resistance}}$$

3.3.2 Other biomechanical considerations in uprighting

There has been conjecture amongst authors as to the position of the centre of rotation, during the correction of mesiodistal axial inclinations, during Stage Three.

Perlow(1968) places "the axis of rotation" at the contact points, of the teeth being uprighted.

Ramos, Weimer and Hanna(1979), however, make the observation that under the influence of the couple, produced by this auxiliary, the centre of rotation would normally be at the centre of resistance. As will be discussed later, the restriction of crown movement results in root movement, occurring predominantly with the centre of rotation closer to the bracket level.

Godfrey(1982) considers, however, that a centre of rotation within the tooth substance may not exist during root torquing. Rather, it may be considered as a fulcrum of movement, which occurs around the arch-wire attachment when applying root torquing procedures.

Gianelly and Goldman(1971) noted that, in controlled root movement, an increasing pressure gradient exists, from the alveolar crest to the root apex.

The experiments of Chan(1978) and Ramos et.al. (1979) have established, experimentally, the force values which are produced, by various differing types of Begg uprighting auxiliaries.

Due to the problems in accurately locating the 'centre of rotation' of a tooth being uprighted, calculation of the levels of strain, clinically produced within the periodontal ligament, in the apical portion of the root, are difficult to determine accurately.

However, if the distance between the root apex and the fulcrum of torquing can be estimated, then the force moments, developed by the auxiliary on one side, must be balanced by the sum of the resistance moments of the dento-alveolar support on the other side, which depends on the amount of deflection permitted by the supporting structures. (Godfrey 1982)

CHAPTER FOUR:

The Physical Properties of Orthodontic Wire (18.8 Stainless Steel).

(4.1) The chemical composition of stainless steels.

Thurow(1966) pointed out that austenitic stainless steels contain a significant quantity of nickel. The nickel has a stabilising effect on austenite, which is stable in carbon steel only at high temperatures. In these chrome-nickel stainless steels, the austenite is stabilised even at room temperature; hence they are generally termed austenitic steels. Austenite would be excessively soft at room temperature, but the addition of chromium (18-20%) to these alloys gives them the necessary strength, as well as making them highly resistant to corrosion.

Stainless steels, types 302 and 304, are commonly used in orthodontics. These and many other alloys, contain approximately, 18% chromium and 8% nickel and are known as 18:8 steels.

Ware and Masson(1975) observed that Wilcock wires are manufactured from austenitic stainless steels, whilst Dentaurum and Unitek orthodontic wires are of the precipitation hardness type.

Although the austenitic 18-8 stainless steels are generally incapable of being hardened by heat treatment, the addition of beryllium, titanium or boron at high temperatures can impart what has been termed precipitation hardness. (MonyPenny 1951) These elements are taken into solution when the steel is heated to 950-1150°C, and remain in a super-saturated state, when the steel is quenched. Reheating to low temperatures, 300-700°C, will result in the compounds being precipitated out as fine particles, evenly dispersed through the crystals of the steel, resulting in hardening.

(4.2) Stress/strain - load/deflection characteristics

Stress is described as the force of reaction (per unit cross sectional area) set up in the wire (Waters, Stephens and Houston 1975).

Strain is defined as the change in dimension per unit dimension.

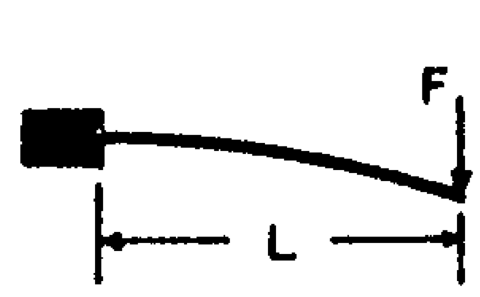
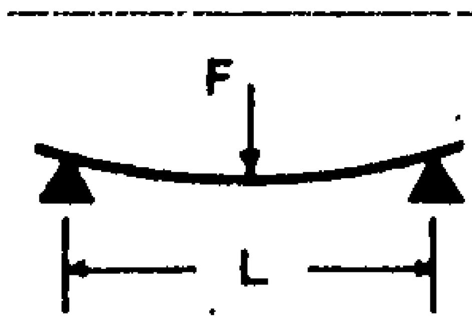
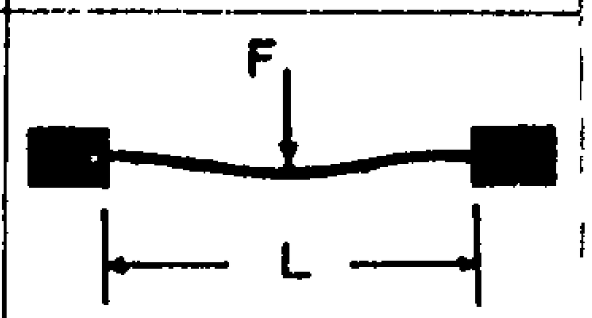
The elastic limit is defined as the maximum stress, that the wire will stand, without becoming permanently deformed.

A graph of stress versus strain is linear up to the elastic limit. Beyond the elastic limit, there is plastic deformation or permanent set.

The elastic modulus is defined by Skinner (1967) as a constant, which is derived by dividing any stress value, equal to or less than the proportional limit by its corresponding strain value. This constant, which is also known as Young's modulus, connotes rigidity.

The testing of wires in orthodontics are generally based on engineering principles derived from the loading of simple or continuous beams. (Ware 1967) See Table II.

TABLE II

Type of Beam	CANTILEVER	FREELY SUPPORTED	RIGIDLY SUPPORTED
Form of Beam			
Deflection D	$\frac{1}{3} \cdot \frac{L^3 F}{E I}$	$\frac{1}{48} \cdot \frac{L^3 F}{E I}$	$\frac{1}{192} \cdot \frac{L^3 F}{E I}$
Ratio of deflection for the same force	64	4	1
Deflection for round wires $I = \frac{\pi d^4}{64}$	$\frac{64}{3\pi} \cdot \frac{L^3 F}{E d^4}$	$\frac{4}{3\pi} \cdot \frac{L^3 F}{E d^4}$	$\frac{1}{3\pi} \cdot \frac{L^3 F}{E d^4}$
Deflection for rectangular wires $I = \frac{WT^3}{12}$	$\frac{64}{16} \cdot \frac{L^3 F}{E W T^3}$	$\frac{4}{16} \cdot \frac{L^3 F}{E W T^3}$	$\frac{1}{16} \cdot \frac{L^3 F}{E W T^3}$

Deflection formulae derived from the experimental loading of various types of beams. (Ware 1967)

where F is the load;

L is the span;

E is the elastic modulus;

and I is the second moment of inertia, which is dependent on the size and shape of the wire.

From this it can be seen that the deflection of a round wire, under a given load will be inversely proportional to the fourth power of the diameter. Ware(1967)

Waters, et.al. (1975) have observed that the load/deflection characteristics are also affected by the type of heat treatment, to which that wire has been subjected during manufacture.

When examining the "stiffness" of an orthodontic wire the above authors prefer to use what they termed 'Flexural Rigidity'.

$$\text{Flexural Rigidity} \propto E\,I$$

where E is the modulus of elasticity

I is the second moment of inertia.

For round wire, the second moment of inertia equals $\frac{\pi R^4}{4}$.

(4.3) Modulus of elasticity and resilience

The elastic modulus, as previously defined, was found by Thurow(1966) to be one of the most invariable physical properties of any metal.

Ingersley(1966) observed that the elastic modulus depended on the atomic structure and appeared to be only marginally affected by heat treatment and cold working.

The elastic limit, by comparison, for austenitic stainless steels can be increased by cold working, although this is at the expense of ductility. (Waters et.al., 1975)

Burstone(1975) concluded that elastic behaviour was characterised by interatomic bounding, whereas plastic behaviour involved displacement along slip planes, that were molecular in nature.

Resilience was described by Skinner(1967) as the amount of energy absorbed by a structure, when it is stressed, so as not to exceed the proportional limit.

Ware and Masson(1975) noted that the modulus of resilience was a measure of the energy available per unit volume of material, up to the elastic limit. It is represented by the area beneath the straight section of the stress-strain curve. The authors concluded that all of the Australian National Specification T32, Type 5 or 6 wires tested had properties which could be used to advantage, by orthodontists employing the Begg technique.

From examination of Table III, it can be seen that these wires generally exhibited a high modulus of resilience, coupled with relatively high values for tensile strength and proof stress. An important characteristic of these orthodontic wires was seen to be a high percentage proof stress to tensile strength and the authors recommended that all wires should be labelled with this information.

Table III, also shows the results of tests relating to elongation, wrapping and the number of times the orthodontic wire could be bent without fracture.

TABLE III

Column	1	2	3	4	5	6	7	8	9	10
Property / Sample	Tensile Strength MPa*	Proof Stress MPa*	Proof % tensile	Modulus of Elasticity 1000 MPa*	Modulus of Resilience 1000 Joule	Elong-ation %	No. of Bends to Fracture	Wrapping Test	AS T32 Standard Type	Draft Revised Standard Type
(c) *Low Class* Elgiloy Red	2180	1260	58	163.3	1510	3.00	25	Broke	A	1
Rocky Mountain Truchrome	2060	1540	74	164.0	1660	1.68	20	Complied	A	1
Unitek Standard	2220	1600	72	166.0	2448	2.30	23	Broke Failed	A	1
(b) *Medium Class* Wilcock Regular	2300	1820	79	165.5	3125	1.79	24	Complied	B	2
Wilcock Regular Plus	2330	1720	74	161.2	3557	2.13	23	Complied	B	2
Remanit Super Spring Hard	2640	2100	80	170.5	4116	1.80	20	Split	C	4
(a) *High Class* Wilcock Special	2730	1690	62	182.5	3782	2.31	29	Complied	D	5
Wilcock Special Plus	2750	2180	78	172.0	4256	2.13	24	Complied	D	5
Wilcock Premium	2010	2220	74	180.2	5900	2 20	30	Split at 4X stretch	D	6
Remanit Super Special	2930	2410	82	183.4	4840	2.30	22	Complied	D	6
Spring Hard Unisil	2800	2300	81	176.8	5581	2.02	19	Complied	D	5

*Divide MPa by 6.9 or 7 for approximate 1000 lbf/in^2 values.

Properties and classification of 0.016 inch diameter orthodontic wires. (Ware and Masson, 1975)

Waters et.al. (1975) prefer the term maximum stored (strain) energy to that of resiliency. Using their Elastic Recovery test and Mandrel test, they have sought to provide a means for an objective comparison of orthodontic wires, in terms of properties, which are of direct clinical importance.

(4.4) Proportional limit and proof stress

Skinner(1967) suggested that, as the point on the stress-strain curve, where it first ceases to be linear (proportional limit) is difficult to determine, "the first marked deviation from direct proportionality between stress and strain might be used as a measure of the limit of direct proportionality."

To enable measurement of the stress/strain relationship on a more reproducible basis, a 0.1% proof stress is often used. This represents the stress necessary to produce a permanent set of 0.1%. (Ware and Masson, 1975)

(4.5) Tensile strength

The tensile strength of a wire is determined by stressing the wire until it breaks. "In manufacturing practice it is found that the finer the wire, the higher will be the tensile strength, provided the percentage reductions during drawing are similar." (Wilkinson, 1962) This finding is illustrated in Table IV, where it has been assumed that all wires are of the same nominal composition and have undergone similar manufacturing procedures.

The author, also, observed that when wires of the same nominal diameter from different manufacturers were tested, whilst the tensile strengths were similar, the proportional limits varied greatly. See Table V.

TABLE IV

Diameter (inch)	Ultimate tensile strength (pounds per square inch)
0.0220	303,000
0.0198	318,000
0.0181	361,000
0.0164	376,000

Wilcock hard-drawn stainless steel arch wires.
(Wilkinson, 1962)

TABLE V

Manufacturer	Tensile strength (pounds per square inch)	Proportional limit	
		(pounds per square inch)	Per cent of ultimate tensile strength
Wilcock	383,000	139,000	36
Assab	379,000	225,000	59
Rocky Mountain	379,000	202,000	53
Unitek	376,000	158,000	42
Wilcock	370,000	192,000	52
Wilcock	365,000	194,000	53

*Test figures supplied by the Commonwealth Bureau of Dental Standards.

Stainless steel wire 0.016 inch.
(Wilkinson, 1962)

The ultimate tensile strength is described as the highest stress that the test material will stand, in tension, without fracture. It is represented by the highest point on the stress-strain curve.

Waters et.al. (1975) have pointed out that tensile tests are normally used to characterise the property of resilience or as they prefer to term it, maximum stored (strain) energy. They demonstrated that if two wires under test, have the same modulae of elasticity, then there will be a correlation, between their tensile strengths and maximum stored (strain) energies.

If, however, the modulae of the wires differs appreciably, as may be the case when different alloys are being compared, then this relationship breaks down.

(4.6) Cold working and heat treatment

Because of the stability of the austenite in these stainless steels, they can not be hardened like carbon steel by quenching or similar heat treatment. (Thurow, 1966)

In fact, these stainless steels are put into their softest and most ductile condition by quenching from 1000°C-1200°C. (MonyPenny, 1951) Heat treatment is necessary however, to give the steels their maximum resistance to corrosion. "This is the only form of heat treatment which should normally be applied to these steels and if they are heated above 400°C in any subsequent fabrication process then they should be reheated as above."

The only way, in which these steels can be hardened, is by cold working. Austenitic stainless steel hardens rapidly by cold working, with realignment of the crystalline structure and transformation of some of the austenite into harder martensite. (Thurow, 1966)

As noted previously by Wilkinson(1962) and also commented on by Burstone, Baldwin and Lawless(1961), cold working increases the elastic properties of a wire and since a small diameter wire is usually subjected to greater working, it will tend to have a higher proportional limit, than a larger wire.

Small amounts of cold working have a marked effect on the proof stress of all stainless steel wires, more so than their tensile strength. (MonyPenny, 1951)

(4.7) Stress relief

Burstone et.al. (1961) noted that residual stresses induced by cold working, modify the stress-strain relationship to a non-linear form and may be responsible for a slight reduction in the load-deflection rate. Following stress relief below the critical temperature, this gradient is raised.

They further observed that a low temperature stress-relief increases the proportional limit of a cold worked stainless steel, and, thereby, increases the allowable working range.

Stress relief aims at 'unlocking' areas of stress within the wire which may weaken it or downgrade its spring action, depending on the direction of loading. (Thurow, 1966)

CHAPTER FIVE:

Orthodontic Springs.

A mechanical spring may be defined as "an elastic body whose primary function is to deflect or distort under load and which recovers its original shape, when released after being distorted." (Wahl, 1949)

(5.1) Characteristics of orthodontic springs.

5.1.1 Load-deflection curve

Wahl(1949) observed that the load-deflection curve, of a typical spring, was linear, in nature.

5.1.2 Tensile strength

He, also, pointed out that springs must normally deflect by a considerable amount, for a given load. Thus, it follows that a relatively large amount of energy must be stored, when the spring is in its deflected position. "Since both deflection and load, for most springs, are proportional to stress and, since energy is proportional to load times deflection, it follows, in general, that the amount of energy, that may be stored, is proportional to the square of the stress. Hence, for best results, relatively high working stresses must be used."

This explains why spring wires, as a rule, have high tensile strengths.

5.1.3 Static and variable loading

(1) Static loading. In this situation, the spring is subjected to a load (or deflection), which is constant, or is repeated only a few times. (Wahl, 1949) This type of loading is applicable to mesiodistal uprighting auxiliaries, which, in general, are activated only once and have a limited span of use.

In the design of a statically loaded spring, it is important that the spring maintains its calibration to a close degree. Thus, load loss, or relaxation, should ideally only amount to a few percent.

If the spring is subjected to a constant loading and the stress is too high, there will be a slow relaxation, with time. This is called "settage" and is due to creep or plastic flow of the material. If the peak stress is kept well below the elastic limit, then the problems of relaxation and settage will seldom occur. In the design of springs, the maximum stress is taken to be the elastic limit, divided by a safety factor. Frequently, this factor is taken to equal 1.5, although lower values may be used.

In choosing a factor of safety, the designer must be guided by many considerations. A higher factor may be used if:

- the consequences of failure are serious

- the peak loading cannot be accurately determined.

The safety factor may be lowered when:

- springs are made of uniform and high grade material and where close control of the manufacturing process is maintained.
- where accurate test data is available to closely approximate service conditions.

The availability of clinical data for Begg uprighting auxiliaries, with regards to peak activation forces, is limited to a small number of studies, making estimation of a valid safety factor difficult.

Timoshenko(1956), in commenting on an adequate margin of safety, pointed out that, if working stresses were high, the choice of a low safety factor could lead to failure in service. Conversely, if the working stresses are low, the provision of a margin of safety, that is high by comparison, may result in a design, that is both impractical and unnecessarily heavy.

Timoshenko(1956) gave the safety factor (n) for simple tension, or compression, in ductile materials as:

$$n = \frac{\delta(YP)}{W}$$

where $\delta(YP)$ is the yield point stress and W is the allowable stress.

(2) Variable loading

With variable loading, the application of the load does not remain constant, but varies with time. Therefore, the spring may be considered to operate between a minimum and maximum stress or loading, which is termed "the stress range". This type of loading is not applicable to that of the Begg uprighting auxiliary.

5.1.4 Energy storage capacity

"Although a great many factors must be taken into account in the choice of spring type for a given application, to the practical spring designer, the amount of energy, which can be stored in a given spring, is usually of primary importance." (Wahl, 1949)

This is in accordance with the findings of Ware and Masson(1975) as previously discussed.

Wahl(1949) compared the energy storage capacity of six different types of springs. It is proposed to discuss only two, which are of direct concern to us. These are the simple tension-bar spring and the helical torsion spring.

The simple tension-bar spring was used as a basis of comparison with other springs, in that its uniform cross-section, when axially loaded, produced a uniform stress distribution, an ideal attribute for an orthodontic spring.

Also, given a maximal stress, the energy storage capacity could be related to the volume of the spring. The simple tension-bar spring was the basis for comparison in that it used a minimum volume of space to fulfil its given function.

The energy storage capacity for this type of spring is given by the formula:

$$US = \frac{\delta Y^2 V}{2E}$$

where (US) is the energy storage capacity in static loading.

δY is the stress at yield point.

V is the volume.

E is the elastic modulus.

A Begg uprighting auxiliary may be considered as a helical torsion spring, (Wahl, 1949), whose arm under activation is subjected to a constant moment.

The energy storage capacity for this type of spring in static loading is given by the formula:

$$US = \frac{\delta Y^2 V}{2.77E}$$

From this, it can be seen that the value is approximately 27% less that of an ideal spring. Thus the modulus of resilience for a helical torsion spring will be reduced in comparison to the tension-bar spring.

5.1.5 Types of stresses produced by loading of orthodontic springs.

These stresses may be described as:

(i) Compression or tension

(ii) Torsion

(iii) Bending or flexure

(i) Compression or tension. In this situation, the force acts along the structural axis and is termed axial laoding. (Burstone, 1975)

(ii) Torsion occurs when a moment operates around the structural axis. In this situation, the greatest elastic deformation occurs at the periphery of the wire.

(iii) Bending or flexure is produced, when the structural axis changes its configuration to one transversely or at right angles to the original orientation. Bending can be produced by either moments, acting at right angles to the cross-section of the wire, or by a transverse force acting on the wire.

(5.2) Appliance design as it affects the characteristics of orthodontic springs.

In the design of an appliance, we are specifically interested in the forces and moments that may be produced.

Burstone(1975) lists three characteristics of specific concern:

(i) moment-to-force ratio

(ii) load-deflection rate

(iii) maximal elastic moment

5.2.1 Moment-to-force ratio

Altering the ratio of the applied moment-to-force will effectively change the centre of rotation, allowing different types of tooth movement to be carried out. There are few instances, where a single force applied to a crown can produce desired tooth movements. (Burstone, 1975)

As mentioned in an earlier chapter, the activation of the uprighting spring results in the application of a couple, upon the tooth. (Ramos, Weimer and Hanna, 1979) In the absence of other forces, this would result in rotational tooth movement, occurring about the centre of resistance of the tooth; that is, approximately 40 percent down the root length, measured from the crestal bone. In the case of the uprighting spring, however, resistance to crown movement results in root movement, occurring predominantly with the centre of rotation closer to the bracket level.

Factors that provide resistance to crown movement are:

(a) Proximal contact of adjacent teeth,

(b) Friction of the bracket to the arch wire contact surface,

(c) Friction of the uprighting spring hook to the arch wire contact surface.

In addition, resistance to crown movement is provided by cinching back the base arch, tying lingual ligatures and the application of class II elastics, where necessary.

5.2.2 Load-deflection rate and

5.2.3 Maximal elastic moment

In our discussion of optimum force levels, we concluded that the applied force should be continuous and provide, as far as possible, a uniform force, during unloading.

Since there is less force change per unit of activation, a low-load deflection rate is to be preferred. Also, a low rate provides more control over the magnitude of the force applied. (Burstone, 1975)

Burstone, Baldwin and Lawless (1961) contended that modification of the linear configuration, of a wire, offers the greatest potential for altering the load-deflection rate and, also, the maximal elastic moment.

The maximal elastic moment, or load, is defined as "the greatest force or moment that can be applied to a member without producing permanent deformation." (Burstone, 1975)

In the discussion of the physical properties of orthodontic wire, it was seen that a reduction in the cross-section of the wire significantly lowered the load-deflection rate. However, as we can see from Table VI below, the maximal elastic moment will also decrease dramatically, giving the possible reduction, in cross section of the wire, a finite limit.

TABLE VI:

DESIGN FACTOR	LOAD-DEFLECTION RATE	MAXIMUM LOAD	MAXIMUM DEFLECTION
	Varies as	*Varies as*	*Varies as*
Mechanical properties of wire	*E (Modulus of Elasticity)*	*Sp (Proportional Limit)*	$\frac{Sp}{E}$
Wire Cross Section (d)* (Round)	d^4	d^3	$\frac{1}{d}$
Wire Cross Section (b, h)** (Rectangular)	bh^3	bh^2	$\frac{1}{h}$
Length (L) (Cantilever)	$\frac{1}{L^3}$	$\frac{1}{L}$	L^2
DESIGN FACTOR	LOAD-DEFLECTION RATE	MAXIMUM LOAD	MAXIMUM DEFLECTION
Addition of wire without changing length	Decreases	No change	Increases
Activation in direction of original bending		Increases	Increases
Alteration of cross section to rectangular form	If rate is maintained as a constant	Increases as $\frac{1}{h}$	Increases as $\frac{1}{h}$

*d diameter
**h dimension in direction of bending
b direction at right angle to h

Factors Influencing Load-Deflection Rate, Maximum Load and Maximum Deflection. (Burstone, 1975)

We would seek to place as small a cross-sectional wire as possible, having due regard to the safety factor. (Burstone, 1975) However, changes in wire configuration may be much more effective.

Load-deflection rate and maximal elastic moment may be altered by:

(a) Altering the length of wire in the spring.

(b) Altering the amount of wire in the spring.

(a) Length of wire

Again, from Table VI it can be seen that the load-deflection varies inversely as the cube of the length of the cantilever, whilst the maximum elastic load varies inversely, as the first power of the length. Therefore, increasing the length of the cantilever can markedly reduce the load-deflection rate and the maximal elastic load reduces only linearly.

When the cantilever is loaded by an applied couple, the moment-deflection rate varies inversely as the second power of the length. However, the maximal elastic moment is not affected by changes in wire length at all, making torsional loading very effective if the length of the wire can be increased. This principle can be applied, if moments alone are required for tooth movements. (Burstone, 1975)

Increasing wire length in the Begg auxiliary is limited by clinical considerations and could be applied more advantageously in the fabrication of vertical loops etc.

(b) Amount of wire

A second parameter that may alter these characteristics is an increase in the amount of wire within the given length.

The addition of helices will decrease the load-deflection rate and, if properly positioned, may not affect the maximal elastic moment.

Burstone, et.al. (1961) observed that, if additional wire, in the form of helices, is placed where the bending moment is greatest, the maximal elastic load or moment will not be increased, as it is a function of length and not the amount of wire within that length.

The load-deflection rate in a cantilever spring, modified with a helix, is determined by the diameter of the helix, the number of turns in the helix and the length of the cantilever.

This is given by the formula:

$$\frac{P}{\Delta} = \frac{EI}{2 r \pi \; n(L^2 + \frac{r^2}{2}) \; + \; Lr^2 + \frac{L^3}{3}}$$

where P = load, Δ = deflection, E = elastic modulus, I = second moment of inertia, L = length of wire, r = radius of helix.

This is in agreement with the work of Gere, as quoted by Ramos, Weimer and Hanna (1979), who concluded that the introduction of more coils and, also, coils of a larger diameter reduced the load-deflection rate.

This principle has been applied in the design of the Begg uprighting auxiliary, in which the coils are placed where the bending moment is maximal.

5.2.4 The direction of activation

If the direction of activation of the spring is in the same direction as the original bending, the load-deflection rate decreases, whilst the maximal elastic load increases.

The reason for this phenomena, known as the Bauschinger Effect, is explained by Burstone et.al. (1961). They observed that any residual stresses, within the wire, took up a more uniform distribution, during this preferred type of loading.

5.2.5 Stress raisers in critical areas

Burstone (1975) pointed out that stress raisers, such as nicks in the wire, sharp bends etc should be kept away from areas of maximal loading moment.

5.2.6 Clinical considerations

Burstone *et.al*. (1961) observed that the design of the spring is not only influenced by mechanical factors but, also, by the limitations imposed by the oral cavity itself. "No matter how ingenious the design of an orthodontic spring might be, it is unsuitable for clinical purposes if it is irritating to the soft tissue, unhygienic, uncomfortable and overly complicated to fabricate and use."

CHAPTER SIX

The Design Variables in Begg Uprighting Auxiliaries and How They Affect Force Delivery.

Production of optimal stress levels in the periodontal membrane and maintenance of relatively constant stresses as the tooth moves during uprighting; in Stage Three; involves the application of a carefully selected range of force.

The design of the auxiliary should be such that it produces a low-load deflection rate and possesses high elastic moment.

These characteristics may be related to the properties of the wire, itself, or to the design of the spring.

These design parameters, which were listed in Chapter Two, include:

(6.1) Diameter of the wire

As was seen in the previous chapter, a reduction in the diameter of the wire, from which the Begg uprighting auxiliary is fabricated, can lead to a dramatic reduction in the elastic range of the orthodontic spring. When activated, this lowering of the safety factor, may lead to plastic deformation in the wire.

Conversely, several authors, including Perlow(1968) and Ramos, Weimer and Hanna(1979), have found that, for a given degree of activation, an increase in the wire diameter, of uprighting springs, of 0.002 inch will raise the level of force two-fold.

Chan(1978), Ramos et.al. (1979) and Lebsack et.al. (1980) have all recommended the use of uprighting springs of 0.012 inch on 0.014 inch diameter. These, they feel, produced force values consistent with previously reported optimal force ranges for tooth movement.

(6.2) The size of the helix

The work of Burstone et.al. (1961) and Burstone(1975) has shown that the introduction of a helix at the point, where the maximum bending moment occurs, can have a favourable effect on the spring characteristics.

Gere, as quoted by (Ramos et.al. 1979) concluded that an increase in the diameter of the coil will lower the load-deflection rate.

Ramos et.al. (1979), in a series of experiments, found that an uprighting spring of 0.078 inch coil diameter produced a greater force than one with a coil diameter of 0.098 inch, although this finding was only significant statistically ($p > 0.01$) with low bracket arch wire angulations.

This parameter is limited by clinical considerations and the need to maintain a good oral hygiene standard, throughout.

(6.3) Number of coils in the helix

Similarly, as observed by Burstone et.al. (1961), increasing the number of coils will favourably affect the load-deflection rate of the orthodontic spring.

Ramos et.al. (1979), in an experiment comparing uprighting springs; of both two and three coil design, found that the two coil sample produced higher forces at the low bracket - arch wire angles. This was reversed at the end of the range, but the authors felt that this was due to experimental procedure, in that small differences in forces could not be accurately picked up. This was shown in the irregularity of the plots within this higher bracket angulation range.

Lebsack et.al. (1980) concluded that a three coil helix maintained a more uniform force and gave a greater range of activation.

(6.4) Type of wire

Newman(1963) commented upon the superior properties of Wilcock Australian wire in the fabrication of uprighting springs. He found, however, that, after heat treatment, uprighting auxiliaries made from other stainless steel orthodontic wires were comparable.

The advantage of the "Australian" wires would seem to be in their high modulus of resilience. Their proof stress to tensile strength is also high, allowing a large elastic range. Begg, from his 1956 article onwards, has constantly emphasised the use of this type of wire, throughout the entire Begg light wire technique, as have most other authors.

However, Ramos et.al. (1979) found no significant difference between two test groups of uprighting springs of 0.014 inch diameter, one of which was described as "Australian" wire and another, which was "domestic U.S.". Both were from TP Laboratories and were of a two-coil design.

Lebsack (1980), however, in a study of force decay over a ninety day period, noted, in general, that uprighting spring pins manufactured from Wilcock wire were less susceptible to fatigue. The resilient nature of the Wilcock wire would be seen to be a contributing factor.

(6.5) Length and angulation of the activating arm

The length of the activating arm has been seen to have evolved to the present-day design, in which it is relatively short. Kesling and Roche(1971) considered that the length of the arm was not significant, but an overly short arm may require high forces to activate it, running the risk of deformation of the coils or introducing a plastic set within the wire. (Fletcher, 1981)

The angulation of the activating arm would seem to be much more critical to the levels of force, produced by uprighting springs. Most authors recommend that the initial angulation of the stem arm to lever arm, prior to activation, be approximately 45°. This may be varied, depending on the clinical judgement of the orthodontist, which will have an effect on both the range and levels of force produced.

Both Ramos et.al. (1979) and Lebsack et.al. (1980) concluded that the levels of force varied inversely, with the degree of bracket-archwire angulation.

Lebsack et.al. (1980) concluded that the decay rate of forces produced by Begg uprighting auxiliaries over a ninety day period varied inversely with the degree of bracket-arch wire angulation. Interestingly, their study showed that the 0.016" and 0.018" uprighting springs underwent plastic deformation of the lever arm, at all angulations tested. (60^{0} to 95°)

An 0.014" 2-coil Australian wire uprighting spring pin produced a mean force as high as 525gms at low bracket-arch wire angulations. (Ramos et.al., 1979) Although this form of auxiliary has been recommended for uprighting, from the studies of Chapter Three, the levels of force would appear to be excessive. However, the corresponding stress produced, within the peridontal ligament, cannot be fully measured, making direct comparisons somewhat difficult.

If it is felt that excessive forces will be produced by activation of the auxiliary, then thought should be given to initially ligating the hook of the activating arm to the archwire rather than seeking full engagement.