168

In Vivo Comparison between Interarch Elastics and Closed Coil Springs for Correction of Overjet in Class II Malocclusions

by

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IN VIVO COMPARISON BETWEEN INTERARCH ELASTICS AND CLOSED COIL SPRING FOR CORRECTION OF OVERJET IN CLASS II MALOCCLUSIONS

BY

MICHELE J. WANG

A Thesis/Practicum submitted to the Faculty of Graduate Studies of the University of Manitoba in partial fulfillment of the requirements for the degree of

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TABLE OF CONTENTS

APPENDICES 79

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ABBREVIATIONS

α	alpha level (probability of rejecting the null hypothesis when it is true)
ß	beta level (probability of accepting the null hypothesis when it is false)
C	centigrade
CO	centric occlusion
CR	centric relation
CR-CO	centric relation to centric occlusion discrepancy
cm	centimeter
g	gram
GAC	(previously) Guild Arts and Crafts
kg	kilogram
max	maximum
md	mandibular
min	minimum
mm	millimeter
ms	millisecond
mx	maxillary
N	number
NS	not statistically significant
OB	overbite
OJ	overjet
OH	oral hygiene
OHI	oral hygiene index
p	probability that the null hypothesis is true
pH	negative logarithm of the hydrogen concentration
RMO	Rocky Mountain Orthodontics
SD	standard deviation
SE	standard error
VAS	visual analog scale
vs	versus
x	mean
^{o}	degree
#	number
%	percentage

DEFINITIONS

Activation refers to the bending of a wire so that it will produce an elastic force for tooth movement.

Anteroposterior refers to a sagittal or horizontal relationship.

Anterior protrusion is that position in which the mandible is positioned anteriorly, so that both mandibular condyles and discs are forward in their glenoid or articular fossae, functioning against the posterior aspects of the articular eminences. In this study, maximum anterior protrusion is measured as the distance between the labial surface of the mandibular and maxillary right central incisors and added to the initial overjet.

Austenitic phase is the body-centered cubic structure of nickel-titanium alloys.

Centric occlusion (intercuspal position, acquired position, habitual position) is the maximum contact or intercuspation attainable between maxillary and mandibular posterior teeth.

Centric relation in this study is defined as the most posterior and superior position of the mandible relative to the maxilla at a given vertical dimension.

Class I malocclusion is Angle's classification of the anteroposterior dental relationship of the first permanent molars in which the buccal cusp of the maxillary first molar is in the buccal groove of the mandibular first molar.

Class II malocclusion is Angle's classification of the anteroposterior dental relationship of the first permanent molars in which the buccal cusp of the maxillary first molar is mesial to the buccal groove of the mandibular first molar.

Compliance is the extent to which a person's behaviour coincides with given advice.

Continuous force is a force which is maintained at some appreciable fraction of the original force from one patient visit to the next.

Creep is the gradual deformation of a material under constant stress, and occurs as a result of the viscoelastic properties of the material. Static creep is the time-dependent deformation produced in a solid subjected to a constant stress. Dynamic creep refers to this phenomenon when the applied stress is fluctuating, such as in a fatigue-type test.

Deactivation refers to the unloading or recoil of a wire or spring following the application of force.

Discrepancy is an inconsistency in the dental relationship between the maxillary and mandibular arches in the sagittal, vertical and/or transverse planes of space.

Disharmony is a disproportionate skeletal relationship between the maxilla and mandible in the sagittal, vertical and/or transverse planes of space.

Elastic modulus is the stiffnes or flexibility of a material within the elastic range and is equal to stress/strain. Within the elastic range, the material deforms in direct proportion to the stress applied (Hooke's Law).

Elongation is the deformation as a result of tensile force application.

Interincisal distance is the vertical distance between the incisal edge of the maxillary and mandibular central incisors.

Intermaxillary is the relationship between a point in the maxillary arch and one in the mandibular arch.

Intermittent force is a force that declines abruptly to zero when the orthodontic appliance is removed by the patient.

Interrupted force is a force that declines steadily to zero between activations.

Intramaxillary is the relationship between 2 points of application in the same dental arch.

Lateral excursion is the position in which the mandible is moved either to the right or left side, and slightly downward.

Martensitic phase is the hexagonal close-packed phase in nickel-titanium alloys that forms as a result of cold working the austenite phase.

Maximum opening is the distance travelled by the incisal edge of the mandibular right central incisor during mouth opening. In this study it was measured as the interincisal distance at maximum opening and added to the initial overbite.

Occlusion is contact of the masticating and incising surfaces of opposing maxillary and mandibular teeth.

Overbite is the vertical overlap of the maxillary and mandibular incisors. Lack of overbite is referred to as anterior open bite.

Overjet is the horizontal overlap of the incisors. Normally, the incisors are in contact, with the upper incisors ahead of the lower by only the thickness of the upper incisal edges. Normal overjet is considered to be between 1-3mm, increased overjet between 3.1-6mm and excessive overjet greater than 6mm. If the lower incisors are in front of the upper incisors, the condition is referred to as negative overjet or anterior crossbite.

Pain affect is the emotional arousal and disruption engendered by the pain experience.

Pain intensity is the magnitude of how much a person hurts.

Pitch angle is the angle between the long axis of the coils and a perpendicular to the long axis of the spring.

Proportional limit (elastic limit) is the maximum stress that a material can withstand without permanent deformation. It is also the maximum stress at which the straight line relationship between stress and strain (Hooke's Law) is valid.

Reliability is the consistency with which an instrument repeatedly measures a certain entity.

Self concept is a set of attributes that reflect a description and evaluation of one's own behaviour and attributes.

Shape-memory is related to the inherent capability of altering atomic bonding as a function of temperature over the transition temperature range.

Slip is the load or stress dependent portion of plastic deformation.

Strain is the change in length per unit length when stress is applied (change in length/original length).

Stress is the force per unit area.

Stress relaxation is a gradual reduction in stress at a constant strain.

Superelasticity is a material's inherent capability of demonstrating a unique nonlinear load deflection curve, with an initial and final region of relatively steep slope, and an extensive intermediate region, where stress remains nearly constant despite a change in strain.

Validity is the extent to which an instrument measures what it purports to measure.

Working range is the maximum deflection of a wire within the elastic range.

LIST OF FIGURES

LIST OF TABLES

ABSTRACT

Orthodontic correction of anteroposterior discrepancies often employ interarch biomechanics using removable elastics. Treatment success with removable appliances is highly dependent on patient compliance. Intraarch studies have demonstrated coil springs to be approximately twice as effective as elastomers for orthodontic tooth movement. The benefits observed for intraarch coils might also apply to coil springs used for interarch mechanics. A fixed treatment modality could provide a more effective means of overjet correction, independent of patient compliance. Overjet correction using interarch coil springs has not yet been documented. This thesis hypothesized that fixed closed coil springs would be more effective in reducing overjet than removable elastics. In addition, it was hypothesized that coil springs would impose greater limitations on mandibular movement, be perceived as less painful and contribute to a deterioration of oral hygiene.

A prospective longitudinal clinical study was done using six adult females with Class II malocclusions and large overjet (3.5-6.5mm). Subjects were randomized to the coil springs (GAC Sentalloy [R] 150g, 23mm) or elastics (RMO Sailboat [R] 150g, 6.4mm) group, which were similar in pretreatment age and height. Measurements in overjet, mandibular movement and oral hygiene were obtained at baseline; and retested every two weeks for a period of three months. Pain and compliance with elastics were self reported weekly and daily, respectively.

With high compliance (89-92%), orthodontic latex elastics were found to be approximately twice as effective in reducing overjet (40.1 ± 4.0%) compared to closed coil springs (19.9 ± 10.6%). Both elastics and coil springs resulted in a sustained reduction in maximal jaw opening (10.6 ± 10.7; 14.8 ± 5.7% with coils; 6.7 ± 7.2; 12.1 ± 1.8% with elastics), minimal decrease in right and left lateral excursions, and an increase in anterior protrusion (7.5 ± 8.1% with coils; 21.1 ± 12.3% with elastics). Pain intensity and pain affect with either coils (12.0 ± 8.7mm) or elastics (16.3 ± 22.5mm) was relatively minimal, fell towards pretreatment levels after one week (4.7 ± 2.9mm for coils; 1.7 ± 2.1mm for elastics) and was subsequently maintained at low

levels. There was no significant change in cumulative oral hygiene scores with either treatment over time, although results tended towards a worsening of oral hygiene with coil springs after one month (4.7 ± 0.3 for coils; 3.0 ± 0.6 for elastics).

These findings show that with high compliance, removable elastics are an effective means of correcting overjet and are associated with clinically acceptable changes in mandibular movement, tolerable levels of pain and no detrimental effects on oral hygiene. Coils springs were associated with a high incidence of failure and offered no significant advantages with regard to operator use, correction of overjet, mandibular movement, pain perception or oral hygiene.

CHAPTER 1

INTRODUCTION

Class II Division 1 malocclusions comprise a significant portion of the general (15-20%) as well as the orthodontic (37%) population (Fisk, 1960; Kelly et al, 1973). A non-extraction treatment plan in a non-growing adult patient often involves the correction of excess overjet (Proffit et al, 1993) using interarch mechanics with removable elastics, which is highly dependent on patient cooperation (Graber, 1971). However, high patient compliance may not be available and the alternative treatment plan of two upper bicuspid extractions may not be a desirable patient option. The recent availability of longer span coils for interarch use could be useful in the correction of anteroposterior discrepancies while acting independent of patient compliance, thus offering an alternative treatment approach to removable latex elastics. They could be considered conservative (in not involving extractions) and effective (in not depending on patient compliance). Closed coil springs have been demonstrated to deliver a low continuous force, consistent with optimum biological tooth movement, and to be approximately twice as effective in intraarch tooth movement when compared to elastomers (Samuels et al, 1993; Sonis, 1994). Intraarch studies demonstrating coil springs to be superior to elastics in tooth movement lead us to believe that they may also be more effective interarch for the correction of anteroposterior discrepancies. Documentation of closed coil springs for interarch use *in vivo* has not yet been reported.

Poor patient cooperation with removable appliances have also been found to be related to the intrusion of the appliance on mandibular function (Egolf et al, 1990). Pain has been cited as one of the main reasons for poor patient compliance with removable appliance wear during orthodontic treatment (Bartsch et al, 1993). Patient's perception of pain associated with various modalities of treatment can therefore have significant implications on expected treatment outcome. Minimizing pain with removable modalities of treatment could possibly increase patient compliance.

Conscientiousness with oral hygiene has also been cited as an indicator of good patient compliance (Egolf et al, 1990). Oral hygiene tends to worsen in the presence of fixed orthodontic appliances, can cause carious lesions, and can be a limitation to orthodontic treatment (Zachrisson, 1974). The extent to which closed coil springs impact on a patient's ability to maintain good oral hygiene is therefore an important consideration in determining overall prognosis.

The primary purpose of this study was to compare the effectiveness of fixed closed coil springs and removable elastics in the correction of overjet in patients with Class II malocclusions. In a clinical setting, many factors are simultaneously taken into consideration when deciding on the utility of a certain modality of treatment. In view of this, other parameters were examined which were thought to be important in affecting the clinical acceptability of use (by either practitioner or patient) of the elastics and coil springs. These factors included the limitations to the range of mandibular movement, the patient's perception of pain intensity and pain affect, and the changes in the oral hygiene status. In elastic wearers, patient compliance (with regard to both amount and pattern) was of interest since this parameter could potentially influence other variables being examined (overjet and oral hygiene). It was also recognized that the compliance, in turn, could be affected by the two other factors, mandibular movement and perception of pain, since these are commonly cited reasons for poor patient compliance with removable appliances.

CHAPTER 2

REVIEW OF LITERATURE

Class II Malocclusions

Definition

The designation Class II, in its original and strictest interpretation, defines the sagittal relationship between the upper and lower first permanent molars as proposed by Edward H. Angle (1897). However, this dental relationship can be found superimposed on an anteroposterior skeletal discrepancy between the maxillary and mandibular jaws, the etiology of which can be due to retrognathism of the mandible, prognathism of the maxilla, or a combination of the two (Epker et al, 1978; Wolford et al, 1978; Lake et al, 1981). A Class II relationship can also occur in a harmonious skeletal pattern, in which the problem is dental or dentoalveolar, and result from protrusion and/or proclination of the maxillary teeth, retrusion and/or retroclination of the mandibular teeth, or a combination thereof (Paquette et al, 1992; Livieratos & Johnston, 1995). Therefore, a simple morphologic classification divides Class II malocclusions into four groups: 1) those with a retrognathic mandible and orthognathic maxilla, 2) those with a prognathic maxilla and orthognathic mandible, 3) combinations of 1 and 2, and 4) dentoalveolar malocclusions (Proffit et al, 1993). In the majority of skeletal Class II patterns, mandibular retrusion is far more common (60-84%) than maxillary prognathism (22-51%) (McNamara, 1981; Bass, 1991). In addition, there exist various vertical components which impact on the horizontal malrelationship, to create further subclasses of Class II malocclusion.

Incidence

It is estimated that approximately 15-20% of the population in the United States and northern Europe have an Angle's classification Class II malocclusion (Kelly et al, 1973; Kelly & Harvey, 1977), and that as many as 37% of cases in a typical orthodontic practice present with a Class II Division 1 problem (Fisk, 1960). Because of the morphogenetic pattern of growth, a Class II disharmony (disproportionate skeletal relationship) will either worsen or remain the same (Goldstein & Myer, 1938; Enlow et al, 1969; Harris & Behrents, 1988; Bishara et al, 1995).

Overjet

A Class II malocclusion is almost always associated with an increased overjet. In a large scale survey of 8,000 American children and youths, approximately 16% were found to have an overjet of 6 mm or more (Kelly et al, 1973; Kelly & Harvey, 1977). It has been found that overjet measurements of greater than 10 mm are usually associated with a skeletal disharmony. A number of studies have confirmed that dental malocclusion, and in particular protruding teeth, can be a social handicap and can cause low self esteem (Jenny, 1975; Morris et al 1977). Early treatment of children with Class II malocclusions is often recommended under the assumption that an improved dental appearance may benefit a child by increasing his or her social acceptance and hence self-concept (Morris et al 1977).

It is also well recognized that a large overjet is a predisposing factor to traumatic injuries of the upper incisor teeth (McEwen et al, 1967; Järvinen, 1978). In a sample of 1445 orthodontically untreated children aged 7 to 16 years, the relationship between traumatic injuries to upper incisors and incisal overjet were studied. The frequency of injuries was 14.2% in children with normal overjet (0-3mm), 28.4% in children with increased overjet (3.1-6mm) and 38.6% in children with excessive overjet (>6mm). The severity of injuries was also greater in children with excessive overjet than in children with overjet ranging from 0 to 6 mm. Two or more injured incisors were found in 19.2% of the children with normal overjet, in 22.2% of the children with increased overjet, and in 46.7% of those with excessive overjet (Järvinen, 1978). The calculated relative risk of injury was 2.0 to 1 in the increased overjet group, and 2.7 to 1 in the excessive overjet group, when compared with the normal overjet group. Early reduction of an increased overjet is therefore recommended in order to reduce the predisposing risk of traumatic injury to the upper incisors.

In Class II malocclusions, the anterior teeth do not provide the protection or guidance normally provided by horizontal and vertical overlap in Class I occlusal patterns. An anterior shift of the mandible to an acquired centric occlusion occurs in order to obtain anterior guidance. In Class II maloccluions, anterior protrusion is the dominant and most used of the border movements, as a result of the tendency to posture the mandible forward (Jensen, 1990).

From the above, it is evident that Class II malocclusions have a high prevalence in the general population and are the most commonly presenting orthodontic problem. These malocclusions are often associated with an increased overjet and can benefit significantly from treatment with respect to improved esthetics, function and stability.

Treatment Modalities

Because of the various types of presenting malocclusions, treatment of a Class II malocclusion requires discretionary therapeutic decisions. Treatment modality is based on a combination of factors, including the morphologic pattern of the malocclusion, severity of the problem and age of the patient (Proffit et al, 1993).

A skeletal dysplasia can be corrected using growth modification, but can only be accomplished during the active growth period in young patients. Treatment is predicated on the belief that environmental factors can achieve an optimal growth potential within the scope of the individual genetic pattern, and that "form follows function". By altering the environmental factors (such as muscles), it is possible to stimulate mandibular growth (in cases of mandibular retrognathism, using functional appliances, e.g. Graber et al, 1985), or inhibit maxillary growth (in cases of maxillary prognathism, using headgear, e.g. Yoshida et al, 1995), thus altering growth direction.

In the adult dentition, a skeletal discrepancy can either be compensated (camouflaged) with the aid of maxillary extractions (Livieratos & Johnston, 1995), or altered with orthognathic surgery (Wolford et al, 1978), since growth modification is not possible. With a dentoalveolar discrepancy, the malocclusion can be addressed with maxillary premolar extractions, distalization of the upper first molars (either with or without second molar extractions, e.g. Cetlin and Ten Hoeve, 1983), or non-extraction using interarch mechanics (Proffit et al, 1993). In the latter, non-extraction treatment plan, a residual overjet often exists towards the end of treatment, which is usually resolved with the use of removable elastics. Failure of elastics to correct the overjet can resort to an alternative treatment option involving extraction of two maxillary premolars, or acceptance of a non-ideal treatment result with remaining overjet.

Therefore, the treatment approach to mild-moderate severity Class II malocclusions of dentoalveolar origin in adult patients entails either extraction of maxillary premolar teeth, or non-extraction with a more extensive use of interarch elastic wear, for maxillary-mandibular arch coordination. The interarch appliances used for correction of anteroposterior discrepancies include either removable latex elastics or fixed closed coil springs.

Elastics and Coil Springs

Elastics

Chemical and Physical Characteristics

Elastomers are classified as polymers and are materials which are capable of rapidly returning to their original dimensions after being substantially deformed (McCabe, 1985; Craig, 1989). Under sustained stress, elastomers undergo slow and irreversible rearrangement within the polymer structure, resulting in permanent deformation (elongation) of the elastomer. The load or stress dependent portion of plastic deformation is called "slip". The time dependent plastic deformation of a material is called "creep". The magnitude of deformation therefore depends on the material, the temperature, the load (slip), and the time of application of the load (creep). At a constant strain, an elastomer will exhibit a gradual reduction in stress (stress relaxation), resulting in a decrease in transmitted force at a fixed strain (DeGenova et al, 1985; Nikolai, 1985).

Elastomers include both natural and synthetic elastics. Latex elastic, or cis-polyisoprene, has chemical structural units derived from isoprene, a naturally occurring rubber. It is cross-linked by the process of vulcanization with sulphur, and the degree of cross-linking determines its flexibility, extensibility and elastic properties. Elastomeric plastic, or polyurethane, is synthetically derived from the addition of diisocyanate to a polyol (Wong, 1976). When exposed to an oral environment, elastomers absorb water and saliva, and permanently stain with time. Environmental factors such as temperature changes, pH variations, oral fluoride rinses, salivary enzymes and masticatory forces have all been associated with the deformation, force degradation and relaxation behaviour of elastomeric chains (Huget et al, 1990).

Application in Orthodontics

The advent of vulcanization by Charles Goodyear in 1839 gave natural rubber a durable quality, which significantly increased its use. Early advocates of natural latex elastics in orthodontics included Angle (1896), Baker (1904) and Case (1908). In 1938, the first cephalometric evaluation of Class II division 1 cases treated with intermaxillary elastics was published (Goldstein & Myer, 1938). The synthetic elastomeric plastics became available much later and were introduced to the orthodontic profession in the 1960s. They were commonly marketed under the name Alastiks. In orthodontic therapy, elastomeric modules (chain or thread) are used to generate forces for intramaxillary canine retraction, rotational correction and space closure, and are changed at each appointment, approximately every 4 weeks. Latex elastics are used for intra or intermaxillary correction and are changed daily by the patient (Baty et al, 1994).

Elastomers are unable to deliver a continuous force level over an extended period of time. The force delivered by elastomeric chains and elastics has been found to decay in an exponential pattern. Several studies have demonstrated that elastic modules held at a fixed stretched distance in distilled water at 37°C lose the greatest amount of force within the first 3 hours, approximately 50% to 75% of their initial force after 24 hours, and an additional 10% of force loss over another 4 weeks. This compares with a 24 hour loss of force of 42% for latex elastics (Andreasen & Bishara, 1970; Hershey & Reynolds, 1975; Kovatch et al, 1976; Wong, 1976).

When stretched between 22 and 40 mm, lengths corresponding to the typical minimum and maximum values for clinical intra or intermaxillary distances (and covering a force continuum of 28-448 g), Alastiks and latex elastics underwent most of their force decay within the first day and then continued to decay at a slower rate during the rest of a three week period. The amount of plastic deformation was found to be greater in plastic Alastiks than in latex elastics (Bishara & Andreasen, 1970). Loss of force in elastics used for intermaxillary traction (13-21%) after 6 hours, was also shown to be greater than that for intramaxillary traction (8-11%, e.g. Yagasawa et al, 1967).

Although elastomeric modules from different companies show substantial differences in initial force delivery, they display similar patterns of force degradation behaviour (Hershey & Reynolds, 1975). Elastomeric chains *in vivo* were found to exhibit significantly more force decay after 30 minutes than those exposed to air, while there was no difference between chains maintained in water and those *in vivo* up to 1 week (Ash & Nikolai, 1978). Short filament chains generally provide higher initial force levels and retain a higher percentage of remaining force than long filament chains (DeGenova et al, 1985), and chains manufactured by a stamping process deliver a more consistent force as compared with injection molded chains.

Although elastomeric auxiliaries are relatively consistent in producing tooth movements, they have several disadvantages. They have a high and rapid exponential decay due to plastic deformation. Also, an elastomer will exhibit a gradual reduction in stress (stress relaxation) at a constant strain, resulting in a decrease in transmitted force. To compensate for this, initial forces must often be greater than desired, and patients must be seen more frequently for changes of elastomerics to ensure the delivery of adequate force levels to cause dentoalveolar changes.

Metal Alloys

Physical Characteristics

Two important characteristics of a metal alloy include the load-deflection rate and the maximal elastic limit. By definition, the load-deflection rate is the force produced per unit activation. It can be observed (Appendix A) that from 0 to the maximal elastic load, there is a linear relationship between load and deflection. As the force increases, the deflection also increases proportionately (Hooke's Law). At the maximal elastic limit, a point is reached where load and deflection are no longer proportional, permanent deformation is produced, and the wire or coil will not return to its original shape. Therefore, behaviour to the left of the maximal elastic limit lies in the elastic range, and behaviour to the right lies in the plastic range. At the extreme right of the graph is the ultimate load, at which point the wire or coil spring will break (McCabe, 1985; Craig, 1989).

On a stress-strain curve, the characteristics of the diagram is similar to that of a load-deflection curve, but with different units. Stress and strain are tissue normalized load and deformation (normalized for the original length and cross-section) which allows comparison of materials independent of the original geometry. The ratio of stress to strain is referred to as the modulus of elasticity.

Application in Orthodontics

In order to deliver a continuous force, a wire must be capable of absorbing and releasing energy. Energy absorption is produced as a result of elastic deformation during the application of force or a load. Elastic deformations are changes in form or configuration that are reversible upon removal of the load.

A low load-deflection rate (high deflection with the application of low loads) is desirable for two important reasons: 1) a low load-deflection rate will maintain a more desirable stress level in the periodontal ligament (since the force on a tooth will not change dramatically in magnitude each time the tooth has been displaced) and 2) a low load-deflection rate offers greater accuracy in control over force magnitude, since linear errors in activation translate into relatively lower levels of force (Burstone, 1994).

The maximal elastic load is the greatest force that can be applied without producing permanent deformation. In the design of an orthodontic appliance, it is desirable to exceed the required force needs, so that permanent deformation or breakage will not occur by accidental overloading, which can be produced by abnormal activation or by masticatory forces (Burstone, 1994).

Nickel-titanium Alloys

Chemical and Physical Characteristics

The first nickel-titanium alloy, Nitinol, had its name derived from the elements making up the alloy - "ni" for nickel, "ti" for titanium, and "nol" for Naval Ordinance Laboratory, its place of origin (Beuhler, 1963). The general composition is approximately 53.5% nickel, 44.9% titanium and 1.6% cobalt. Nickel-titanium alloys possess about one fifth to one fourth the stiffness of stainless steel arch wires with same cross-section size and segment length. These alloys have a wide elastic working range and a high resistance to permanent deformation. Nickel-tianium wires can be activated over twice the distance of stainless steel with minimum permanent deformation. The mechanical properties of nickel-titanium alloys can vary considerably with composition modifications and with mechanical and thermal histories.

The later generation nickel-titanium alloy, Japanese NiTi, was developed by the Furukawa Electric Company in Japan, and possessed two unique properties of "superelasticity" and "shape-memory". "Superelasticity" refers to the property of having a load-deflection curve with an extensive intermediate region, where load remains nearly constant despite a change in deflection. This feature signifies a large working range (wide elastic range) and a high resistance to permanent deformation (resistance to both creep and slip) despite a substantial deflection of the wire. The initial and final regions of the load-deflection curve are of relatively steeper slope

(Miura et al, 1986; Hurst et al, 1990; Bishara et al, 1995b; Manhartsberger & Seidenbusch, 1996).

The "shape-memory" phenomenon is related to the inherent capability of altering its atomic bonding as a function of temperature over the transition temperature range (TTR). Below the TTR the molecules are in a close-packed hexagonal lattice (martensitic phase), the alloys are ductile and may be plastically deformed. When heated above the TTR, the crystal structure is a body-centered cubic lattice (austenitic phase), and the alloys revert to their original shape (Kousbroek, 1984; Muira et al, 1986; Muira et al, 1988; Hurst et al, 1990; Bishara et al, 1995b). By controlling the temperature range, therefore, a change in crystal structure (martensitic transformation) can be produced (Miura et al, 1986). The specific TTR is a function of the chemical composition of the alloy and its processing history. The TTR can be altered by varying the nickel content of the alloy or by substituting cobalt for part of the nickel (Beuhler, 1969; Andreasen, 1985). It has been determined that the TTR of the Japanese nickel-titanium wires is much lower than that of the original Nitinol wires, and is close to the temperatures of the oral environment (Miura et al, 1988).

The transformation of austenite to martensite can also be promoted by a certain level of stress as well as a reduction in temperature. Therefore, the "superelastic" regions are associated with the transformation of austenite to martensite on loading, and the reverse transformation of martensite to austenite on unloading; the remainder of the stress-strain or load-deflection curve is associated with elastic deformation of the austenite or martensite phases.

The shape recovery of thermoelastic wires was tested after they were stretched 12% of their original length. The mean percent recovery ranged between 89% to 94% in one study (Hurst et al, 1990), and was close to 100% in another (Bishara et al, 1995b).

Application in Orthodontics

Nickel-titanium alloys were first introduced into orthodontics in 1971 (Andreasen & Hillmann, 1971). Because nickel-titanium archwires possess a large working range, they can undergo large deflections to engage into severely malaligned teeth, without permanent deformation. In orthodontic practice, a wire or spring is activated, and it is the rebound force generated during the deactivation (unloading) period which is used for tooth movement. The load-deflection characteristics of nickel-titanium reveal a large intermediate region during unloading, indicating the delivery of near constant forces over a long range of deactivation. These forces have been shown to be low, within the biologically acceptable range, and to be capable of tooth movement (Kusy & Greenberg, 1982). Clinically, this characteristic can reduce the number of archwire changes necessary for alignment and levelling of a malocclusion (Andreasen, 1980). The availability of rectangular cross-section archwires (with greater engagement in the bracket slot) with low force delivery also allows three dimensional tooth correction in pretorqued and preangulated appliances during the initial phases of orthodontic treatment (Andreasen & Amborn, 1989).

The "shape-memory" property of nickel-titanium enables an archwire to be conditioned to "memorize" a particular archform. In the sequence of orthodontic treatment, a cast of an existing malocclusion is set to an ideal archform, the thermodynamic archwire is heated above its TTR, then cooled below the TTR and engaged intraorally into the malocclusion. Subsequent activation of the wire intraorally above the TTR reverts the wire to its original shape while exerting continuous forces to correct the malocclusion (Miura et al, 1990).

Japanese nickel-titanium alloys possess the unique property of "superelasticity". These alloys have a large working range with high resistance to permanent deformation, and deliver a light continuous force over a long range of deactivation. Light continuous forces have been proposed to be more consistent with optimal biologic tooth movement. Their thermodynamic "shape-memory" properties enable them to be sensitive to, and activated by, intraoral temperatures.

Closed Coil Springs

<u>Physical Characteristics</u>

The load-deformation properties of archwires and springs are similar; but deformation of archwires is usually expressed as angular bending or linear deflection while deformation of springs is expressed as elongation or shortening. Forces applied to the structural axis of springs include tension (elongation), compression (shortening) and torsion in addition to bending forces. If a moment operates at right angles to the lines of the structural axis, a torsional component is produced. In torsion the greatest elastic deformation occurs at the periphery of the wire. Bending or flexural forces are produced by either moments acting at right angles to the cross section of the coil or a transverse force acting on the coil (Lopez et al, 1979; Han & Quick, 1993).

Many variables have been shown to affect the inherent force-deflection characteristics of orthodontic springs. Miura et al (1988) demonstrated that when the diameter of a "superelastic" Nitinol coil spring wire increases with constant lumen size, the load (at which the "superelastic" activity is manifest) increases but the range diminishes in proportion to the decrease of the stretch. When the lumen of the coil increases with constant wire diameter, the load at which the "superelastic" activity occurs decreases and the range increases according to the increase of the stretch (Appendix A). Boshart et al (1990) demonstrated that as the pitch angle (angle between the coils and a perpendicular to the long axis of the spring) increases, the load-deflection rate of a spring increases. Conversely, as spring length increases, the load-deflection rate decreases. The various parameters affecting the load-deflection rate and stiffness of coil springs include the wire size, lumen size, pitch angle and length. The load-deflection rate is proportional to the wire size and pitch angle, and inversely proportional to the lumen size and spring length (Miura et al, 1988; Angolhar, 1992; Melsen et al, 1994). The surface-to-volume ratio of a spring is much larger than an archwire, however, studies have demonstrated coil springs to be highly resistant to corrosion (Edie et al, 1981).

When extended to generate an initial force value in the range of 150-160 g, closed coil springs experienced a force loss of only 8-20% after 28 days, which was substantially less than that compared to latex elastics or synthetic elastic modules (Angolkar et al, 1992). After being stretched (75-200% of resting length), nickel-titanium springs were found to exert a nearly constant force, as compared to that exerted by either stainless steel springs or polyurethane elastics (Webb et al, 1978; Muira et al, 1986; Han & Quick, 1993).

Nickel-titanium closed coil springs possess the desirable properties of having a high resistance to permanent deformation and delivering a continuous force over a long range of deactivation, as demonstrated previously for their archwire counterpart. Because coil springs can be ligated intraorally, and act independent of patient co-operation, they could potentially overcome the problem of compliance associated with orthodontic elastic use.

Comparative Studies with Elastics and Coil Springs

In vivo comparative studies between elastics and coil springs have been conducted in patients having symmetrical bicuspid extractions in the same arch, in which each side of the arch was randomized to received canine retraction with one of each method. In a group of 27 patients, a total of 100 quadrants were closed with either GAC Sentalloy^R nickel-titanium closed coil spring at 150 g of force, or 3/16" elastics delivering 180 g of force and changed once per day. Mean rate of tooth movement in the nickel-titanium group (0.51 mm per week) was almost twice as rapid as that closed with conventional intraarch (0.27 mm per week) elastics (Sonis, 1994). In a similar group of 17 patients receiving GAC Sentalloy^R closed coil springs at a force of 150 g, rate of space closure was significantly greater (approx. 5.8 mm) and more consistent than in the group receiving space closure with elastic modules (approx. 3.8 mm) after 160 days (Samuels et al, 1993).

Clinically, more efficient space closure with closed coil springs would indicate an overall reduction in the length of treatment time, as compared to space closure with elastomers. In addition, because the amount of traction of the tooth is often within the range of deactivation of the coil spring, space closure can often be accomplished with a single activation, thus signifying a reduced chair time within a shortened treatment time.

Relationship between Force and Tooth Movement

The force systems generated by an activated orthodontic appliance initiate a cascade of reactions that result in the remodelling of the periodontal supporting structures (cementum, periodontal ligament fibers, and alveolar bone), which ultimately leads to new positions for the teeth. The true mechanical parameter in tooth movement is not the magnitude of the force of the orthodontic appliance, but rather the magnitude of the stress generated by the appliance in the surrounding periodontium (Quinn and Yoshikawa, 1985). The extrinsic mechanical stimulus (force created by the appliance) is transmitted as a local stress which induces a local strain, and in turn contributes to changes in the tissue environment. Depending on the reactive stresses, compressive, tensile and torsional strains are experienced by the tissues of the periodontium. These changes evoke changes in the cellular activity which ultimately lead to remodelling of the periodontal supporting tissues (Quinn and Yoshikawa, 1985).

The relationship between the applied mechanical stimulus and the ultimate repositioning of the teeth is still not completely understood. However, experimental information exists, from which working hypotheses have been developed. Two major theories of orthodontic tooth movement involve regulatory mechanisms through blood flow and piezoelectricity.

Blood Flow Control Theory

The blood flow theory is the classic theory of tooth movement, and relates tooth movement to cellular changes produced by alterations in blood flow through the periodontal ligament. In this theory, an alteration in blood flow within the periodontal ligament is produced by the sustained pressure that causes the tooth to shift position within the periodontal ligament space, compressing the ligament in some areas while stretching it in others. Pressure and tension within the periodontal ligament, by reducing (pressure) or increasing (tension) the diameter of blood vessels in the ligament space, alter blood flow. Alterations in blood flow create changes in the chemical environment, such as a fall in oxygen in the compressed areas and a rise in oxygen in the tension areas (Yamaguchi and Nanda, 1992; Vandevska-Radunovic et al, 1994).

With the application of light forces, blood flow through the partially compressed periodontal ligament decreases in minutes. The resulting changes in the chemical environment produces a different pattern of cellular activity. Animal experiments indicate that increased levels of cyclic AMP, the "second messenger" for many cellular functions including differentiation, appears after 4 hours of sustained pressure (Sandy et al, 1993). Prostaglandins have also been demonstrated to be important mediators of mechanically induced stress. In a rat model, injection of prostaglandin was found to increase osteoclast numbers and indomethacin, which inhibits prostaglandin synthesis, blocked the appearance of osteoclasts (Yamasaki et al, 1980). Further work showed local prostaglandin injection to increase the rate of orthodontic tooth movement in primates (Yamsaki et al, 1982). With decreased blood flow, monocytes in the periodontal ligament are stimulated to form osteoclasts, which appear within the compressed ligament 36 to 72 hours after the application of force. These cells attack the adjacent lamina dura, removing bone in the process of "frontal resorption", and tooth movement occurs.

If heavy forces are applied which totally occlude blood vessels and remove the blood supply to an area within the periodontal ligament, a sterile necrosis (hyalinization) ensues within the compressed area. When this occurs, remodelling of the bone adjacent to the necrotic area must be accomplished by cells derived from adjacent undamaged areas. After a delay of several days, cellular elements from other areas of the periodontal ligament invade the necrotic area, and osteoclasts differentiate within the adjacent bone marrow spaces and attack the underside of bone adjacent to the necrotic periodontal ligament area (undermining resorption). A delay in tooth movement occurs due to time for stimulation of the differentiation of cells within the marrow spaces, and also because of time for removal of bone from the underside of the bone.

Therefore, the degree of hyalinization is associated with the magnitude of the stresses in the periodontal ligament. With light forces, only small areas of hyalinization occur and these are quickly resorbed, thus allowing tooth movement to occur. Since tooth movement is force-dependent (at low to moderate forces), an increased force will result in a greater amount of tooth movement but also, a greater amount of hyalinization. Eventually a force level will be reached at which the amount of hyalinization can not be resorbed by "frontal resorption" within the periodontal ligament, but rather "undermining resorption" from the marrow spaces, and tooth movement is delayed.

Piezoelectric Control Theory

Piezoelectricity is a phenomenon observed in many crystalline materials in which a deformation of the crystal structure produces a flow of electric current as electrons are displaced from one part of the crystal lattice to another. Bone mineral is a crystal structure with piezoelectric properties. Therefore, forces that produce bending of the bone, also produce piezoelectric signals. The piezoelectric signal has a quick decay rate following the initial applied force, and the production of an equivalent signal which is opposite in direction to the original signal, upon removal of the force.

This theory relates tooth movement to changes in bone metabolism controlled by the electric signals produced from flexing and bending of the alveolar bone. When bones are mechanically strained, very low electrical voltages, referred to as piezoelectric potentials, are generated. Mechanical distortion is thought to generate streaming potentials which evoke osteogenic change through the proteoglycan "strain-memory". Histochemical changes in the periodontal structure have been noted when forces or electrical potentials are applied (Davidovitch, 1991). It has been demonstrated in animal studies that the rate of orthodontic tooth movement can be enhanced by the application of electrical potential to the periodontium. The rate of tooth movement was found to double when an electrical stimulus was applied (Davidovitch, 1991). However, other experiments found little or no advantage of a vibrating application of pressure over a sustained force for the movement of teeth (McDonald, 1993), suggesting that piezoelectric signals may have a limited role in bone remodelling associated with orthodontic tooth movement. Therefore, it appears that both mechanisms may play a role in the biologic control of tooth movement.

Phases of Tooth Movement

Tooth movement occurs in several stages, and a different relationship is found to exist, depending on which stage of tooth movement is being investigated. The stages have been characterized as initial phase, lag phase, and post-lag phase (Burstone, 1994). Similar stages in tooth movement have been reported by others (Storey, 1973; Reitan, 1975). Initially there is a very rapid tooth movement, probably due to distortion or strain of the periodontal supporting structures. These strains have been described as bioelastic at low stresses (Storey, 1973); as the stresses are increased, the strains become bioplastic and finally biodisruptive. During this initial phase, a linear relationship between stress and strain probably does not exist for the full range of deformation from elastic to disruptive conditions.

Within a few days the initial phase is followed by a lag period, during which little or no tooth movement occurs. It has been noted that during this phase of tooth movement, the periodontial ligament histologically has a hyalinized appearance (Reitan, 1975). It has been suggested that hyalinization leads to devitalization and that this hyalinized ligament must be resorbed before tooth movement can continue.

After the lag phase, which can extend into weeks, tooth movement progresses at a rapid rate. Histologically, the hyalinized region is removed by undermining resorption of the adjacent bone. During this post-lag phase, the osteoclasts are found over a very wide surface area, resulting in direct resorption of the bony surface facing the periodontal ligament.

The processes that occur at different phases of tooth movement make the relationship between forces and rate of tooth movement time dependent. The rate of tooth movement as a function of force or stress is different for the various stages.

Force Magnitude and Force Duration

The relationship between the force magnitude delivered by orthodontic appliances and the rate of orthodontic tooth movement is controversial. However, it is generally maintained that for low to moderate forces, tooth movement is force-dependent.

An early study by Schwartz (1932) advised that applied forces should not result in capillary blood pressures exceeding a certain level at root surface. Using the methods of the time, Schwartz reported this level to be 20-26 g/cm^2. Exceeding this level would induce what was later described as "undermining resorption". Forces as small as 4 g were found to move teeth at a measurable rate of 0.1 mm/week (Weinstein et al, 1963), and forces ranging between 25-150 g have been associated with up to 1mm/month tooth movement (Burstone et al, 1961; Proffit et al, 1993). It was found that within an individual patient, heavier forces served to move teeth at a greater rate (Hixon et al, 1970).

A much more contentious issue relates to the presence or absence of an "optimum" force, above which increasing forces would actually cause a decreased rate of tooth movement. Studies by Storey and Smith (1952) using light (175-300 g) and heavy (400-600 g) initial forces for cuspid retraction, found an optimum range of forces to exist between 150-250 g. Forces below this range were ineffective in tooth movement and forces beyond this range caused increased protraction of the molar tooth (anchorage loss), as compared to cuspid retraction. These findings parallel those of Gianelly (1971) who found that rate of tooth movement under the influence of heavy forces could be slower than that under light forces. The above studies support the concept of an "optimum" force for tooth movement and are also consistent with the histological findings of increased hyalinization, and the clinical findings of an increased lag period, occurring with the application of high forces. As mentioned previously, the magnitude of the stress generated in the surrounding periodontium by the orthodontic appliance is the actual mechanical determinant of tooth movement. It has been estimated that forces for canine retraction between 100-200 g yield mean compressive stresses of approximately 70-140 g/cm^2 for the average cuspid root, which assumes one half of the root surface to be under compressive stress (Freeman, 1965).

It has also been proposed that an optimum force does not exist and that increasing stress beyond a certain stress level does not alter the rate of tooth movement (Quinn and Yoshikawa, 1985). This phenomenon would be consistent with the saturation of a stimulation-dependent activity. In support of this theory, forces between 150-400 g found higher forces to result in greater cuspid retraction than anchorage loss (Mitchell et al, 1973). In a similar study, the same findings were obtained with forces between 2-11 ounces, which is approximately 60-310 g (Boester and Johnston, 1974). With the above hypothesis, however, it can always be argued that the forces examined did not approximate those beyond the "post-optimum" force region of the curve and that use of higher forces could have resulted in reduced tooth movement.

In addition to force magnitude, tooth movement is dependent on force duration. Orthodontic force duration can be classified by the rate of decay as continuous, interrupted or intermittent. A continuous force is one in which the force is maintained at some appreciable fraction of the original force from one patient visit to the next. An interrupted is on in which force levels decline steadily to zero between activations. With an intermittent force, force levels decline abruptly to zero, when the orthodontic appliance is removed by the patient.

Both continuous and interrupted forces are produced by fixed appliances that are constantly present. Intermittent forces are produced by patient-activated appliances, such as removable appliances and elastics (Proffit et al, 1993).

A review of the literature on the other parameters which were examined in this study namely: centric relation and centric occlusion, patient compliance, mandibular movement, pain perception, and oral hygiene, will be presented below.

Centric Relation and Centric Occlusion

The principle of a centric relation (CR) position has been a point of contention for several decades, during which time there has been several changing definitions.

Differences in opinion is related to contradictory theories of jaw movement, differences in both positional and dynamic states of jaw recordings, and the selection and use of various different articulators.

Historically, CR corresponded to a single posterior terminal hinge position, which was an imaginary line between the two condylar centers of rotation (Lucia, 1964). The CR position was later defined as a physiologic relationship of the mandible to the skull, with the condyle positioned far posteriorly and superiorly in the glenoid cavity, along the posterior incline of the articular eminence (Long, 1973; Phillips, 1986). It was believed that in this position the joint was unloaded, the ligaments were under little tension and the muscles were minimally activated. This retruded position has been documented to have high reproducibility, in some cases to within 0.1 mm (Shafagh & Amirloo, 1979; Sindledecker, 1981; Rosner & Goldberg, 1986). While regarded as a reliable reference position, it is, however, not a recommended treatment position (Gilboe, 1983; Wood, 1988). More recently, CR has been defined as a functional position with the condyle positioned anteriorly and superiorly, or centrically in the glenoid fossa (Gilboe, 1983). This latter position has been expounded as a recommended treatment and therapeutic condylar position (Roth, 1992).

Using a SAM articulator and mandibular position indicator (MPI), condylar position differences between CR and centric occlusion (CO) was measured three dimensionally. It was found that in many patients, CR does not coincide with CO (Hoffman et al, 1973; Rosner & Goldberg, 1986; Utt et al, 1995). Twenty of the 107 patients (18.7%) were found to have an anteroposterior or superoinferior condylar displacement of 2.0 mm or more on one or both sides.

In another study examining CR-CO differences cephalometrically subjects with Class II malocclusions were documented to have larger mean anteroposterior CR-CO discrepancies (1.2 mm) than Class I subjects (0.7 mm, e.g. Williamson et al, 1978). Among Class II malocclusion subjects, the range of CR-CO discrepancy was between 0 and 4 mm, and five of the twenty-eight subjects had a horizontal slide of 2.5 mm or greater. Furthermore, it was noted that Class II subjects also had a greater superoinferior discrepancy, with seven of twenty-eight cases seating 3 mm or more superiorly with a range of 0 to 5 mm, while the Class I range was 0 to 2.5 mm (Williamson et al, 1978).

Some investigators have advocated the use of radiographs to determine condyle position (Mongini, 1981; Williams, 1983; Hatcher et al, 1986). However, a consensus between the American Dental Association (1984) and the American Academy of Craniomandibular Disorders (1990) concluded that radiographs are contraindicated to assess condylar position for diagnostic purposes. Techniques such as computed tomography (CT), magnetic resonance imaging (MRI), arthrography, and arthroscopy may improve diagnostic capability, but are also associated with disadvantages and limitations, primarily related to cost and access.

Therefore, when CR is defined as the most posterior and superior position of the condyle in the glenoid fossa, it is highly reproducible but not physiologic. When CR is defined as the most anterior and superior condylar position, or a centric position, it is considered physiologic, but is very difficult to reproduce.

Patient Compliance

Achievement of orthodontic treatment success is highly dependent on patient cooperation, which consists of a number of components such as attendance at appointments, appliance wear, and maintenance of oral hygiene (Graber, 1971; Woolass et al, 1988; Brattstrom et al, 1991). Recently, it has been found that, in general, non-compliance of patients is increasing (Koltun & Stone, 1986; Sahm et al, 1990). It has also been observed that the manner in which a patient copes with pain and oral dysfunction associated with orthodontic treatment is largely a reflection of that patient's personality orientation, and the degree to which the patient is self-conscious of their dental malocclusion (Burns, 1970; Egolf et al, 1990; Hackett, 1993).

Of the various studies conducted to examine sex differences with orthodontic cooperation, some reported girls to be more cooperative than boys (Starnbach & Kaplan, 1975; Clemmer & Hayes, 1979) while others found no difference between the sexes (McDonald, 1973; Swetlik, 1978). Age, however, was consistently associated with patient cooperation, and patients 14 years or younger were found to be more compliant than older children (Allan & Hodgson, 1968). Another factor significantly associated with lack of patient compliance involved pain. Pain was cited as the most frequent reason for not wearing headgear or elastics, and was related to social inconveniences such as impediment of speech (Egolf et al, 1990; Bartsch et al, 1993). When examining non-removable modalities of orthodontic treatment, however, no correlation was found between patient's perception of pain and the level of orthodontic force exerted (Jones & Richmond, 1985; Samuels et al, 1993).

In orthodontics, patient compliance can be assessed by either indirect or direct means. Indirect measures involve compliance judgments or estimates by the patient or their provider (Gross et al, 1985; Hays & DiMatteo, 1987; Egolf et al, 1990). A regular and uniform pattern of appliance wear has been found to facilitate a higher amount of total wear time, in that the behavioural components become habitual and associated with contingent cues and social responses. In a study by Cureton et al (1993), patients who were requested to monitor their headgear wear with a headgear calendar were found to be more compliant (8.4 hours) than those patients who did not maintain such a calendar (4.4 hours). Among the calendar patients, there was a high degree of correlation between the number of hours recorded and the number of hours actually worn. The data indicated that the clinician could subtract about 4 hours from the average indicated calendar wear and be close to the patient's actual wear. Among the non-calendar patients, there was a poor correlation between the number of hours stated and the number of hours actually worn. In patients who indicated verbally that they wore their headgear 12 hours, actual wear ranged from 2 to almost 12 hours. Therefore, patients not maintaining a calendar often exaggerated their compliance, usually to a number close to the number requested and are consistent in the amount of misrepresentation (Cureton et al, 1993).

Direct measures of compliance have been confined to a few studies that used objective timing devices built into the removable appliances (Swetlik, 1978, Clemmer & Hayes, 1979; Sahm et al, 1990). These timing devices provide evidence that the mean compliance rate for removable appliance wear rarely exceed 57% of the daily hours of wear required, which corresponded to a mean daily wear of 8.7 hours (Clemmer & Hayes, 1979; Sahm et al, 1990).

Therefore, orthodontic treatment with removable elastics is highly dependent on patient compliance for treatment success. Patient compliance is partially attributed to pain, but can improve with the use of compliance schedules. Females, particularly those 14 years or younger, have been found on average to be more cooperative than males.

Mandibular Movement

In humans, the maximum incisal bite force occurred at a mean opening of 17.3 mm, and the bite force at an opening of 8 mm averaged only 73% of the maximum value (MacKenna & Turker, 1978). In another study, maximum occlusal forces were reduced from an average of 35.6 kg at an opening of 6 mm to 31 kg at an opening of 2.5 mm (Proffit et al, 1993). In most cases, natural anterior teeth were found to dominate the influence of the posterior border constraints (Lundeen at al, 1978; Jensen, 1990). Minimum or decreased EMG activity has been demonstrated for a given bite force with the mouth opened 10 to 20 mm, rather than in occlusion or at an opening of 1 to 2 mm (Gibbs & Lundeen, 1982).

Chewing forces have been measured in the natural dentition without disturbance to the occlusion using a sound transmission system (Gibbs et al, 1977). A high frequency of occlusal gliding with a large extent of lateral jaw movements were found during mastication. The mean percentage of gliding contacts occurring during chewing was found to be 60% while entering and 56% while leaving the intercuspal position (Suit et al, 1975). The harder the food being chewed, the more lateral was the closing jaw movement. Average maximal bite force during the occlusal phase was 74 kg (range 23 to 128 kg), which was approximately 36.2% of the maximum biting force. The highest recorded force persisted for an average of 115 ms or 59% of the total 194 ms occlusal period, and the average number of chews per patient was 266. The measurement of total occlusal forces recorded using the technique in this study are higher and more accurate than that measured by transducers placed in single tooth-supported restorations (Gibbs et al, 1977).

Cumulative evidence exists to indicate that optimum masticatory activity occurs at a mean opening which is considerably less than maximum opening. Furthermore, the magnitude of the occlusal forces associated with masticatory activity are enormous.

Pain Perception

Visual Analog Scale

Pain is a complex multifactorial phenomenon involving emotional, attentional, cognitive, and motivational factors. The pain response is dependent on the patient's subjective perception of pain, cultural background, previous experiences, and other forms of psychologic input that give meaning to the situation in which pain occurs. An important principle in pain measurement, as in any evaluation of sensory experience, is to have the critical observations in pain made by the person experiencing the pain. Pain measurement, therefore, is directly dependent on subjective reporting, and the person experiencing the pain is asked to match their perceived intensity of pain to a scale.

The Visual Analog Scale (VAS) is probably the most frequently used self-rating instrument for the measurement of pain in clinical and research settings. Much evidence exists to support the validity and reliability of using the VAS to rate both pain intensity and pain affect (Downie et al, 1978; Kremer et al, 1981; Littman et al, 1985; Jensen et al, 1989). The VAS is usually more sensitive to treatment change than other measures (Verbal Graphic Rating Scale, Numerical Rating Scale, Picture Scale) which have a limited number of response categories. The VAS also eliminates inherent difficulties in the interpretation and meaning of verbal scales. Most of the research conducted with these measures use young or middle-aged subjects, who demonstrate little difficulty understanding and using the VAS (Huskisson, 1974; Scott et al, 1977).

Scoring has also been found to be similar between males and females (Seymour et al, 1985; Ngan et al, 1989).

In a study using VAS of different lengths (5,10,15 and 20 cm) and with different end phrases (troublesome, miserable, intense, unbearable, and worst imaginable pain) to rate dental pain, scales of length 10 cm or 15 cm had the smallest measurement error, and the end phrase "worst imaginable pain" was found to be the best descriptor for comparing pain between different groups (Seymour et al, 1985).

There is evidence for an affective component of pain that is conceptually and empirically distinct from pain intensity. Pain intensity may be defined as how much a person hurts, and pain affect is defined as the emotional arousal and disruption engendered by the pain experience. Because feelings about events can be mixed, it is likely that the domain of pain affect consists of multiple dimensions, which may be closely related to one another. Despite this, pain affect can be reliably quantitated using the same measures used to assess pain intensity.

It is well recognized that pain is a personal experience and is most validly and reliably measured using a subjective patient scale. The Visual Analog Scale is the most frequently used self-rating instrument for the measurement of pain. Scales of 10cm length had the smallest measurement error, and the end phrase "worst imaginable pain" was the best descriptor for pain comparison.

Pain and Orthodontic Treatment

Orthodontic pain is multifactorial and depends, in part, on the type of appliance, degree of initial crowding, level of initial force, and dental arch examined. Initially it was believed that a relationship existed between the forces applied to teeth and the resultant discomfort prior to or during their movement, with larger forces causing greater periodontal compression and resulting in greater pain. However, a wide range of individual responses have been documented with the application of similar forces. Studies have found no correlation between the force magnitude (estimated as a function of the severity of crowding) and the pain experienced (Burstone, 1962; Jones & Richmond, 1985).

In support of this, Samuels et al (1993) found patient discomfort with coil springs to be no different than that reported for elastic modules. In this group of 17 patients having symmetrical bicuspid extractions in the same arch, space closure was conducted by means of nickel-titanium closed coil springs or elastic modules. In each patient, each side was randomized to receive one of each treatment and cuspid retraction was carried out for a period of 6 weeks.

In a group of 70 patients undergoing orthodontic treatment, discomfort (as assessed by a VAS) was found to occur within 4 hours of either separator or archwire placement, increased up to 24 hours and then decreased to pretreatment levels within 7 days (Ngan et al, 1989; Wilson et al, 1989). In these studies, no significant differences were found in pain reportings of patients older than 16 years of age compared to those under 16 years, and no difference in discomfort was found between the sexes (Ngan et al, 1989; Wilson et al, 1989).

It has been proposed that pain resulting from orthodontic tooth movement is caused by a combination of pressure, ischemia, inflammation and edema (Furstman & Bernik, 1972) or by a lowering of pain threshold and disruption of input from the periodontal ligament (Soltis et al, 1971). Burstone (1962) identified an immediate and delayed pain response, and speculated the former to be related to the initial compression of the periodontal ligament immediately after arch wire placement, whereas the latter, which started a few hours later, was due to hyperalgesia of the periodontal ligament. Hyperalgesia, which is an increased sensitivity to noxious agents such as histamine, bradykinin, serotonin, acetylcholine and substance P, can be induced by prostaglandins (Ferreira et al, 1978; Higgs & Moncada, 1983). In two separate animal studies, the level of prostaglandins was found to increase and peak between 24 to 36 hours and decrease within 7 to 14 days (Kess et al, 1987; Kamogashira et al, 1988) after the application of orthodontic forces.

A simple correlation between force level and pain experience has not been found, possibly because of the complex multifactorial nature of pain. Discomfort associated with orthodontic treatment, was found to occur within 4 hours of either separator or archwire placement, peaked at 24 hours and subsequently decreased to pretreatment levels within 7 days. The pain associated with intraarch coil springs has been reported to be similar to that of elastomers, when used for cuspid retraction.

Oral Hygiene

Oral hygiene habits are generally assessed by toothbrushing technique, plaque accumulation and soft tissue appearance. Toothbrushing and flossing are recognized as effective means of plaque removal from the smooth surfaces of enamel (Wright, 1977; Honkala et al, 1986). Since plaque and gingivitis is more marked on the buccal surfaces, this has been found to correlate with the normal brushing cycle, since little or no attention is usually given to the cleaning of lingual surfaces (MacGregor & Rugg-Gunn, 1979).

The methods children employ for toothbrushing, and the amount of time devoted to daily oral hygiene, is very variable. Of 3698 fourteen year old children questioned, 54% brushed twice daily, 36% brushed once per day and 10% brushed three times or more (MacGregor & Balding, 1987). Mean amount of time devoted to brushing was found to be less than one minute in most children (Honkala, 1984).

Overall, there is an increase in frequency of toothbrushing and improvement in oral hygiene in both boys and girls as they become teenagers and no significant difference between right and left handed brushers (MacGregor & Balding, 1987). Studies have shown a higher rate of oral hygiene compliance in females and for girls to have lower plaque, bleeding and pocketing scores than boys (Buckley, 1980; Addy et al, 1990).

The presence of orthodontic bands and brackets, along with archwires and attachments, hinders the mechanical removal of plaque along the gingival margin (Zachrisson, 1974; Addy et al, 1990). However, longitudinal studies have shown that plaque levels do not necessarily increase during orthodontic treatment if toothbrushing and oral hygiene is outlined prior to treatment (Zachrisson & Zachrisson, 1971; Lundstom et al, 1980; Pender, 1986).

In general, most of the indices used to measure plaque accumulation utilize a numerical scale to measure the extent of surface area of a tooth covered by plaque. The first index using a numerical scale was developed by Ramfjord (1959) and relied on six teeth. The plaque score per person was obtained by averaging the individual tooth scores. The Oral Hygiene Index was developed by Green & Vermillion in 1960 and later simplified to also include six tooth surfaces that were representative of all anterior and posterior segments of the mouth. A positive correlation has been demonstrated between this index and the earlier Russell's Periodontal Index (1956).

Later, a plaque index was introduced which focused on the gingival third of the tooth surface and examined only the facial surfaces of the anterior teeth (Quigley & Hein, 1962). The scores in the gingival area were then redefined and made more objective (Turesky et al, 1970). This index is a sensitive, simple, and useful method for qualitatively assessing individual or group oral hygiene status (Fischman, 1986).

Oral hygiene habits are often a reflection of patient compliance. Fixed orthodontic appliances can contribute to a worsening of oral hygiene and create limitations to treatment. Numerical plaque indices are an objective means of rating oral hygiene status, and have indicated females to have superior oral hygiene levels as compared to males.

CHAPTER 3

OBJECTIVES

The purpose of this study was to compare the effects of interarch elastics and closed coil springs on overjet correction in patients with Class II malocclusions. The study was also designed to examine in a non-invasive manner, pertinent parameters associated with elastic or coil spring use which may impact on their clinical acceptability. These parameters included the range of mandibular movement, the patient's perception of pain, and oral hygiene. Information obtained from this study may be used to formulate a rationale decision with regard to choice of treatment modality in the correction of overjet in patients with Class II malocclusions.

Clinical Relevance

Class II Division 1 malocclusions have a high prevalence in the general population and are one of the most commonly presenting orthodontic problems. These malocclusions are associated with an increased overjet and may benefit significantly from treatment with respect to improved esthetics, function and stability. A dental Class II Division 1 malocclusion in a non-growing patient, treated non-extraction, commonly has an anteroposterior discrepancy. Current orthodontic therapy conventionally employs interarch mechanics using removable elastics to correct this problem. Though potentially effective, elastics are highly dependent on patient compliance for treatment success. Quantitative changes in overjet are not well established, particularly for interarch mechanics, and continue to be predicated on clinical judgement, rather than scientific documentation. To date, no *in vivo* study has been reported that examines the relationship between compliance with Class II elastics and overjet correction.

The recent availability of nickel-titanium coil springs for interarch use, offers a new approach to the correction of overjet. The "superelastic" properties of nickel-titanium coil springs enable the provision of a light continuous force over a long range of deactivation (unloading of the force) with minimal permanent deformation. Since light continuous forces have been proposed to be more consistent with optimal biologic tooth movement, the use of nickel-titanium coil springs could be a significant improvement in the efficiency of tooth movement. Furthermore, the thermodynamic "shape-memory" properties of nickel-titanium springs enable them to be sensitive to, and activated by, intraoral temperatures. Because they are fixed and not reliant on patient cooperation, they could potentially overcome the problem of compliance associated with orthodontic elastic use. Coil springs could also be used in cases of latex sensitivity (Safadi et al, 1996). They would also be indicated in the handicapped, or in patients lacking the manual dexterity to replace removable elastics. Failure of elastics to correct a significant overjet can resort to an alternative treatment option involving extraction of two maxillary premolar teeth. Effectiveness of coil springs in correcting overjet could therefore signify a more conservative approach in the treatment of Class II malocclusions, and offer an alternative to elastics in cases where it is not the preferred modality of treatment.

Hypotheses

In comparison to removable interarch elastics, fixed interarch mickel-titanium coil springs:

1. Will be more effective for the correction of overjet.
2. Will impose a greater limitation on the range of mandibular movement (sustained maximal opening, maximal right and left lateral excursions, maximal anterior protrusion).
3. Will result in a decreased perception of pain
4. Will contribute to a worsening of oral hygiene.

Limitations

1. These experiments were performed in a small sample size (n=6). Caution should therefore be exercised when extrapolating the findings from this research to the general clinical situation.
2. This study examined the effects of a specific type, length and force of elastic (RMO Sailboat^R 6.4mm, 150 g) and closed coil spring (GAC Sentalloy^R 23 mm, 150 g).

Comparisons between elastics and coil springs of a different type or dimension may therefore not be similar to that found in this study.

3. Certain parameters (pain, compliance) were assessed using self-reported questionnaires and therefore were dependent on the recollections and honesty of the subjects.

Delimitations

All experiments were conducted in female patients (14.93 ± 0.94 SD years) currently undergoing orthodontic treatment in the Undergraduate and Graduate Clinic with a Class II malocclusion and residual overjet, in which interarch elastics were scheduled to be used for final correction of the malocclusion.

Assumptions

1. None of the subjects experienced significant mandibular growth during the study period which could contribute to overjet reduction.
2. The overjet reduction was due to a combination of maxillary and mandibular dentoalveolar changes, and not incisal tipping (retroclination of the maxillary anteriors and proclination of the mandibular anteriors).
3. The self-reported questionnaires are an accurate reflection of true experience.
4. The additional task with the compliance questionnaires in the elastic group, and the additional appointments for coil replacement in the coil group, did not impact adversely on any of the parameters examined.
5. Baseline scores for pain intensity and pain affect were zero.

CHAPTER 4

METHODOLOGY

Study Design

A prospective longitudinal intervention study was performed to compare two different treatments. Measurements in overjet, mandibular movement, and oral hygiene were obtained at baseline and repeated following the initial application of treatment with either coil springs or elastics. Patients were then given either coil springs or elastics to be worn as prescribed, and retested every two weeks for a period of three months.

Subjects

Description of Subject Groups

A total of eight healthy subjects currently in orthodontic treatment were recruited from both the Graduate and Undergraduate Orthodontic Clinics at the University of Manitoba. Five were assigned to the coil springs group and three were assigned to the elastic group, using a randomized method.

Inclusion Criteria

Subjects were selected on the criteria of being a non-growing female patient (of at least 14 years old), with an Angle Class II molar classification and minimum overjet of 3 mm. Subjects had a non-extraction treatment plan, in which all intraarch spaces were closed, and were in continuous upper and lower archwires of a minimum size of .016"x.022" stainless steel.

Exclusion Criteria

Subjects were not included in the study if they had a history of wearing orthodontic elastics or coil springs, had a crossbite (anterior, lateral, posterior) or had contact between the lingual surface of the upper incisors and labial surface of the lower incisors. They were also not included if they possessed existing periodontal or pathological conditions, had a combined orthodontic-orthognathic surgery treatment plan, a history of temporomandibular disorder, or restricted mandibular movements. In addition, they were not included if they were taking medications known to influence tooth movement

Throughout the study, subjects were excluded if they demonstrated poor patient compliance, developed dental or temporomandibular joint problems, or experienced intolerable pain. Poor patient compliance was considered to be an unusually high incidence of poor attendance at appointments, broken brackets or loose bands, refusal to wear the elastics or coils, or lack of cooperation with the filling out of questionnaires

Ethical Approval

Ethical approval for this project was obtained from the Committee on Research involving Human Subjects, Faculty of Dentistry, University of Manitoba in February 1995 (Appendix B).

Informed Consent

The subjects were invited to an initial screening and evaluated according to the inclusion and exclusion criteria. If suitable, they were informed of the details of the experiment, risks and benefits of participation, and their responsibilities, in language that they could fully understand (Appendix C). Any questions were answered and they were allowed up to one week to further ask questions and decide of they would like to participate. If they decided to participate, they were asked to sign an informed consent form (Appendix D). Written information with details of the study, a copy of the informed consent and instructions for the testing sessions (Appendix E), were given to each participant. As well, elastic subjects received an envelope containing the compliance questionnaire (Appendix F) and all participants received the pain questionnaire (Appendix G), a pen, a roll of tape, and a 24 hour emergency phone number, to be contacted in the event of any problems, within an hour of its occurrence.

Participants of the study were given financial remuneration, commensurate with their involvement, to a maximum of $100.

Instrumentation

GAC Sentalloy^R closed coil springs (23 mm length [eyelet to eyelet]; wire size 0.229 mm; pitch angle 0.229 mm; lumen size 0.9 mm; 150 g; GAC International, Central Islip, New York) and American nickel-titanium closed coil springs (20 mm length [eyelet to eyelet]; wire size 0.175 mm; pitch angle 0.175 mm; lumen size 0.8 mm; 75 g; American Orthodontics, Sheboygan, Wisconsin) were used, and compared to RMO Sailboat^R elastics (lumen diameter 6.4mm, 150 g, Rocky Mountain Orthodontics, Denver, Colorado).

Overjet was measured using a 65 mm stainless steel endodontic ruler (Union Broach Corporation, New York), with the end calibrated at 0 mm. Overjet was measured to the nearest 0.25 mm by visual inspection. Mandibular movement was measured using a digital electronic caliper (Model 500, Mitutoyo, New Jersey; accuracy ± 0.02mm; repeatability ± 0.01mm). A self-recording chart (Appendix F) was used to assess patient compliance with elastic wear. A 10 cm Visual Analog Scale (Appendix G) was used to rate both pain intensity and pain affect (limitation of the intervention to daily activity). Oral hygiene was evaluated using Turesky-Gilmore-Glickman modification of the Quigley-Hein Plaque Index (Appendix H), and scored using a sterile dental explorer (Hu Friedy no. 60E).

Procedures

Tensile Testing

A simple tensile test was performed (Appendix I) to determine extension changes with loading and unloading in both Rocky Mountain Orthodontics Sailboat^R elastics (6.4 mm, 150 g) and GAC Sentalloy^R closed coil springs (23 mm, 150 g).

Determination of Coil Length

GAC Sentalloy[R] closed coil springs are available in three lengths for interarch use - 18mm, 23mm, and 28mm. According to manufacturers' instructions (Appendix J), the appropriate length is determined by measuring from the distoincisal of the upper cuspid bracket to the mesial of the lower first molar hook (the points of attachment for the coil spring), with the patient's mouth at maximal opening. This measurement then has 5 subtracted from it and the remainder is divided by two. (calculated length = [maximal opening - 5]/2) The coil spring length closest to this result is then selected as the optimum length for that patient. For all five coil subjects, this length was determined to be closest to 23 mm (measured between the center of the eyelet at each end, not the actual length of the coil). At either end of the coil, the design of the attachment was identical. The product specifications also indicated that the coil springs exert a constant force of 150 grams when activated between 1mm to 20mm, at body temperature.

Practice Session

Experiments were conducted in the Graduate Orthodontic Clinic. A familiarization session was carried out for each subject immediately before the first test session to allow them to become accustomed to the testing procedure. Verbal and written instructions for all parameters of the study were kept consistent for each subject.

Test Session

At each test session, which lasted approximately an hour, measurements were recorded in the absence of either coils or elastics, in triplicate, in a rotating fashion, and with a period of relaxation between replicates. All test sessions were performed by the same investigator, without reference to previous sessions, and using the same equipment, sterilized between patients. Before and after the study period, subjects' heights were measured on a Harpenden stadiometer. The parameters of overjet, patient compliance, mandibular movement, pain perception and oral hygiene were measured as will be described below.

Overjet

With the subject in a semi-recumbent position, overjet was measured in centric occlusion (CO) in triplicate at each test session. Pre and post-treatment, overjet was also measured in centric relation (CR). Centric relation was obtained by guiding the subject's mandible and applying chin pressure, while supporting the angles of the mandible in a posterior and superior direction, while asking the patient to relax and close slowly. The difference between overjet measurements in CR and in CO was then taken as the CR-CO discrepancy, and recorded in magnitude and direction. CR measurements were taken before and after treatment, and differences in the CR-CO discrepancy were used to correct overjet measurements for condylar change.

Patient Compliance

Subjects in the elastic group were asked to wear elastics 24 hours per day, to remove them only while eating and brushing their teeth, and to change them three times per day (coincident with meals). A self-recording chart was given to subjects in the elastic group to indicate the amount and pattern of elastic wear, and was to be filled out at the same time daily throughout the three months. The forms were returned every second test session, in exchange for a new form. Subjects in the coil spring group had the coils fixed to the orthodontic appliance and therefore wore the coils 24 hours per day. Patients in the coil group were asked to support their mandible when yawning, to prevent over-stretching of the coil spring. At each test session, every two weeks, the coils were examined and replaced.

Mandibular Movement

Subjects underwent a series of jaw motions consisting of sustained maximal opening, right and left lateral excursions and anterior protrusion. Each measurement was measured in triplicate, in rotating fashion, using a digital electronic caliper. Measurements each session were done in the absence of coils or elastics.

Pain Perception

Subjects rated both the level or intensity of pain associated with the wearing of elastics or coil springs (pain intensity) and the extent to which the intervention limited their daily activity (pain affect), using the Visual Analog Scale (VAS). The VAS is a 10 cm long line with clearly defined boundaries at each end, representing the extremes of the pain experience. The VAS end descriptors for pain intensity were "no pain" and "worst imaginable pain" and for pain affect were "no effect" and "incapable of activity". It is advised that numbers not be superimposed on a VAS since certain numbers are preferred and interfere with the distribution of results. The scale therefore has an infinite number of points between the two extremes. The patient is asked to place a vertical line through the scale to represent their pain intensity or pain affect. The point on the line before treatment represents 0, and the distance from the "no pain" or "no effect" end to the vertical mark indicates that patient's pain score (in millimeters). Baseline scores for pain intensity and pain affect were assumed to be zero.

Subjects were asked to conduct their ratings at the same time each week throughout the three months, and once having filled out the form, to tape it and place it into a sealed envelope. The forms were returned at each test session , in exchange for new forms.

Oral Hygiene

At each observation period, oral hygiene was evaluated using the Turesky-Gilmore-Glickman modification of the Quigley-Hein Plaque Index taken from the labial/buccal surface at four sites (the most posterior lower right and left premolars and the upper and lower right lateral incisors). The posterior sites (treatment) were compared to the anterior (control) sites; and right and left posterior sites were compared with patient handedness.

Data Collection

Data for each of the measured parameters were collected each test session and entered onto a spreadsheet (Lotus 123 for Windows, version 5.0).

Statistical Analysis

All calculations were performed in Lotus 123, and those subjected to statistical analysis were imported into SigmaStat. Differences between the two treatment groups were determined using unpaired student t-tests. The level of significance was assessed at an alpha level of 0.05. Graphical plotting of the data was performed using SigmaPlot Scientific Graphing System, version 5.01 (Jandel Corporation). For all the parameters examined, changes were expressed as a percentage of the reference baseline value, so that a reliable estimation of treatment effect could be made within each subject, unconfounded by interindividual differences at baseline.

CHAPTER 5

RESULTS

Subject Demographics

There was no significant difference in age between the subjects in the coil springs group (14.7 ± 1.2 SD years, range 13 years 9 months to 16 years, n=3) and the elastic group (15.2 ± 0.8 years, range 14 years 6 months to 16 years 10 months, n=3, p=0.59). There was also no significant difference in the heights of the subjects in the coil (165.6 ± 7.0 cm) and elastic group (162.0 ± 5.5 cm, p=0.52). Pre-treatment heights (163.8 ± 6.0 cm, n=6) were also similar to post-treatment heights (164.1 ± 6.3 cm, p= 0.26). All patients attended all test sessions.

Coil Springs

Reliability of Coil Springs

According to manufacturers' claims (Appendix J) coil springs utilized in this study were capable of withstanding intraoral use for up to a 6 month period. In addition, the thin plastic sheath covering the coil would provide protection of the mucosa of cheeks during flexion and extension of the coils. Following placement of intact coils, the plastic covering began stripping within 6 hours of initial placement. Within 24 hours all subjects had lost the plastic from at least one coil, and by 48 hours the coverings were no longer present on any of the 10 coils placed. Loss of the plastic coverings caused concern in participants and was reported within hours of its occurrence. When participants returned to the clinic, it was found to be of minimal consequence (uneventful intraoral trauma) and were not replaced. All coils subsequently placed did not have a plastic covering.

Coil springs were associated with an unusually high incidence of failure (Appendix K). In all instances of coil failure, whether it involved one or both coils, both coils were replaced. All the removed coils were kept for examination.

Methods of Overcoming Coil Failure

A total of 5 different methods of ligation were employed over the course of the study period (Appendix L) in an attempt to discover an optimum method of ligation, to prevent further failure of the coils. At both the cuspid and molar, the eyelet was secured to either the bracket or archwire and, in general, there was a trend towards greater freedom of movement of the coil-bracket or coil-archwire interface. Ligation method #5 was the manufacturers' recommendation, given only after a significant number of coil failures. Using this technique, coils were found to last 9, 15 and 20 days, respectively. Coils were then placed, using this technique, into 2 patients (who were not originally part of the study but who fulfilled all inclusion and exclusion criteria, Appendix M). In both these subjects, the coil springs broke after only 7 days. Of the 7 subjects who wore coil springs, the shortest duration that coils were intact was 1 day and the longest was 20 days (Figure 1). The mean length of time that coils were intact was 9.8 ± 6.7 SD days (n=7) and the mean length of time taken to replace a broken coil was 1.8 ± 1.4 days (n=5, Figure 2).

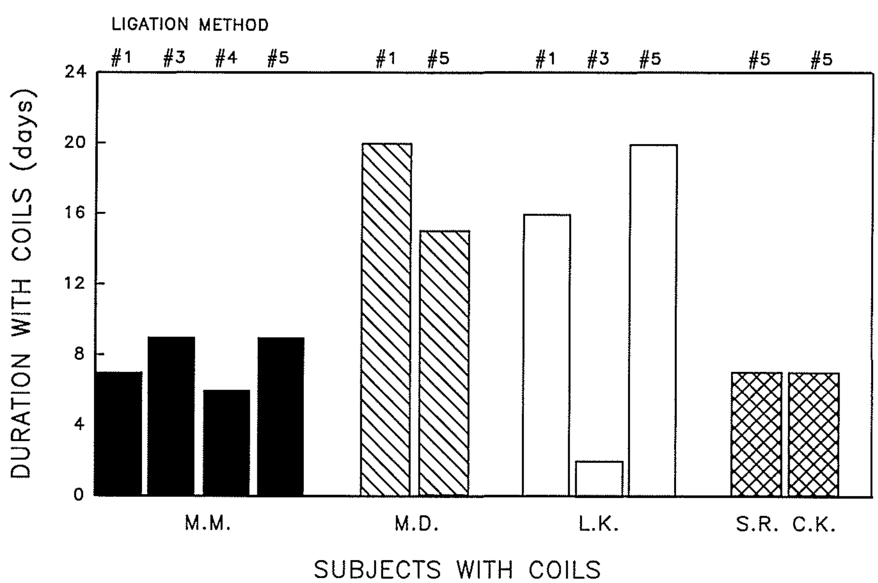


Figure 1. Duration (days) spent with intact GAC closed coil springs in the original coil subjects (n=3) and later recruited subjects (n=2), between sessions 1-4. Ligation methods used for attachment of coils are indicated at the top.

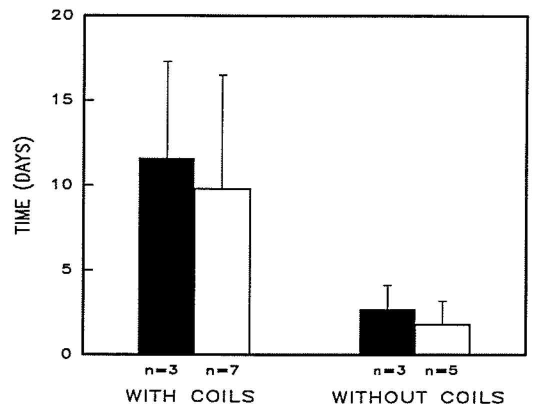


Figure 2. Mean time (days) spent with and without coil springs over the duration of the study. The solid bars (■) indicate the subjects in the coil group (n=3). The open bars (□) indicate all subjects who received coils (n=7, left) and the original coil group (n=5, right).

Loss of Subjects

Of the original 5 subjects randomized to the coil group, 2 subjects were subsequently excluded from the study due to an unacceptably high incidence of coil failure and voluntary withdrawal (KH) and lack of compliance with the completion of self-questionnaires (SL). The remaining 3 subjects (MM, MD, LK) constitute the coil sample which was then used for comparison with the elastic group (Appendix N).

Nature of Coil Failure

A total of 36 GAC coil springs were inserted. Of the 18 occasions that a subject returned with coil failure, 5 occasions involved both coils and 13 involved a single coil. Of the single coil failures, 8 were on the left side and 5 were on the right side, in a group in which 2 reported left side chewing and 5 had no preferential chewing side. Of interest, the 2 with predominantly left side chewing had 4 incidents of coil breakage on the left and 1 on the right. According to the recollections of the subjects, the occurrence of coil breakage was not associated with a particularly challenging intraoral activity. Of the 23 coils that broke, 14 were in close proximity to the cuspid and the remaining 9 were in proximity to the molar. The vast majority of the coils displayed breakage within the coil itself, immediately at the junction between the coil and metal plate housing the eyelet.

Coil and Elastic Parameters

The intraoral distance between the distal of the maxillary cuspid bracket and the mesial of the mandibular first molar hook at three measured and static positions (centric occlusion, maximal opening, and a manufacturers' "calculated length"), was compared for the two treatment groups (Figure 3). There was no significant difference between the two groups at any of the 3 positions. However, values tended to be larger for the maximal opening and "calculated lengths" in the elastic group. Within the coil group, the subject with the longest "calculated length" (25mm, subject M.M.) was found to have the greatest number of failures, whereas the other 2 with shorter spans - 20.5mm (M.D.) and 20mm (L.K.) - were found to have a fewer number of failures (Figure 4). In the elastic group the values for "calculated length" were 29mm (L.H.), 25.5mm (T.K.) and 17.5mm (R.L.). Bars in all figures display mean ± SE.

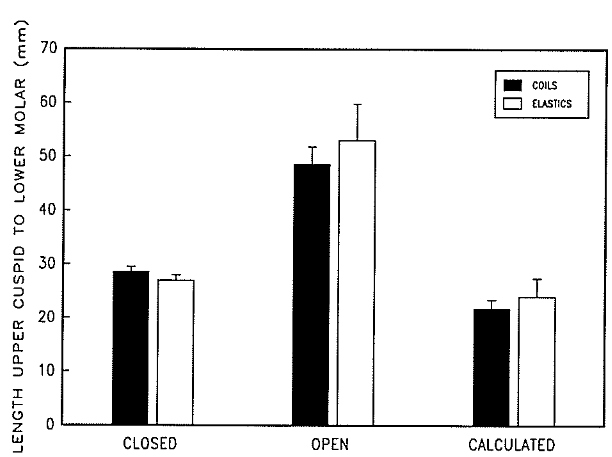


Figure 3. Mean distance (mm) from the distal of the maxillary cuspid bracket to the mesial of the mandibular first molar hook for the coil (■) and elastic (□) groups at three different positions: maximum intercuspation, maximum opening, and a "calculated length", equal to (maximum opening-5)/2. Measurements were taken prior to the first test session.

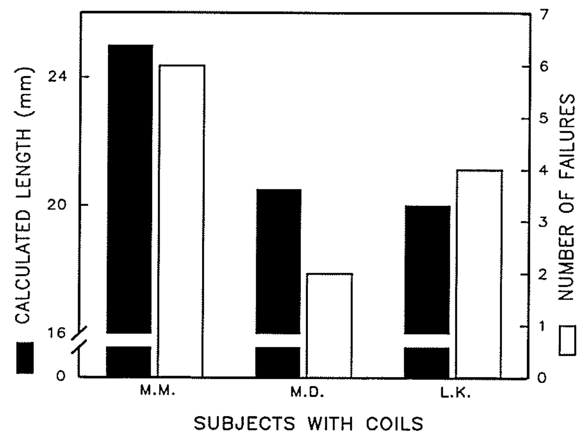


Figure 4. "Calculated length" between the distal of the maxillary cuspid bracket and the mesial of the mandibular first molar hook (mm), measured prior to test sessions (■) and the number of coil failures experienced throughout the study (□) for subjects in the coil group (n=3).

Overjet

Change in Overjet in both Groups

In the coil springs group, GAC Sentalloy^{R} coil springs were examined every 2 weeks for a period of 6 weeks. Because of the high incidence of failure, the GAC coil springs were then replaced with American coil springs for a period of 1-3 weeks. These coils were then removed and replaced with elastics (identical to those in the original elastic group), for a minimum of 5 weeks, after which a final test session was performed. With the American coils, there was evidence of coil deformation in 2 of the 6 coils placed, and no instances of coil failure (Appendix O).

There was no significant difference in overjet between the 2 groups at baseline (4.4 ± 0.4 SE mm in the coil group vs 5.0 ± 0.7 SE mm in the elastic group). Immediately following initial placement of either coils or elastics (session 1), both groups also responded in a similar reduction of overjet (Figures 5,6). With time there was a reduction of overjet in each group. After 6 weeks of treatment (session 4), there was a marked difference between the two groups in the degree of overjet reduction, with 19.9 ± 10.6% in the coil group compared to 40.1 ± 4.0% in the elastic group. The placement of American coils resulted in an increase in overjet in all 3 subjects (10.2 ±

8.9%), and the subsequent placement of elastics reversed the American coil effect and was successful, in all 3 subjects, in reducing the overjet to an amount less than that previously achieved with GAC coils (31.7 ± 17.5%).

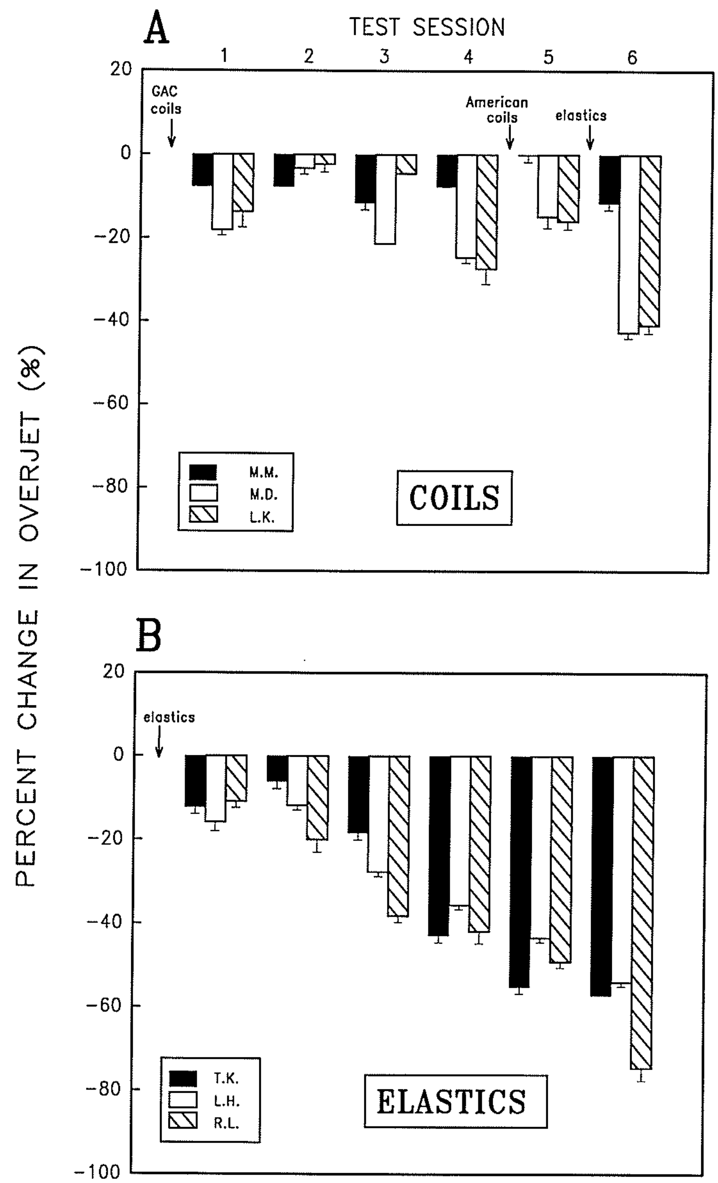


Figure 5. Percent change in overjet (%) for subjects in the coil group (n=3) following chronic wearing (sessions 1-4) of GAC coils, American coils (session 5) and RMO elastics (session 6, A); and the percent change in overjet in subjects in the elastic group at similar times (sessions 1-6), after wearing RMO elastics (n=3, B).

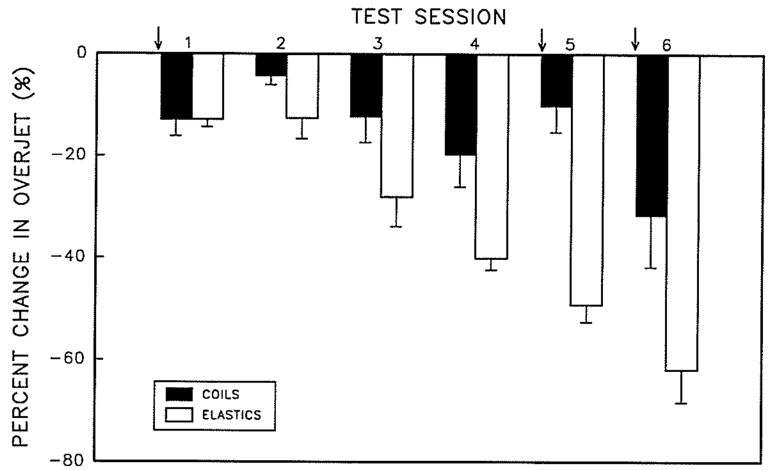


Figure 6. Mean percent change in overjet (%) in subjects of the coil group (n=3, ■) and elastic group (n=3, □) at each test session over the duration of the study (three months). Arrows indicate the initiation of GAC coil, American coil and RMO elastic wear in subjects in the coil group.

Change in Overjet and Compliance in the Elastic Group

The average compliance for the elastic group ranged from 89-92% throughout this study. With this amount of compliance, overjet progressively reduced, in a staircase-like effect, from 13.0 ± 2.5 SE % (session 2) to 61.9 ± 11.1% (session 6, Figure 7). When converted to absolute values, overjet reduction was between 0.4 ± 0.1 mm and 0.8 ± 0.3 mm per test session (Figure 8).

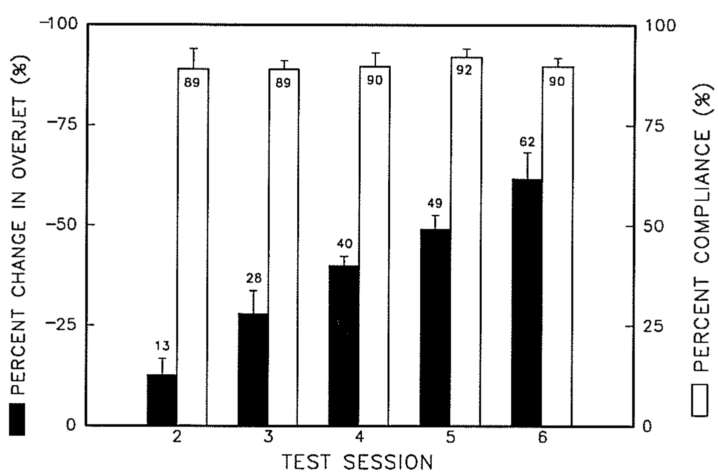


Figure 7. Mean percent reduction in overjet with elastics (%, ■) and mean percent compliance with elastic wear (%, □) in subjects in the elastic group (n=3) at each test session over the duration of the study (three months).

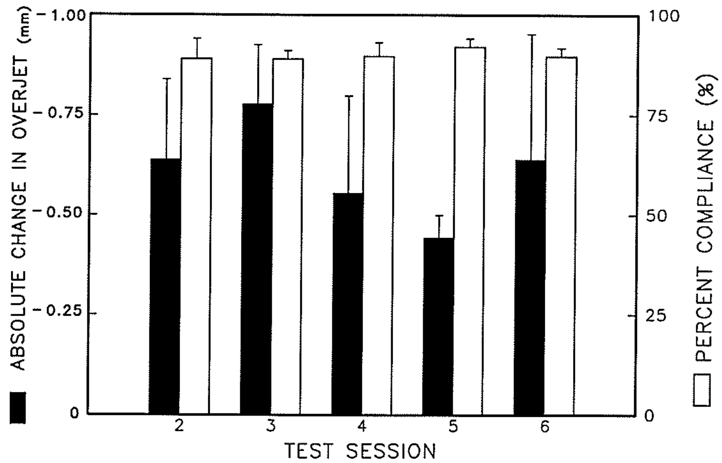


Figure 8. Mean absolute reduction in overjet with elastic wear (mm, ■) and mean percent compliance with elastic wear (%, □) in the elastic group (n=3) at each test session over the duration of the study (three months).

Change in Overjet in the Coil Group

In the coil group, overjet decreased from 4.4 ± 2.9 SE % (session 2) to 19.9 ± 10.6% (session 4, Figure 6). In absolute values, overjet reduction with GAC coils was 0.2 ± 0.1 SD mm, 0.4 ± 0.5mm and 0.3 ± 0.5mm (sessions 2, 3 and 4 respectively), and with American coils was 0.4 ± 0.1mm. A cross-over of elastic treatment in the coil group resulted in a relative overjet decrease of 31.7 ± 17.5 SD % or 0.9 ± 0.5 mm/5 weeks.

Correction for CR-CO Difference

Throughout this study, the difference between CR and CO was either unchanged (n=1) or increased (n=5). If the difference increased, in most cases this was 0.5 mm (n=4) but in one case was 1.5 mm (Table 1). The percent change, and absolute change, in overjet, at sessions 4 (following GAC coils) and 6 (following American coils and elastics), was recalculated, correcting for the CR-CO discrepancy (Table 2, Figure 9). In the diagrams illustrating percent change in overjet, the values at sessions 4 and 6 are relative to the overjet at baseline. For the diagrams illustrating absolute change in overjet, session 4 is the cumulative effect from session 2, 3 & 4, and session 6 is the cumulative effect from session 5 & 6. In all cases the correction resulted in a reduced, but more accurate estimate of, treatment effect, with one exception. Absolute change in overjet in the coil group at session 6 was unchanged with the correction since in all

3 coil subjects the CR-CO difference was unchanged between session 4 and session 6 (Table 1). After approximately 6 weeks (session 4), the absolute reduction in overjet with elastics (1.3 ± 0.4 SE mm) was far greater than that with coil springs (0.5 ± 0.6 mm). Furthermore, the subsequent wearing of elastics in the coil group for 5.6 ± 0.4 weeks (0.5 ± 0.4 mm), resulted in as much overjet reduction as that previously achieved by coils (0.5 ± 0.6 mm) over 6.0 ± 0.1 weeks.

Correction of overjet occurred simultaneous with changes in CR-CO discrepancy. When total overjet was corrected for this CR-CO discrepancy (Figure 9), overjet correction was separated into two different components - a "corrected" overjet and a "residual" overjet. After the correction, the relative proportion of the two overjet components to the total overjet measurement, was similar in both the elastics and coil springs group. Also there was an increase in the percentage of "corrected" overjet with time in both treatment groups. (session 4 vs session 6).

Mandibular Movement

The evaluation of mandibular movements was performed at each test session in the absence of either coil springs or elastics. Both treatments resulted in a sustained reduction in maximum opening with a 10.6 ± 10.7 to 14.8 ± 5.7 SE % decrease in the coil group and a 6.7 ± 7.2 to 12.1 ± 1.8% decrease in the elastic group (Figure 10). There was a minimal decrease in both right and left lateral excursions with both treatments. Coils resulted in a 5.3 ± 5.9% decrease to 0.8 ± 5.7% increase in right excursion and 4.8 ± 13.4 to 11.2 ± 6.9% decrease in left excursion. Elastics resulted in a 2.5 ± 3.7% to 12.5 ± 3.8% decrease in right excursion and 1.5 ± 6.2 to 5.9 ± 6.4% decrease in left excursion. An initial challenge with either treatment resulted in a minimal decrease (4.6 ± 3.2% with coils and 2.1 ± 2.3% with elastics) in anterior protrusion. With time, both treatments increased the patient's ability to protrude in the anterior direction, with elastic wear (21.1 ± 12.3%) producing a more marked effect than coils (7.5 ± 8.1%).

Treatment	Subject	Baseline		End GAC Coils (session 4)		End Elastics (session 6)	
		CR-CO (mm)	OJ (mm)	CR-CO (mm)	OJ (mm)	CR-CO (mm)	OJ (mm)
COILS	M.M	0	4.3 ± 2.5	0.5	4.0 ± 2.3	0.5	3.8 ± 2.2
	M.D.	0	5.1 ± 2.9	0.5	3.8 ± 2.2	0.5	2.9 ± 1.7
	L.K.	1.5	3.7 ± 2.1	1.5	2.7 ± 1.5	1.5	2.2 ± 1.3
	mean ± SE		4.4 ± 0.4		3.5 ± 0.4		3.0 ± 0.5
ELASTICS	T.K.	1.0	4.1 ± 2.4	1.5	2.3 ± 1.4	1.5	1.8 ± 1.0
	L.H.	1.5	6.3 ± 3.7	2.0	4.1 ± 2.4	2.0	2.9 ± 1.7
	R.L.	0	4.6 ± 2.7	1.0	2.7 ± 1.5	1.5	1.2 ± 0.7
	mean ± SE		5.0 ± 0.7		3.0 ± 0.5		1.9 ± 0.5

Table 1. Centric relation-centric occlusion slide and absolute overjet in subjects of the coil spring group (n=3) at baseline, following chronic GAC coil wear, and following elastic wear; and in subjects of the elastics group (n=3) at similar times, uncorrected for the CR-CO discrepancy.

Treatment	Subject	Baseline		End GAC Coils (session 4)		End Elastics (session 6)	
		CR-CO (mm)	OJ (mm)	CR-CO (mm)	OJ (mm)	CR-CO (mm)	OJ (mm)
COILS	M.M	0	4.3 ± 2.5	0.5	4.5 ± 2.6	0.5	4.3 ± 2.5
	M.D.	0	5.1 ± 2.9	0.5	4.3 ± 2.5	0.5	3.4 ± 2.0
	L.K.	1.5	3.7 ± 2.1	1.5	2.7 ± 1.5	1.5	2.2 ± 1.3
	mean ± SE		4.4 ± 0.4		4.4 ± 0.4		3.3 ± 0.6
ELASTICS	T.K.	1.0	4.1 ± 2.4	1.5	2.8 ± 1.6	1.5	2.3 ± 1.3
	L.H.	1.5	6.3 ± 3.7	2.0	4.6 ± 2.6	2.0	3.4 ± 2.0
	R.L.	0	4.6 ± 2.7	1.0	3.7 ± 2.1	1.5	2.7 ± 1.5
	mean ± SE		5.0 ± 0.7		3.7 ± 0.5		2.8 ± 0.3

Table 2. Centric relation-centric occlusion slide and absolute overjet in subjects of the coil spring group (n=3) at baseline, following chronic GAC coil wear, and following elastic wear; and in subjects of the elastics group (n=3) at similar times, corrected for the CR-CO discrepancy.

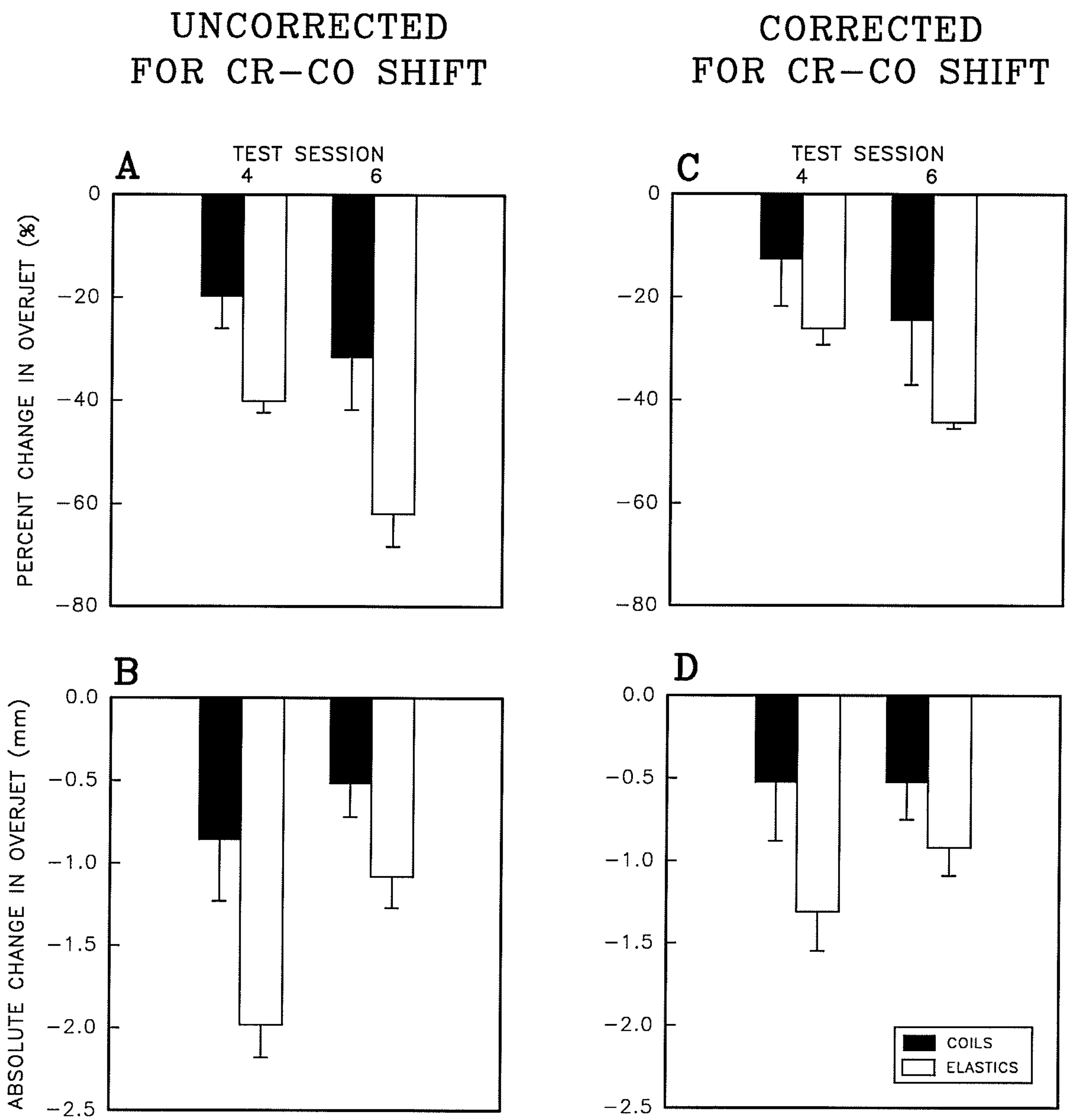


Figure 9. Percent reduction in overjet (%) and absolute reduction in overjet (mm) when uncorrected for CR-CO shift (A & B) and when corrected for CR-CO shift (C & D) in the coil (■) and elastic (□) groups, at test sessions 4 (end GAC coils) and 6 (end elastics).

PERCENT CHANGE IN MANDIBULAR MOVEMENT (%)

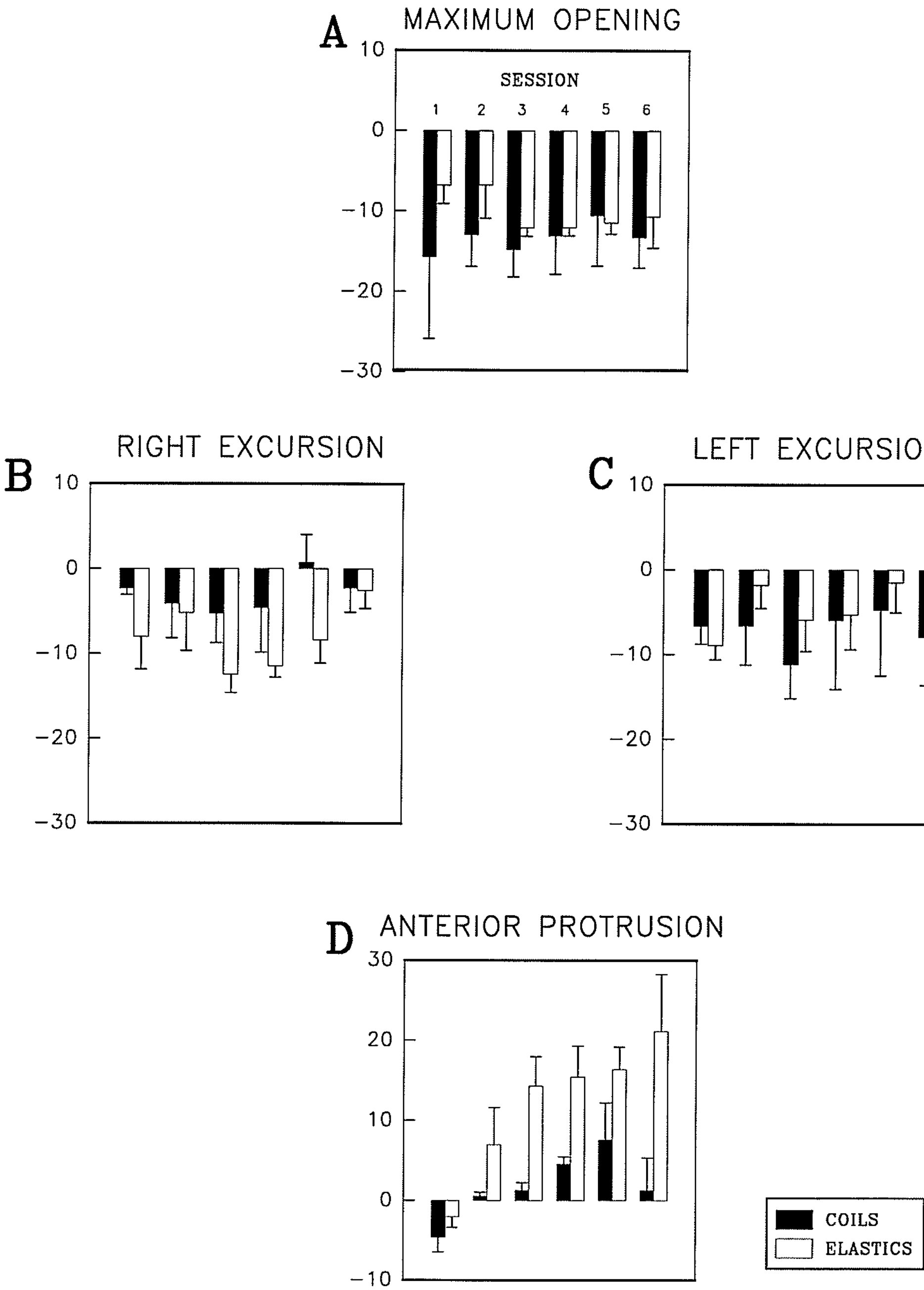


Figure 10. Percent change in mandibular movement (%) during maximum opening (A), right lateral excursion (B), left lateral excursion (C), and anterior protrusion (D), in the coil (■) and elastic (□) group, at each test session throughout the study period (three months).

Pain Perception

Participant's self-reporting of pain intensity within 2 weeks of initially receiving treatment was 12.0 ± 8.7 SE mm in the coil group and 16.3 ± 22.5 mm in the elastic group, out of a maximum value of 100 mm (Figure 11). These values are relatively low compared to the level of pain intensity typically associated with chronic pain (50 mm on the VAS scale). Within another 2 weeks, subject's perception of pain intensity decreased sharply to 4.7 ± 2.9 mm for coils and to 1.7 ± 2.1 mm for elastics. Subsequent to this, pain intensity was reported at even lower levels, and in most cases fell to zero in the elastic group. Pain perception in 3 subjects who each received GAC coils, American coils and elastics reported initially high values which decreased with time. This trend was consistently observed for each of the 3 subjects. The late introduction of elastics to coil subjects failed to elicit reportings similar to that when elastics were first initiated into elastic subjects (Table 3). This was a retrospective reporting by coil spring subjects, of all three treatments, following the removal of elastics. At no time did any subject report a need to take analgesics for their level of discomfort.

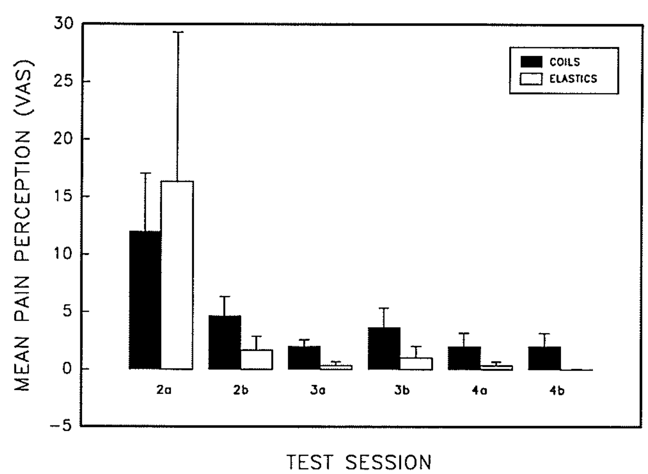


Figure 11. Mean (± SE) pain perception on the Visual Analog Scale (mm) reported by subjects in the coil (■) and elastic (□) group each week following treatment.

		VAS score (mm)		
		after GAC coils	after American coils	after RMO elastics
SUBJECT	M.D.	56	15	3
	M.M.	41	17	5
	L.K.	18	9	14

Table 3. Mean pain perception on the Visual Analog Scale (mm) in 3 subjects from the coil group following GAC coil, American coil, and RMO elastic wear.

Reporting of subjects perception of the limitation of treatment to their daily activity was consistent with that of pain intensity, with initially higher values within 2 weeks of treatment (13.3 ± 20.6 mm for coils, 12.0 ± 13.7 mm for elastics) followed by a marked fall in reported values (Figure 12).

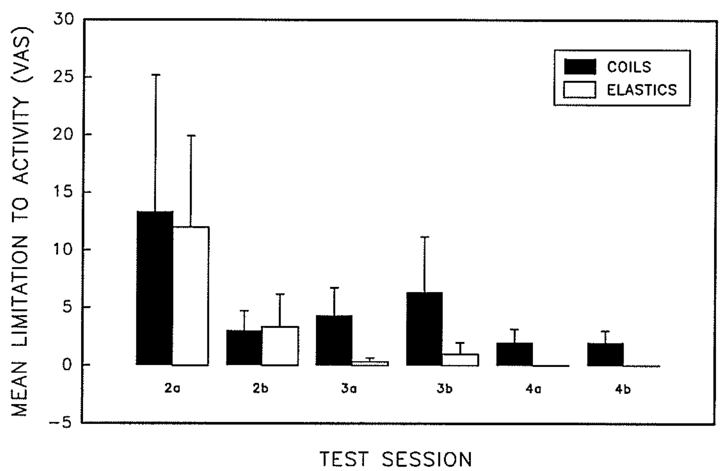


Figure 12. Mean perception regarding limitation to daily activity on the Visual Analog Scale (mm) reported by subjects in the coil group (n=3, ■) and elastic group (n=3, □) each week following treatment.

Oral Hygiene

The oral hygiene index of the maxillary and mandibular left lateral incisors were used as control sites, and compared to both the left and right mandibular second bicuspids. Scores for the maxillary lateral incisor were lower than those of the mandibular lateral incisor, and scores for treatment areas were similar to that of the mandibular lateral incisor. This trend was seen in both the coil and elastic groups. All subjects were right handed, and there appeared to be little difference in the oral hygiene scores between the left and right treatment areas (Figure 13). The mean cumulative score from all 4 sites was similar between the two groups at baseline (although the mean value in the elastic group was greater than that in the coil group) (2.3 ± 2.1 SE for coils, 3.7 ± 1.5 for elastics). With time, there was no difference between the two treatments, although results tended towards worsening of oral hygiene in the coil group, which was apparent after 1 month of treatment (4.7 ± 0.3 for coils; 3.0 ± 0.6 for elastics, Figure 14).

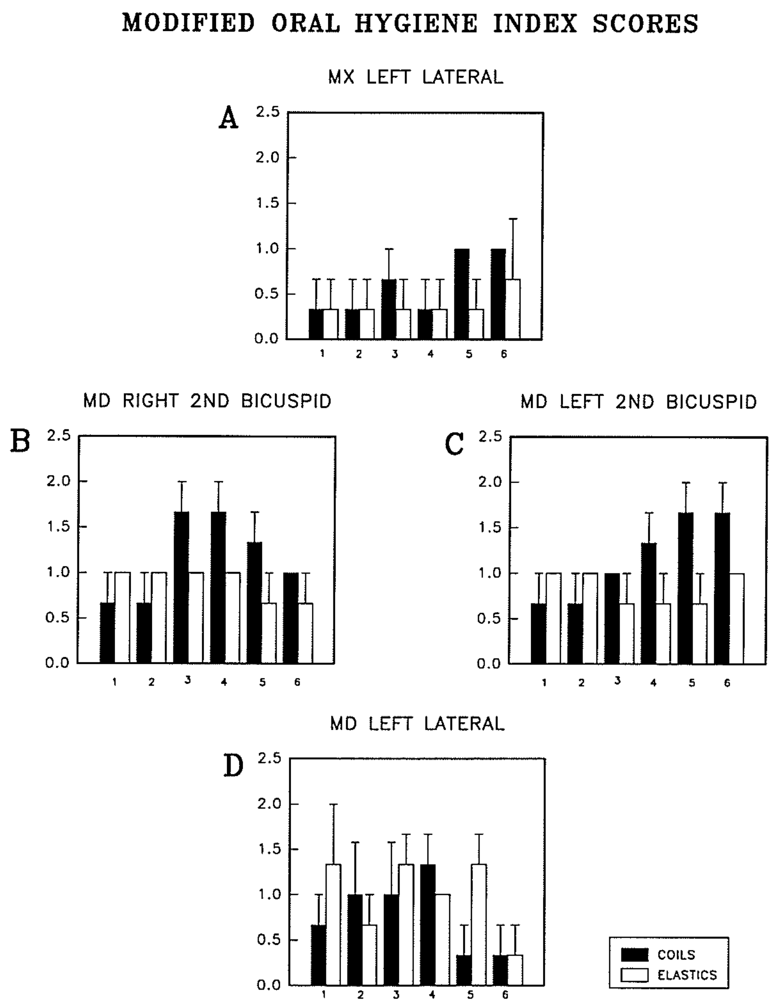


Figure 13. Mean change in the scores of the modified oral hygiene index at the maxillary left lateral incisor (A), mandibular right second bicuspid (B), mandibular left second bicuspid (C), and mandibular left lateral incisor (D), in the coil (■, n=3) and elastic (□, n=3) group at each test session throughout the study (three months).

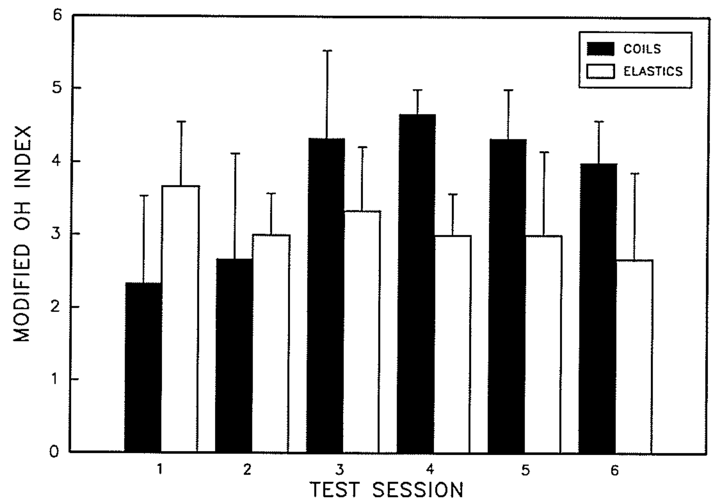


Figure 14. Mean modified oral hygiene index score, summated from 4 sites (see Figure 13), in the coil group (n=3, ■) and elastic group (n=3, □) at each test session throughout the study (three months).

Summary of Results

1. RMO Sailboat[R] elastics (150 g) were approximately twice as effective as GAC Sentalloy[R] coil springs (150 g) in reducing overjet.
2. GAC interarch Sentalloy[R] closed coil springs (23 mm) were associated with a high incidence of failure and were deemed clinically unreliable.
3. American coil springs (75 g) were capable of withstanding intraoral forces but were ineffective in maintaining overjet previously reduced by GAC coil springs.
4. High compliance with elastic wear (~89-92 %) resulted in a progressive reduction in overjet of 1.0-1.4 mm/month.
5. Both coil springs and elastics resulted in a sustained reduction in maximal jaw opening, minimal decrease in right and left lateral excursions, and an increase in anterior protrusion, consistent with the direction of force applied with interarch treatment.
6. Patient's pain intensity and pain affect with either coil springs or elastics was relatively minimal, fell after one week and was subsequently maintained at low levels throughout the rest of the study.

7. There was no significant change in cumulative oral hygiene scores with either coil springs or elastics over time, though results tended towards a worsening in oral hygiene with coil springs after a month.
8. A comparison of pre and post-treatment height measurements indicated no significant growth in any of the subjects over the study period, indicating that mandibular growth was not a likely contributor to the overjet reduction which was measured in these experiments.

CHAPTER 6

DISCUSSION

A prospective longitudinal clinical study was performed using six adult females with Class II malocclusions to compare the short term effects of removable latex elastics and fixed nickel-titanium closed coil springs on overjet correction. Use of interarch elastics over a 6 week period resulted in a positive treatment effect with clinically satisfactory changes in overjet reduction. Overjet changes with either treatment were obtained within two weeks and in each subject there was a consistent trend towards decrease in overjet throughout the study duration. Elastics were approximately twice as effective as coil springs in reducing overjet. Furthermore, placement of elastics into coil spring subjects reduced overjet to an extent greater than that previously achieved with coil springs.

Based on intraarch studies which compared elastomers and coil springs within patients for cuspid retraction and found tooth movement with coil springs to be approximately twice as efficient as elastics (Sonis, 1994) or elastomeric modules (Samuels et al, 1993), it was originally hypothesized that interarch coils springs would also be more effective than removable elastics for the correction of overjet. The findings from this thesis are therefore opposite to that found in studies comparing intraarch coil springs and elastics.

Because of the occurrence of coil failure in this study a true continuous force was not delivered. Had the coils remained intact, overjet correction might have been greater than that observed for the coils in this study.

Compliance with elastic wear was higher (approximately 90%) than the "equivalent coil compliance" (approximately 80%). Despite similar initial forces (150 g), the force profile for the two treatments was different. Periods of non-compliance with elastic wear were of short duration (approximately 6 hours), scattered throughout the study period. In comparison, periods without an applied force with coil springs was of considerably longer duration (1.8 days). Also, the occurrence of coil failure coincided with a critical time period in the sequence of cellular events involved in tooth movement. It has been shown that the time dependent sequence of events between cellular activation and tooth movement range between 7-14 days (Proffit et al, 1993). In this study, the average duration of time that coils remained intact was 9.8 days. Therefore, it can be speculated that periods of coil absence provided a window of opportunity for the "resetting" of cellular events, during which time overjet reverted towards pretreatment levels. The suggested relationship between the timing of coil spring breakage and the underlying cellular events with bone remodelling is just one plausible explanation for the relatively low values obtained with overjet change in this study.

To further determine the critical time period of the force delivery and tooth movement, a study could be designed in which subjects wore coil springs for 7 days, others for 8 days, etc. up to a period of 14 days before removing the coil. Each group would be further subdivided into subjects having the coil spring absent for varying periods of time (e.g. one, two, three,...days). Analysis of the relationship between the pattern of coil wear and degree of overjet change may elucidate information related to the presence or absence of a critical time dependency for interarch correction.

It would have been interesting to determine the amount of overjet change in an elastic group with a compliance pattern simulating that of the coil spring breakage to determine the relative effect of prolonged periods of non compliance on overall overjet reduction. The data in this study is consistent with the notion that a force profile with an intermittent regime, as provided by elastics, is superior in correcting overjet than a continuous regime interrupted by periods of no force (as a result of breakage), as delivered by coil springs.

An unexpectedly high incidence of failure was found with the use of interarch GAC Sentalloy[R] closed coil springs, which was not anticipated since there was no documentation of interarch coil spring use prior to this research project. Although the precise cause of the failures is not known, it is speculated to be related to a combination of physical characteristics of the coil, overall coil spring and eyelet design, and ligation technique. In virtually all instances, coil breakage occurred within the coil spring at the interface between the spring and metal plate, which in turn was directly fastened to either the bracket or molar hook.

Use of the manufacturers' recommended formula to determine the appropriate length of coil spring resulted in two of the three subjects having a "calculated length" (20mm, 20.5mm) below the length of coil spring used (23mm), which would suggest a margin of safety. Manufacturers' user information indicated a constant force delivery by the coil spring when activated between 1mm and 20mm. The actual difference in span between maximum intercuspation and maximum opening for the coil subjects was 28mm, 16mm and 16mm, which was close to, and in one case exceeded, the maximum value at which a constant force would be delivered by the coil springs.

Since maximum opening and "calculated length" values were greater in the elastic group than in the coil springs group, it is likely that coil spring subjects were subjected to lower intraoral forces than that present in the elastic group.

In vitro testing is often conducted under passive conditions of static loading without consideration for dynamic loading patterns. Intraorally, the coils were mounted at an angle to the occlusal plane. It is conjectured that during function, high occlusal and masticatory forces produced a combination of tensile, compressive, torsional and bending stresses, all of which contributed to a complicated and nonuniform loading pattern; and that a concentration of these stresses occurred at the interface between the coil spring and metal plate (site of failure) which caused the ultimate breakage of the device. In support of this theory, American coil springs, which were ligated at a considerable distance from the coil/plate interface, did not experience any incidents of coil failure.

Close examination of the coil spring group revealed that the subject with the longest "calculated length" was found to have the greatest number of failures, which is consistent with the above speculation that high intraoral forces played a significant role in the failure of the coil springs. Interarch biomechanics, therefore, may be governed by principles different from those found intraarch, and factors such as occlusal and masticatory forces, which are of relatively minor importance during intraarch tooth movement, may play a major role in interarch treatment modalities. This difference between intra and interarch mechanics would explain the variance in findings between intraarch and interarch studies with regard to cuspid retraction and overjet correction, respectively. *In vitro* studies and intraarch *in vivo* studies should therefore be extrapolated to interarch situations with caution.

The changes in mandibular movement observed with coil springs and elastics were consistent with the direction of force applied with treatment. Anterior protrusion progressively increased with time, and was affected to a greater extent in elastics than coil spring subjects. This change is in agreement with the documentation of Class II malocclusions having a predominantly anterior component to mandibular movement in the normal chewing cycle (because of the lack of anterior guidance), as part of the adaptive neuromuscular changes for function (Gibbs & Lundeen, 1982). It has been proposed that intermaxillary Class II elastics mediate their effect primarily through the meniscotemporocondylar frenum, the retrodiscal pad (Petrovic and Stutzmann, 1975). This structure stimulates an increase in contractile activity of the lateral pterygoid muscle, which in turn increases condylar cartilage growth. Increased contraction of the lateral pterygoid muscle could explain the changes observed in this study with reduced overjet and increased anterior protrusion. However the time period of observation was too short to have allowed for changes in condylar cartilage.

There was a sustained reduction in maximal opening with time, which was similar in elastics and coil spring subjects. Based on studies which demonstrate optimum length of masticatory muscles and maximum masticatory force to be achieved when the upper and lower anterior dentitions are vertically separated by 10 to 20 mm (MacKenna & Turker, 1978; Weijs & van der Wielen-Drent, 1983), the approximately 15% reduction in maximal opening obtained in this study would not be expected to have an appreciable limitation on patients' normal masticatory function. Both right and left lateral excursions were minimally affected by either treatment.

It was originally hypothesized that coil springs, being fixed, would impose a greater limitation on the range of mandibular movement in all directions, when compared to elastics. It is possible that during the occasions of coil absence there was an opportunity for muscles to return to their resting length, thus negating a true fixed appliance effect. It is also possible, as borne by the results, that certain mandibular movements are more sensitive to Class II forces than others; and that each excursion is affected to a similar extent by fixed and removable appliances.

Maximum pain intensity and pain affect values reported in this study were considerably lower than that experienced by chronic pain sufferers (Polatin and Mayer, 1992). The similarity between pain affect and pain intensity reportings further indicated that the pain experienced by subjects had little effect on their daily activities. The relatively high patient compliance with elastic wear during the study period, but more notably, during the pain peak, further attests to the low level of discomfort experienced with elastics. None of the patients reported a need to discontinue treatment because of discomfort, or the need to take analgesics. Therefore, the pain level and pattern associated with elastics and coil springs in this study indicate a level of discomfort that is relatively low and well tolerated by patients.

The profile for pain reporting obtained in this study was similar for removable elastics and fixed coil springs, and closely parallels that documented in the literature. Reportings peaked at one week and then fell sharply after this first week towards pretreatment levels. Ngan et al. (1989) found orthodontic pain to onset at 4 hours, to peak at 24 hours and subsequently subside within one week. It is possible that documentation of a closer time frame of the pain profile would have yielded an even earlier decline in the pain peak, similar to that of Ngan et al. The pattern of the pain profile found in this and other experiments (Ngan et al, 1989; Wilson et al, 1989) suggest a fall in pain stimulus or alteration in the periodontal ligament that enables the patient to accommodate to the level of discomfort within approximately a week. This accommodation effect is consistent with the observation that introduction of elastic wear into the coil springs group, after eight weeks of coil wear, failed to elicit a response in pain intensity or pain affect similar to the early pain response seen after one week.

It was originally hypothesized that the delivery of a continuous force (with coil springs), would be perceived as less painful than an intermittent force (with elastics). The remarkable similarity in pain profile for both treatments strongly suggests that other factors occuring during tooth movement are more discriminatory to pain than the treatment modalities employed.

A high level of compliance with elastic wear was maintained throughout this study (approximately 90%) and was greater than the average compliance associated with removable appliance wear (57%, e.g. Clemmer & Hayes, 1979; Sahm et al, 1990). A number of factors exist in this study each of which could potentially explain the high compliance. Experiments were conducted in adult females who are, in general, highly compliant patients (Starnbach & Kaplan, 1975). High compliance may also have been attributed to the self-reporting questionnaire which was administered to document daily wear. As shown by Cureton et al. (1993), calendars are a reliable measure of patient compliance and increase cooperation by serving as a visual reminder, as well as providing daily feedback. While it is possible that the self-reporting could have been overestimated, it is unlikely in view of the changes in overjet measured in the elastic wearers. It is also possible, as suggested by Cureton et al. (1993) that the reduction in overjet provided intrinsic positive reinforcement among the elastic group to further enhance elastic wear. These experiments were conducted in patients of the University of Manitoba Orthodontic Clinic who tend to be highly motivated. Additionally, the financial incentive offered, commensurate with the subjects' participation, may have been a motivating factor in obtaining good cooperation. High patient compliance could also have been attributed to the Hawthorne effect (Campbell et al, 1995), in which variables modify the effect of the putative causal factors under study (e.g. subjects of a research project complying with given instructions in a desire to please the investigator).

High compliance with elastics was highly desirable since this group was being compared to a group with fixed coil springs, in which compliance was theoretically 100%. It is also possible, once having high compliance, to interpolate results to approximate overjet correction with a lower level compliance, but difficult to extrapolate the findings with low compliance to predict overjet correction with high compliance. The maintenance of high compliance during the initial two weeks in which pain reports were the highest, confirm the relatively minimal discomfort associated with elastic wear.

Placement of intermaxillary coil springs and elastics affected oral hygiene to the same extent, and there was a tendency towards worsening of oral hygiene in the coil spring group after 1 month, suggesting difficulty with brushing in the presence of coil springs. It is possible that fear of breakage of the coil springs impacted on brushing technique to result in the altered pattern of oral hygiene observed. It is also possible, as mentioned earlier, that improvement in overjet throughout treatment positively affected oral hygiene habits in the elastic group. These changes should be evaluated in light of the fact that the coil spring subjects had superior (but not statistically significant) hygiene scores at baseline compared to the elastic subjects. It is conceivable that a longer observation period would allow for a greater difference in the two groups.

The evolution of a different coil design and/or ligation method to overcome the challenge of GAC coil failure still needs to be addressed. Use of coil springs as presently recommended are not a valid alternative to conventionally used elastics in the routine correction of interarch problems. However, they can offer limited advantages in cases of contraindicated elastic use, providing the practitioner is aware of the problems inherent in coil use. In this study, manufacturer's claims of coil spring performance were proven to be grossly incorrect. These findings highlight the need for rigorous screening processes and well controlled clinical trials of products, prior to their availability for clinical use, in the interest of treatment efficacy.

CHAPTER 7

CONCLUSION

A prospective longitudinal clinical study was done using six adult female subjects with Class II malocclusions to compare the short term effects of removable latex elastics and fixed nickel-titanium closed coil springs on overjet correction. Other pertinent parameters of clinical use, including mandibular movement, pain perception, patient compliance and oral hygiene, were objectively evaluated concurrent with overjet correction. This research constitutes the first *in vivo* comparison between interarch elastics and coil springs use.

Interarch elastics were approximately twice as effective as coil springs in reducing overjet, which is the converse of that found in the literature for intraarch tooth movement. With treatment, there was a moderate increase in anterior protrusion and reduction in jaw opening, consistent with the direction of force applied by the appliance, and little change in lateral excursions. Pain intensity and pain affect associated with elastic or coil use was relatively low, and subsided after one week towards pretreatment levels. Oral hygiene status was not affected by elastic wear, and a non-significant trend was observed with worsening of oral hygiene after one month of coil wear.

The cumulative evidence from this research study shows that with high compliance, elastics are an effective, unobtrusive, comfortable and hygienic modality of treatment for the correction of anteroposterior discrepancies. In comparison, closed coil springs were associated with a high incidence of failure and were less effective than elastics in reducing overjet. They are of limited clinical utility and offer no significant advantages over elastics with regard to restriction of mandibular movement, perception of pain or oral hygiene.

Future Recommendations

The findings from this research project highlight a number of areas which warrant further research.

In vitro Experiments: A physical model could be developed with cycling simulating the displacement of jaw movements. Motion analysis could then be performed to observe the behaviour of coil springs during function in order to elucidate the loading patterns and the mechanism of coil failure. Coils that failed could be examined by a materials specialist to determine the nature of failure.

Coil Design: In these experiments, the physical dimensions of the GAC and American coil springs were different, as were their initial forces and methods of ligation. The GAC coils were of adequate force (150g) to reduce overjet, but were relatively rigidly attached and associated with a high incidence of coil failure. In comparison, the American coils were flexible and capable of withstanding intraoral forces but generated forces too low (75g) to affect overjet. It is possible that a hybrid coil design incorporating the features of high force (as present in the GAC coils) and a flexible attachment mechanism (as present in the American coils), might overcome the problem of coil failure while providing correction of overjet. It is also possible that an unprotected coil in the dimensions used by either the GAC or American coil springs is too fragile to withstand intraoral forces, and that a design similar to the Jasper Jumper with a much larger coil spring, coated with a thick polyethylene coating, may be necessary (Weiland and Bantleon, 1995). The coil should also be mounted in a manner that allows for rotation of the spring in order to minimize bending and torsion, which could have contributed to coil spring breakage.

Electromyographic Experiments: In this study, condylar position was ascertained by clinically measuring the centric relation to centric occlusion difference using the bimanual technique, and defining centric relation as the most posterior and superior condylar position. Overjet measurements were corrected for the CR-CO differences, and deductions were made regarding the relative contribution of neuromuscular forces to overall anteroposterior change. Electromyography (EMG) could be used to directly examine the degree and pattern of muscle activity with acute elastic and coil spring wear, and muscular adaptation with chronic treatment.

Effect of Different Forces: These experiments were conducted using a relatively light force. It would be interesting to examine the effect of a higher force (e.g. Unicycle elastics) on overjet reduction.

Pain Profile: In this study, pain associated with elastic and coil spring wear was found to peak after one week and subsequently subside to pretreatment levels over the duration of the remaining 6 weeks. Pain reporting, however, was done on a weekly basis. The profile of pain observed in this study warrants a closer examination of the pain experience during the initial week, by monitoring pain in intervals of hours and then days.

Long-term Studies: These experiments were performed in patients with different initial overjet measurements over a specified period of time. Consequently, at the end of the experiment, varying amounts of overjet existed with varying amounts of remaining treatment time. It would be interesting to treat the cases to completion and observe the relapse of overjet, in the absence of elastic or coil spring wear. Minimal relapse of the overjet would suggest the initial overjet correction to have occurred predominantly through dentoalveolar change, whereas, marked relapse would suggest the correction having taken place through neuromuscular adaptation (muscle splinting, postural change) or temporary anterior positioning of the condyle within the fossa. Laminographic radiographs of the temporomandibular joint could be taken pre-treatment and post-treatment to confirm seating of the condyle within the temporal fossa.

Larger Sample Size: This study was conducted in a small sample size which precluded the analyzing of results with statistical analysis. This experiment should therefore be repeated with a larger sample size, using a hybrid coil (with an initial force similar to GAC coils and ligation method similar to American coils).

REFERENCES

Addy M, Dummer PMH, Hunter ML, Kingdon A, Shaw WC. The effect of toothbrushing frequency, toothbrushing hand, sex and social class on the incidence of plaque, gingivitis and pocketing in adolescents: A longitudinal cohort study. Community Dental Health 1990; 7: 237-247.

Allan TK, Hodgson EW. The use of personality measurements as a determinant of patient cooperation in an orthodontic practice. Am J Orthod 1968; 54: 433-439.

American Academy of Craniomandibular Disorders. Craniomandibular disorders: guidelines for evaluation, diagnosis, and management. Chicago: Quintessence 1990: 25-33.

American Dental Association. Recommendations in radiographic practices. 1984 Council on Dental Materials, Instruments and Equipment. J Am Dent Assoc 1984; 109: 764-765.

Andreasen GF. Treatment advantages using nitinol wire instead of 18-8 stainless steel wire with the edgewise bracket. Quintessence Int 1980; 4: 43-51.

Andreasen GF, Amborn RM. Aligning, levelling, and torque control: a pilot study. Angle Orthod 1989; 59: 51-60.

Andreasen GF, Bishara SE. Comparison of alastik chains and elastics involved with intraarch molar to molar forces. Angle Orthod 1970; 40: 151-158.

Andreasen GF, Hillmann TB. An evaluation of 55 cobalt substituted nitinol wire for use in orthodontics. J Am Dent Assoc 1971; 82: 1373-1375.

Andreasen GF, Wass K, Chan KC. A review of super-elastic and thermodynamic nitinol wire. Quintessence Int 1985; 9: 623-626.

Angle EH. The Angle system of regulation and retention of the teeth, and treatment of frctures of the maxillae. Philadelphia: White Dental Manufacturing, 1897.

Angolkar PV, Arnold JV, Nanda RS, Duncanson MG Jr. Force degradation of closed coil springs: An in vitro evaluation. Am J Orthod Dentofac Orthop 1992; 102: 127-133.

Ash J, Nikolai R. Relaxation of orthodontic elastic chains and modules *in vitro* and *in vivo*. J Dent Res 1978; 57: 685-690.

Baker H. Treatment of protruding and receding jaws by the use of intermaxillary elastics. Int Dent J 1904; 25: 344-356.

Bartsch A, Witt E, Sahm G, Schneider S. Correlates of objective patient compliance with removable appliance wear. Am J Orthod Dentofac Orthop 1993; 104: 378-386.

Bass NM. The esthetic analysis of the face. Eur J Orthod 1991; 13: 343-350.

Baty DL, Storie DJ, von Fraunhofer JA. Synthetic elastomeric chains: A literature review. Am J Orthod Dentofac Orthop 1994; 105: 536-542.

Beuhler WJ, Cross WB. 55-Nitinol unique wire alloy with a memory. Wire J 1969; 2: 41-49.

Beuhler WJ. Proceedings of the Seventh Navy Symposium ONR 16 Office of Technical Services, US Dept of Commerce, Volume 1, Unclassified. Washington 1963: 1-30.

Bishara SE, Andreasen GF. A comparison of time related forces between plastic alastiks and latex elastics. Angle Orthod 1970; 40: 319-328.

Bishara SE, Jorgensen GJ, Jakobsen JR. Changes in facial dimensions assessed from lateral and frontal photographs. Part II - Results and conclusions. Am J Orthod Dentofac Orthop 1995a; 108: 489-499.

Bishara SE, Winterbottom JM, Sulieman AA, Rim K, Jakobsen JR. Comparisons of the thermodynamic properties of three nickel-titanium orthodontic archwires. Angle Orthod 1995b; 65: 117-122.

Boester CH, Johnston LE. A clinical investigation of the concepts of differential and optimal force in canine retraction. Angle Orthod 1974; 44: 113-119.

Boshart BF, Currier GF, Nanda RS, Duncanson MG Jr. Load-deflection rate measurements of activated open and closed coil springs. Angle Orthod 1990; 60: 27-32.

Brattstrom V, Ingelsson M, Aberg E. Treatment cooperation in orthodontic patients. Br J Orthod 1991; 18: 37-42.

Buckley LA. The interrelationship between irregular teeth, plaque, calculus and gingival disease. Br Dent J 1980; 148: 67-69.

Burns MH. Use of a personality rating scale in identifying cooperative and non-cooperative orthodontic patients. Am J Orthod 1970; 57: 418.

Burstone CJ, Groves MH. Threshold and optimum force values for maxillary anterior tooth movment. J Dent Res 1961; 39: 695.

Burstone C. Mechanics: the biomechanics of tooth movement. In: Kraus B, Riedel R, eds. Vistas in orthodontics. Philadelphia: Lea & Febiger, 1962: 197-213.

Burstone CJ. Application of bioengineering to clinical orthodontics. In: TM Graber and RL Vanarsdall eds. Current orthodontic principles and techniques. Vol 2. Philadelphia: W.B. Saunders, 1994.

Campbell JP, Maxey VA, Watson WA. Hawthorne effect: implications for prehospital research. Ann Emerg Med 1995; 26: 590-594.

Case CS. A practical treatise on the technics and principles of dental orthopedia. Chicago: CS Case Co, 1908.

Cetlin NM, Ten Hoeve A. Nonextraction treatment. J Clin Orthod 1983; 17: 396-413.

Clemmer EJ, Hayes EW. Patient cooperation in wearing orthodontic headgear. Am J Orthod 1979; 75: 517-523.

Craig RG. Polymers and polymerization. In: RW Rienhardt, ed. Restorative dental materials 8th edition. St. Louis: C.V. Mosby Company, 1989: 139-148.

Cureton SL, Regennitter FJ, Yancey JM. The role of the headgear calendar in headgear compliance. Am J Orthod Dentofac Orthop 1993; 104: 387-394.

Davidovitch Z. Tooth movement. Crit Rev Oral Biol Med 1991; 2: 411-450.

DeGenova DC, McInnes-Ledoux P, Weinberg R, Shaye R. Force degredation of orthodontic elastomeric chains - a product comparison study. Am J Orthod 1985; 87: 377-384.

Downie WW, Leatham PA, Rhind VM, Wright V, Branco JA, Anderson JA. Studies with pain rating scales. Ann Rheum Dis 1978; 37: 378-381.

Edie JW, Andreasen GF, Zaytoun MP. Surface corrosion of nitinol and stainless steel under clinical conditions. Angle Orthod 1981; 51: 319-324.

Egolf RJ, BeGole EA, Upshaw HS. Factors associated with orthodontic patient compliance with intraoral elastic and headgear wear. Am J Orthod Dentofac Orthop 1990; 97: 336-348.

Enlow DH, Moyers RE, Hunter WS, McNamara JA Jr. A procedure for the analysis of intrinsic facial form and growth. Am J Orthod 1969; 56: 6-23.

Epker BN, Wolford LM, Fish LC. Mandibular deficiency syndrome: Surgical considerations for mandibular advancement. Oral Surg 1978; 45: 349-363.

Ferreira SH, Nakamura M, Castro M. The hyperalgesic effects of prostacyclin and prostaglandin E2. Prostaglandins 1978; 16: 31-37.

Fischman SL. Current staus of indices of plaque. J Clin Periodontol 1986; 13: 371-374, 379-380.

Fisk RO. When malocclusion concern the public. J Can Dent Assoc 1960; 26: 397-412.

Freeman DC. Root surface area related to anchorage in the Begg technique. Master's thesis, University of Tennessee, 1965.

Furstman L, Bernik S. Clinical consideration of the periodontium. Am J Orthod 1972; 61: 138-155.

Gianelly AA, Goldman HM. Biologic basis of orthodontics. Chapter 4. pp 159-177. Philadelphia: Lea and Febiger.

Gibbs CH, Lundeen HC. Jaw movements and forces during chewing and swallowing and their clinical significance. In: Lundeen HC, Gibbs CH, eds. Advances in occlusion. Boston: John Wright Inc, 1982.

Gibbs CH, Mahan PE, Lundeen HC. Measuring masticatory force by sound transmission. J Dent Res 1977; 56: 165.

Gilboe DB. Centric relation as the treatment position. J Prosthet Dent 1983; 50: 685-689.

Goldstein A, Myer E. Cephalometric appraisal of orthodontic management of Class II malocclusion. Angle Orthod 1938; 8: 290-329.

Graber TM. Patient motivation. J Clin Orthod 1971; 5:674-688.

Graber TM, Rakosi T, Petrovic AG. Dentofacial orthopedics with functional appliances. St. Louis: C.V. Mosby Company, 1985.

Greene JC, Vermillion JR. The oral hygiene index: A method for classifying oral hygiene status. J Am Dent Assoc 1960; 61: 172-179.

Gross AM, Samson G, Dierkes M. Patient cooperation in treatment with removable appliances: A model of patient noncompliance with treatment implications. Am J Orthod 1985; 87: 392-397.

Hackett PMW. Orthodontic treatment: a facet theory approach to the study of personal reasons for the uptake of treatment for malocclusion. Soc Sci Med 1993; 21: 55-62.

Han S, Quick DC. Nickel-titanium spring properties in a simulated oral environment. Angle Orthod 1993; 63: 67-71.

Harris EF, Behrents RG. The intrinsic stability of Class I molar relationship: a longitudinal study of untreated cases. Am J Orthod 1988; 94: 63-67.

Hatcher DC, Blom RJ, Baker CG. Temporomandibular joint spatial relationships:osseous and soft tissues. J Prosthet Dent 1986; 56: 344-353.

Hays RD, Di Matteo MR. Key issues and suggestions for patient compliance assessment: Sources of information, focus of measures, and nature of response options. J Compliance Health Care 1987; 2: 37-53.

Hershey HG, Reynolds WG. The plastic module as an orthodontic tooth-moving mechanism. Am J Orthod 1975; 67: 554-562.

Higgs GA, Moncada S. Interactions of arachidonate products with other pain mediators. In: Bonica JJ, Lindbolm U, Iggo A, eds. Advances in pain research and therapy. New York: Raven Press, 1983: 617-626.

Hixon EH, Aasen TO, Arango J, Clark RA, Klosterman R, Miller SS, Odom WM. On force and tooth movement. Am J Orthod 1970; 57: 476-489.

Hoffman PJ, Silverman SI, Garfinkel L. Comparison of condylar position in centric relation and in centric occlusion in dentulous subjects. J Prosthet Dent 1973; 30: 582-588.

Honkala E, Nyssönen V, Knuuttila M, Markkanen H. Effectiveness of children's habitual toothbrushing. J Clin Periodontol 1986; 13: 81-85.

Honkala E. Frequency, pattern and duration of habitual toothbrushing in children. J Pedodont 1984; 8: 367-376.

Huget EF, Patrick KS, Nunez LJ. Observations on the elastic behaviour of a synthetic orthodontic elastomer. J Dent Res 1990; 69: 496-501.

Hurst CL, Duncanson MG Jr, Nanda RS, Angolkar PV. An evaluation of the shape-memory phenomenon of nickel-titanium orthodontic wires. Am J Orthod Dentofac Orthop 1990; 98: 72-76.

Huskisson EC. Measurement of pain. Lancet 1974; 2: 127-131.

Järvinen S. Incisal overjet and traumatic injuries to upper permanent incisors. Acta Odont Scand 1978; 36: 359-362.

Jenny J. A social perspective on need and demand for orthodontic treatment. Int Dent J 1975; 25: 248-256.

Jensen MP, Karoly P, O'Riordan EF, Bland F Jr, Burns RS.et al. The subjective experience of acute pain: An assessment of the utility of 10 indices. Clin J Pain 1989; 5: 153-159.

Jensen WO. Occlusion for the Class II jaw relations patient. J Prosthet Dent 1990; 64: 432-434.

Jones ML, Richmond S. Initial tooth movement: Force application and pain - a relationship? Am J Orthod 1985; 88: 111-116.

Kamogashira K, Yanabu M, Ichikawa K Itah T, Matsumoto M, Ishibashi K, Abe K. The effects of upper incisor separation on the submandibular and sublingual glands of rats. J Dent Res 1988; 67: 602-610.

Kelly J, Harvey C. An assessment of the teeth of youths 12-17 years. Washington, D.C., National Center for Health Statistics, U.S. Public Health Service, DHEW Publication No (HRA) 77-1644, 1977.

Kelly JE, Sanchez M, Van Kirk, LE. An assessment of the occlusion of teeth of children. Washington, D.C., 1973, National Center for Health Statistics, U.S. Public Health Service, DHEW Publication No (HRA) 74-1612, 1973.

Kess B, Zwilling B Lanese R, Shanefeld J, Davidovitch Z. The effect of indomethacin on periodontal PGE content during orthodontic treatment. J Dent Res 1987; 66: 332.

Koltun A, Stone GC. Past and current trends in patient noncompliance research: Focus on diseases, regimes-programs, and provider-disciplines. J Compliance Health Care 1986; 1: 21-32.

Kousbroek R. Shape memory alloys in metal and ceramic biomaterials. Volume 2. Ducheyne P, Hastings GW, eds. Boca Raton, Florida: CRC Press Inc, 1984: chapter 3.

Kovatch JS, Lautenschlager EP, Keller J. Load-extension-time behaviour of orthodontic Alastiks. J Dent Res 1976; 55: 783-786.

Kremer E, Atkinson JH, Ignelzi RJ. Measurement of pain: Patient preference does not confound pain measurement. Pain 1981; 10: 241-248.

Kusy RP, Greenberg AR. Comparison of elastic properties of nickel-titanium and beta titanium arch wires. Am J Orthod 1982; 82: 199-205.

Lake SL, McNeill RW, Little RM, West RA. Surgical mandibular advancement: a cephalometric analysis of treatment response. Am J Orthod 1981; 80: 376-394.

Littman GS, Walker BR, Schneider BE. Reassessment of verbal and visual analog ratings in analgesic studies. Clin Pharmacol Ther 1985; 38: 16-23.

Livieratos FA, Johnston LE Jr. A comparison of one-stage and two-stage nonextraction alternatives in matched Class II samples. Am J Orthod Dentofac Orthop 1995; 108: 118-131.

Long JH. Locating centric relation with a leaf gauge. J Prosthet Dent 1973; 29: 608-610.

Lopez I, Goldberg J, Burstone CJ. Bending characteristics of nitinol wire. Am J Orthod 1979; 75: 569-575.

Lucia VO. A technique for recording centric relation. J Prosthet Dent 1964; 14: 492-505.

Lundeen HC, Shryock EF, Gibbs CH. An evaluation of mandibular border movements: Their character and significance. J Prosthet Dent 1978; 40: 442-451.

Lundstom F, Hamp SE, Nyman S. Systematic plaque control in children undergoing long-term orthodontic treatment. Eur J Orthod 1980; 2: 27-39.

MacGregor IDM, Balding JW. Toothbrushing frequency in relation to family size and bedtimes in English schoolchildren. Community Dent Oral Epidemiol 1987; 15: 181-183.

MacGregor IDM, Rugg-Gunn AJ. A survey of toothbrushing sequence in children and young adults. J Periodontal Res 1979; 14: 225-230.

MacKenna BR, Turker KS. Twitch tension in the jaw muscles of the cat at various degrees of mouth opening. Arch Oral Biol 1978; 23: 917-920.

Manhartsberger C, Seidenbusch W. Force delivery of NiTi coil springs. Am J Orthod Dentofac Orthop 1996; 109: 8-21.

McCabe JF. Synthetic polymers. In: Anderson's applied dental materials, 6th ed. Oxford: Blackwell Scientific Publications 1985: 79-81.

McDonald FT. The influence of age on orthodontic patient cooperation. Dent Abstr 1973; 18: 52.

McDonald F. Electrical effects at the bone surface. Eur J Orthod 1993; 15: 175-183.

McEwen JD, McHugh WD, Hitchin AD. Fractured maxillary central incisors and incisal relationships. J Dent Res 1967; 46: 1290.

McNamara JA. Components of Class II malocclusion in children 8-10 years of age. Angle Orthod 1981; 51: 177-202.

Melsen B, Topp LF, Melsen HM, Terp S. Force system developed from closed coil springs. Eur J Orthod 1994; 16: 531-539.

Mitchell DL, Boone RM, Ferguson JH. Correlation of tooth movement with variable forces in the cat. Angle Orthod 1973; 43: 154-161.

Miura F, Mogi M, Ohura Y, Hamanaka H. The super-elastic property of the Japanese NiTi alloy wire for use in orthodontics. Am J Orthod Dentofac Orthop 1986; 90: 1-10.

Miura F, Mogi M, Ohura Y, Karibe M. The super-elastic Japanese NiTi alloy wire for use in orthodontics. Am J Orthod Dentofac Orthop 1988; 94: 89-96.

Miura F, Mogi M, Okamoto Y. New application of superelastic NiTi rectangular wire. J Clin Orthod 1990; 24: 544-548.

Mongini F. The importance of radiography in the diagnosis of TMJ dysfunctions. A comparative evaluation of transcranial radiographs and serial tomography. J Prosthet Dent 1981; 45: 186-198.

Morris AL. Seriously handicapping orthodontic conditions. Washington, D.C., 1977, National Academy of Sciences.

Ngan P, Kess B, Wilson S. Perception of discomfort by patients undergoing orthodontic treatment. Am J Orthod Dentofac Orthop 1989; 96: 47-53.

Nikolai RJ. Material behaviour of orthodontic appliances. In: Bioengineering analysis of orthodontic mechanics. 1st edition, Philadelphia: W.B. Saunders Co, 1985: 78-90.

Paquette DE, Beattie JR, Johnston LE Jr. A long term comparison of nonextraction and premolar-extraction edgewise therapy in "borderline" Class II patients. Am J Orthod Dentofac Orthop 1992; 102: 1-14.

Pender N. Aspects of oral health in orthodontic patients. Br J Orthod 1986; 13: 95-103.

Petrovic A, Stutzmann J, Oudet C. Control process in the postnatal growth of the mandibular condylar cartilage. In: McNamara JA Jr, ed. Determinants of mandibular form and growth. Ann Arbor. Center for Human Growth and Development, University of Michigan, 1975.

Phillips RW. Report of Commitee on Scientific Investigation of the American Academy of Restorative Dentistry. J Prosthet Dent 1986; 55:736-772.

Polatin PB, Mayer TG. Quantification of function in chronic low back pain. In: Turk DC and Melzack R, eds. Handbook of pain assessment. New York: The Guilford Press, 1992.

Proffit WR, Fields HW, Nixon WL. Occlusal forces in normal and long-faced adults. J Dent Res 1983; 62: 566-571.

Proffit WR, Fields HW, Ackerman JL, Sinclair PM, Thomas PM, Tulloch JFC. Contemporary orthodontics 2nd ed. St. Louis: C.V. Mosby Co., 1993.

Quigley G, Hein J. Comparative cleansing efficiency of manual and power brushing. J Am Dent Assoc 1962; 65: 26-29.

Quinn RS, Yoshikawa DK. A reassessment of force magnitude in orthodontics. Am J Orthod 1985; 88: 252-260.

Ramfjord SP. Indices for prevalence and incidence of periodontal disease. J Periodont 1959; 30:51-59.

Reitan K. Biomechanical principles and reactions. In Graber TM and Swain BF, eds. Current orthodontic concepts and techniques. 2nd edition. Philadelphia: WB Saunders Co., 1975.

Rosner D, Goldberg GF. Condylar retruded contact position and intercuspal position correlation in dentulous patients. Part 1: Three-dimensional analysis of condylar registrations. J Prosthet Dent 1986; 56:230-237.

Roth RH. Diagnosis and treatment planning. J Clin Orthod 1992; 26: 585-606.

Russell AL. A system of classification and scoring for prevalence surveys of periodontal disease. J Dent Res 1956; 35: 350-359.

Safadi GS, Safadi TJ, Terezhalmy GT, Taylor JS, Battisto JR, Melton AL. Latex hypersensitivity: its prevalence among dental professionals. J Am Dent Assoc 1996; 127: 83-88.

Sahm G, Bartsch A, Witt E. Microelectronic monitoring of functional appliance wear. Eur J Orthod 1990; 12: 297-301.

Samuels RHA, Rudge SJ, Mair LH. A comparison of the rate of space closure using a nickel-titanium spring and an elastic module: A clinical study. Am J Orthod Dentofac Orthop 1993; 103: 464-467.

Sandy JR, Farndale RW, Meikle MC. Recent advances in understanding mechanically induced bone remodeling and their relevance to orthodontic theory and practice. Am J Orthod Dentofac Orthop 1993; 103: 212-222.

Schwartz AM. Tissue changes incidental to orthodontic tooth movment. Internat J Orthod 1932; 18: 331-352.

Scott J, Ansell BM, Huskisson EC. The measurement of pain in juvenile chronic polyarthritis. Ann Rheum Dis 1977; 36: 186-187.

Seymour RA, Simpson JM, Charlton JE, Phillips ME. An evaluation of length and end-phrases of visual analogue scales in dental pain. Pain 1985; 21: 177-185.

Shafagh I, Amirloo R. Replicability of chinpoint guidance and anterior programmer for recording centric relation. J Prosthet Dent 1979; 42: 402-404.

Sindledecker L. Effect of different centric relation registrations on the pantographic representation of centric relation. J Prosthet Dent 1981; 46: 271-279.

Soltis E, Nakfoor P, Bowman D. Changes in ability of patients to differentiate intensity of forces applied to maxillary central incisors during orthodontic treatment. J Dent Res 1971; 50: 590-596.

Sonis AL. Comparison of NiTi coil springs vs elastics in canine retraction. J Clin Orthod 1994; 28: 293-294.

Starnbach HK, Kaplan A. Profile of an excellent orthodontic patient. Angle Orthod 1975; 45: 141-145.

Storey E. The nature of tooth movement. Am J Orthod 1973; 63: 292-314.

Storey E, Smith R. Force in orthodontics and its relation to tooth movement. Austr Dent J 1952; 56: 11-18.

Suit SR, Gibbs CH, Benz ST. Study of gliding tooth contacts during mastication. J Periodontol 1975; 47:331-334.

Swetlik WP. A behavioral evaluation of patient cooperation in the use of extraoral elastic and coil spring traction devices. Am J Orthod 1978; 74: 687.

Turesky S, Gilmore ND, Glickman I. Reduced plaque formation by the chloromethyl analogue of victamine C. J Periodontol 1970; 41: 41-43.

Utt TW, Meyers CE Jr, Wierzba TF, Hondrum SO. A three-dimensional comparison of condylar position changes between centric relation and centric occlusion using the mandibular position indicator. Am J Orthod Dentofac Orthop 1995; 107: 298-308.

Vandevska-Radunovic V, Kristiansen AB, Heyeraas KJ, Kvinnsland S. Changes in blood circulation in teeth and supporting tissues incident to experimental tooth movement. Eur J Orthod 1994; 16: 361-369.

Webb RI, Caputo AA, Chaconas SJ. Orthodontic force production by closed coil springs. Am J Orthod 1978; 74: 405-409.

Weijs WA, van der Wielen-Drent TK. Sarcomere length and EMG activity in some jaw muscles of the rabbit. Acta Anat 1983; 113: 178-188.

Weiland FJ, Bantleon HP. Treatment of Class II malocclusions with the Jasper Jumper appliance - a preliminary report. Am J Orthod Dentofac Orthop 1995; 108: 341-350.

Weinstein S, Haack DC, Lightle MY, Snyder BB, Attaway HE. On equilibrium theory of tooth position. Angle Orthod 1963; 33: 1-26.

Williams BH. Oriented lateral temporomandibular joint laminographs. Angle Orthod 1983; 53: 228-233.

Williamson EH, Caves SA, Edenfield RJ. Morse PK. Cephalometric analysis: comparisons between maximum intercuspation and centric relation. Am J Orthod 1978; 74: 672-677.

Wilson S, Ngan P, Kess B. Time course of the discomfort in young patients undergoing orthodontic treatment. Pediatr Dent 1989; 11: 107-110.

Wolford LM, Walker G, Schendel S, Fish LC, Epker BN. Mandibular deficiency syndrome: Clinical delineation and therapeutic significance. Oral Surg 1978; 45: 329-347.

Wong AK. Orthodontic elastic materials. Angle Orthod 1976; 46: 196-205.

Wood GN. Centric relation and the treatment position in rehabilitating occlusions: A physiologic approach. Part 1: Developing an optimum mandibular posture. J Prosthet Dent 1988; 59: 647-651.

Woolass KF, Shaw WC, Viader PH, Lewis AS. The prediction of patient cooperation in orthodontic treatment. Eur J Orthod 1988; 10: 235-243.

Wright GZ, Banting DW, Feasby WH. Effect of interproximal flossing in the incidence of proximal caries in children. J Dent Res 1977; 56: 574-578.

Yagasawa F, Nishimaki H, Ono E. Degradation of orthodontic elastics: Part 1. J Jap Orthodont Soc 1967; 26: 49-55.

Yamaguchi K, Nanda RS. Blood flow changes in gingival tissues due to the displacement of teeth. Angle Orthod 1992; 62: 257-264.

Yamasaki K, Miura F, Suda T. Prostaglandin as a mediator of bone resorption induced by experimental tooth movement in rats. J Dent Res 1980; 59: 1635-1642.

Yamasaki K, Shibata Y, Fukuhara T. The effect of prostaglandins on experimental tooth movement in monkeys (*Macaca fuscata*). J Dent Res 1982; 61: 1444-1446.

Yoshida N, Jost-Brinkmann PG, Yamada Y. Initial tooth movement under extraoral force and considerations for controlled molar movement. Angle Orthod 1995; 65: 199-208.

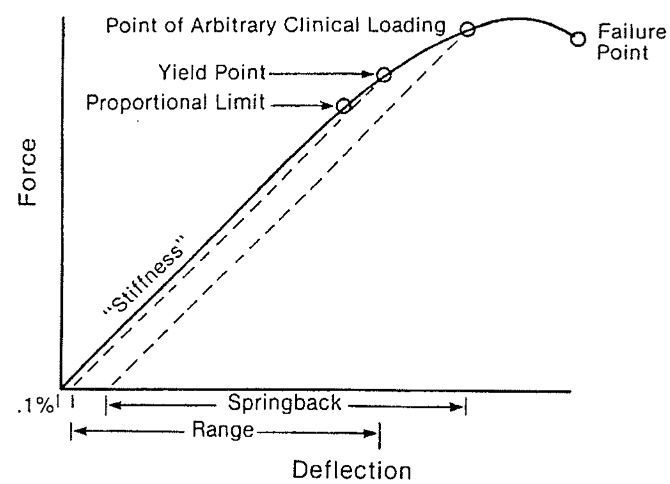
Zachrisson BU, Zachrisson S. Caries incidence and orthodontic treatment with fixed appliances. Scand J Dent Res 1971; 79: 183-192.

Zachrisson BU. Oral hygiene for orthodontic patients: Current concepts and practical advice. Am J Orthod 1974; 66: 487-497.

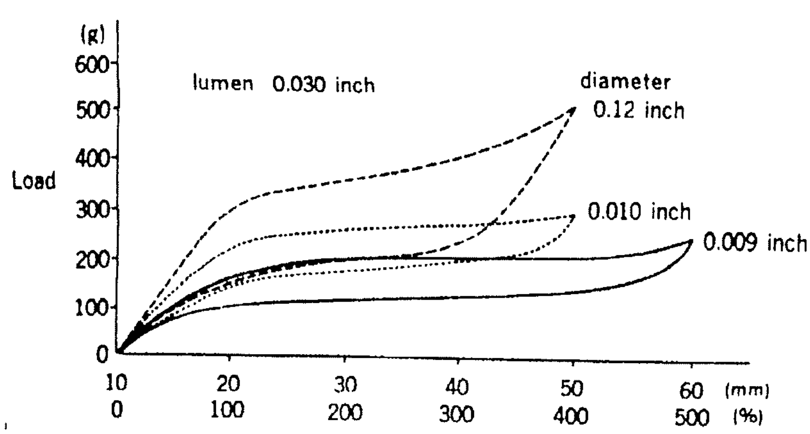
APPENDICES

Appendix A

Force-deflection Curve for Metal Alloys (Proffit 1993)



Force-deflection Curve for Closed Coil Springs (Miura et al, 1988)



Appendix B

Human Ethics Committee Approval Letter, Faculty of Dentistry

Date: February 3, 1995

Committee Reference EC26/94P

Names of investigators: Drs. Michelle Wang and Dean Kriellaars

Your project entitled:

Comparison between orthodontic elastics and nickel-titanium (NiTi) coil springs for correction of overjet in Class II malocclusions,

revised on January 17, 1995, has been approved by the Committee.

PLEASE NOTE

Any significant changes in the approved protocol must be reported to the Chair of the committee for the Committee's consideration and decision, prior to the implementation of the changes in the protocol.

Yours sincerely,

C. Dawes B.Sc., B.D.S., Ph.D.
Chair
Committee on Research
Involving Human Subjects

Appendix C

Information for Participants in Elastic & Coil Spring Study

The purpose of this study is to compare the effectiveness of orthodontic elastics and metal coil springs in the correction of the protrusion of upper teeth. Correction of this protrusion is often done towards the end of treatment and is usually accomplished with elastics which are worn full-time and removed only while eating and brushing. The correction can also be done using small coil springs which are attached to the same areas as the elastics but do not have to be changed.

To be accepted for this project, you must have some protrusion of your upper front teeth and not have worn elastics or metal coil springs prior to participating in this study. You must have braces on all the upper and lower teeth from at least the first molar of one side to the first molar of the other side. You must have healthy gums and your orthodontic treatment plan should not include surgery.

You will be evaluated and if selected for the study, will have up to one week to decide if you would like to participate. If participating, you will receive either the elastics or coil springs to correct the protrusion of your teeth. The elastics and coil springs used in this study are identical to those used in routine orthodontic treatment and will be used in an identical manner. The risks associated with these are identical to those in clinical practice and include: slight discomfort, possible irritation to the inside of the cheek, possible swallowing or aspiration of the appliances, minimal lengthening of the height of the teeth, tipping of the teeth, and the possibility of retrusion of the top teeth. The benefits associated with participation include: a financial renumeration, the possibility of a shortened treatment time, and the contribution to knowledge in this area of orthodontics. In the event of marked discomfort, participants are asked to stop wearing elastics or to return to the clinic to have the coil springs removed.

In one session at the very beginning and at the very end you will have your height measured at the Health Sciences Center. Every two weeks for three months, there will be a testing session lasting approximately an hour. At these sessions, measurements of the teeth will be taken while you perform jaw exercises; measurements of the elastics or coil springs will be done; and a small plastic mold will be made of the front teeth. Photographs may also be taken of your teeth. A chart will also be given to you to fill out at home assessing your perception of any discomfort and the amount of elastic wear (if in the elastic group). The information gathered from this study will be used solely for the research project by the researchers involved, and will not reveal the identity of any participants.

Each subject will be compensated $100 ($11.11 per session) for participation in the study (as remuneration for time, transportation, parking, etc.). There is no obligation to participate, and you may refuse participation, or participate and then withdraw from the study at any time, not only without penalty, but also without compromising ongoing orthodontic treatment at the Orthodontic Graduate or Undergraduate Clinic.

If you wish to participate, or have any further questions regarding this study, please contact Dr. Michele Wang, at the Orthodontic Graduate Clinic (789-3545).

Appendix D

Informed Consent for Elastic & Coil Spring Study

The aim of this study is to determine whether better results for certain orthodontic problems can be obtained with orthodontic elastics or with coil springs.

I have read and understand the information sheet given to me, and all questions have been answered to my satisfaction regarding the orthodontic elastic and coil spring study.

I understand that the study requires 9 sessions: 7 testing sessions two weeks apart over 3 months which will last approximately an hour, and another 2 sessions - one at the beginning and one at the end - which will last approximately 15 minutes. The testing sessions will involve taking measurements on the elastic/coil spring, and on the teeth, as well as jaw exercises. A small plastic mold will be made of my front teeth and photographs may be taken. I will also be given a chart to take home and fill out relating any discomfort associated with treatment, and the length of time I wear the elastics (if I am in the elastic group). I may be excluded from the study at any time should my compliance be poor or marked discomfort develops due to the wearing of elastics or coil springs.

I understand that, to eliminate bias, I will be assigned one or the other treatment by the flip of a coin. The elastics and coil springs used in this study are identical to those used in clinical orthodontic treatment, and I understand the risks and benefits associated with their use. The information from this study may appear in scientific publications, but the identity of participants will be protected and will remain anonymous.

I understand that I am under no obligation to participate, and can refuse treatment without compromising ongoing orthodontic treatment at the Graduate Orthodontic Clinic.

I will be compensated $100 for any inconvenience resulting from my participation in this study ($11.11 each session). I have volunteered to participate in this study on my own, and I realize that I am able to withdraw from the study at any time, without any penalty or compromise to my orthodontic treatment.

Signature of Participant: ____________________________
Signature of Parent/Guardian: ________________________

Date: _______________

Signature of Witness: ____________________________

Appendix E

Patient Instructions for Testing Sessions

1. OVERJET
A ruler will be used to measure the relationship between your top and bottom front teeth.

2. FORCE
A special ruler will be used to measure the force of the elastic or coil spring. When this is done, bite as you normally do so that your back teeth are touching.

3. JAW MOVEMENTS
A special ruler will be used to measure the movement of your jaw. Starting from a normal biting position, you will be asked to: open as wide as you can, move your jaw to the left as far as possible, move your jaw to the right as far as possible, and move your jaw forward as far as possible

4. DISCOMFORT
You will be given some forms to take home and asked to rate the discomfort associated with the wearing of either the elastics or coil springs. Check to make sure that the day on the form coincides with the day of the week (if you forgot to fill out a form then try to recall the rating for the missed day or leave that day blank). You should fill out the forms at the same time each day, then fold the form into three parts, tape it shut, and place it in the big brown envelope provided. You should not retrieve the form once it is placed in the envelope, and should bring the envelope with you to each testing session. At each session you will be given a new set of forms.

5. WEARING OF ELASTICS
If you are in the elastic group, you should wear your elastics 24 hours per day. You should remove them only while eating or brushing the teeth, and should change them three times per day (after meals). You will be given a chart to fill out indicating when you wear your elastics. You should fill out the chart at the end of each day and bring the chart with you to each testing session, at which time a new chart will be given to you.

6. WEARING OF COIL SPRINGS
If you are in the coil spring group, you should report any problems with discomfort or breakge as soon as possible, by calling the emergency phone number given to you in your envelope. Whenever yawning, you should support the bottom of your chin, to assist in preventing breakage of the coil.

7. HEADGEAR
If you usually wear a headgear, please stop wearing it during both the day and night for the duration of this study.

Appendix F

Elastic Wear Questionnaire

Please indicate with an "X" each time you change your elastics every day

Example:

	Day 1	Day 2	Day 3	Day 4	Day 5	Day 6	Day 7
Week 1	x	x	x	x		x	x
	x	x		x	x	x	x
	x	x	x	x	x	x	

PATIENT NAME:________________________ MONTH:____________________

	Day 1	Day 2	Day 3	Day 4	Day 5	Day 6	Day 7
Week 1							
Week 2							
Week 3							
Week 4							

Appendix G

Visual Analog Scale

What is the level or intensity of pain you are currently experiencing?

No Pain | Worst Imaginable Pain

____

To what extent does pain limit your daily activity?

No Effect | Incapable of Activity

____

Appendix H

Turesky-Gilmore-Glickman Modification of the Quinley-Hein Plaque Index

SCORE	DESCRIPTION
0	No plaque
1	Separate flecks of plaque at the cervical margin of the tooth
2	A thin, continuous band of plaque (up to 1mm) at the cervical margin
3	A band of plaque >1mm but covering less than one-third of the crown
4	Plaque covering at least one-third but less than two-thirds of the crown
5	Plaque covering two-thirds or more of the crown

Appendix I

Tensile Testing for RMO Sailboat^{R} Elastics and GAC Sentalloy^{R} Coil Springs

FORCE (g)	DEFLECTION (mm)				
	RMO ELASTICS		GAC COIL SPRINGS		
	unicycle (n=3)	sailboat (n=3)	18mm (n=3)	23mm (n=3)	28mm (n=3)
0	0	0	0	0	0
40	2.9 ± 0.3	3.1± 0.2	0.8 ± 0.1	0.5 ± 0.1	0.2 ± 0.1
80	5.3 ± 0.3	7.0 ± 0.2	1.0 ± 0.2	1.4 ± 0.2	0.3 ± 0.2
120	7.6 ± 0.4	13.4 ± 0.3	2.2 ± 1.3	2.5 ± 0.7	3.5 ± 0.7
160	10.6 ± 0.6	21.2 ± 0.8	10.5 ± 1.6	19.0 ± 5.1	20.8 ± 6.4
200	14.9 ± 1.1	29.5 ± 1.6	30.4 ± 4.5	45.1 ± 8.9	60.3 ± 15.8

Deflection values indicate: mean ± SD

Appendix J

User Information for GAC Interarch Sentalloy^{R} Coil Springs

Interarch Coil Spring
User Information

Background

Sentalloy Interarch Coil Springs provide unprecedented tooth movement without trauma and without patient cooperation. At body temperature the springs exert a *constant* force of 150 grams, and they are available in three lengths - 18mm, 23mm, and 28mm. The appropriate length is determined by measuring with the patient's mouth at full opening the distance from the midpoint of the cuspid to the molar hook.
Regardless of the length of the coil or whether it is activated 1mm or 20mm, the force remains constant at 150 grams. Since this force is activated at body temperature, it cannot be bench tested. *The key to success is strict adherence to the following directions:*

Measurement

With the patient's mouth fully wide open, measure in millimeters from the cuspid to the molar hook. Subtract five from this measurement and divide the remainder by two. Then choose the Interarch Coil Spring size that is nearest to this result. For example, if the distance from the cuspid to the molar hook measures 50mm, the correct size coil spring would be determined by subtracting five from 50, then dividing the 45 remainder by two to get 22.5. The correct size coil spring is 23mm.

Placement

Maxillary Arch

1. Ligate the arch wire to the maxillary centrals and laterals.
2. Feed one eyelet of the coil spring onto the arch wire.
3. Insert the arch wire into the buccal tubes and ligate the balance of the maxillary arch, keeping the eyelet between the cuspid and lateral brackets.
4. For best results, crimp a stop 2mm mesial to the cuspid bracket to control coil sliding (see diagram on reverse side).

Mandibular Arch

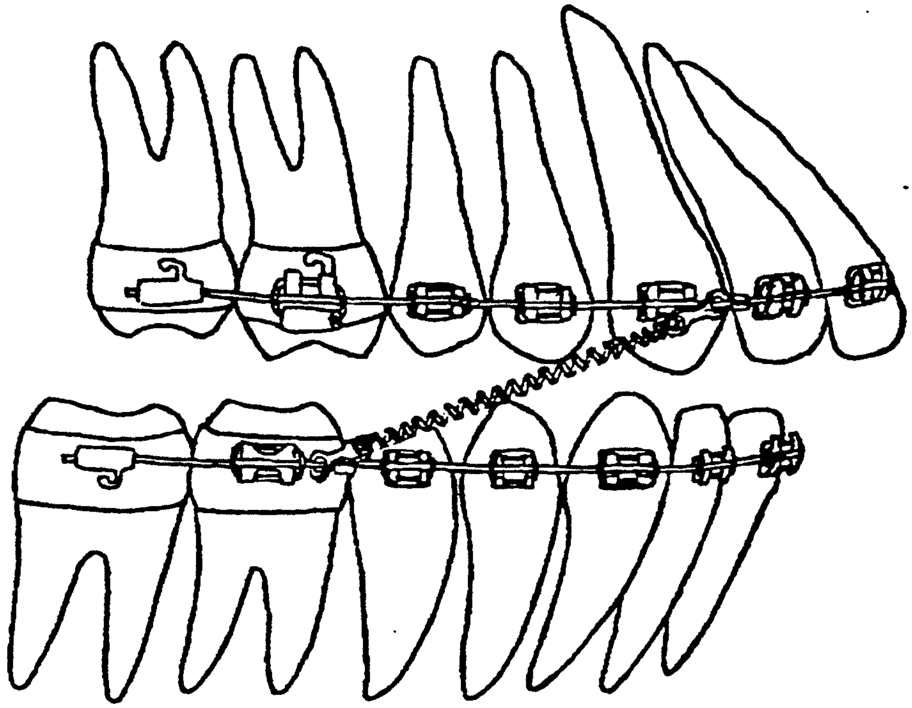
1. Place the other eyelet over the molar hook and bend the hook closed.
2. If there is no molar hook, place the eyelet on the arch wire between the second bicuspid and the molar. Then crimp a stop onto the wire, leaving 1mm clearance on both sides of the eyelet (see diagram on reverse side).

The Sleeve

The latex sleeve is used solely to assist initial acceptance of the coil spring by the patient. The sleeve may be removed prior to placement, or if it tears, with no contraindications. Replacement sleeves may be ordered, if desired. To replace the sleeve:

1. Feed a ligature wire through the eyelet.
2. Slide a sleeve over the ligature wire.
3. Slide the sleeve off the wire onto the coil.
4. Remove the ligature wire and reattach the eyelet.

(revised 12/1/94)



Sentalloy Interarch Coil Spring
With Crimpable Stops on
Maxillary and Mandibular Arches

Reorder Information:

Description	Reorder Number
Interarch Coil Springs 18mm (pkg of 10)	10-005-00
Interarch Coil Springs 23mm (pkg of 10)	10-005-01
Interarch Coil Springs 28mm (pkg of 10)	10-005-02
Interarch Coil Spring Sleeves 40mm (pkg of 10)	10-005-88
Interarch Coil Spring Sleeves 50mm (pkg of 10)	10-005-99

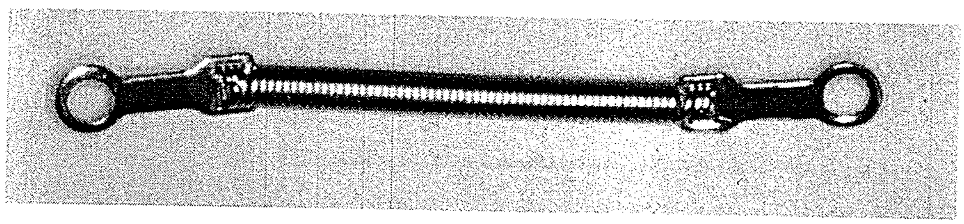
GAC
International, Inc
(800) 645-5530

Appendix K

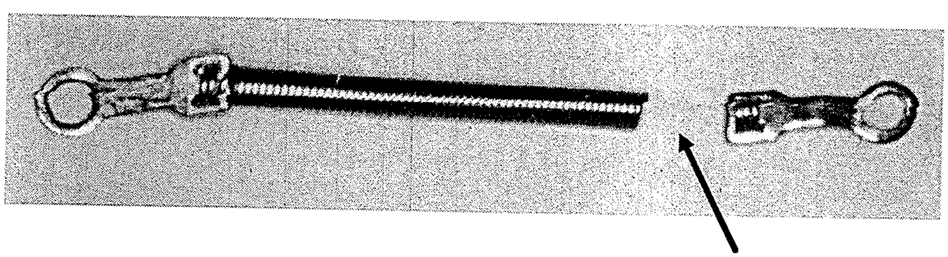
GAC Sentalloy^R Closed Coil Spring (23mm)

The figure below illustrates an intact coil spring before usage (before) and coil spring following intraoral wear (after) showing site of failure within the coil, at the interface between the coil and metal plate housing the eyelet, at either the cuspid or molar attachment. Of the 36 coils which were inserted, 23 broke; and of those that broke, all were at the site indicated.

Before



After



Site of Failure

Appendix L

Methods of Ligation for Closed Coil Springs

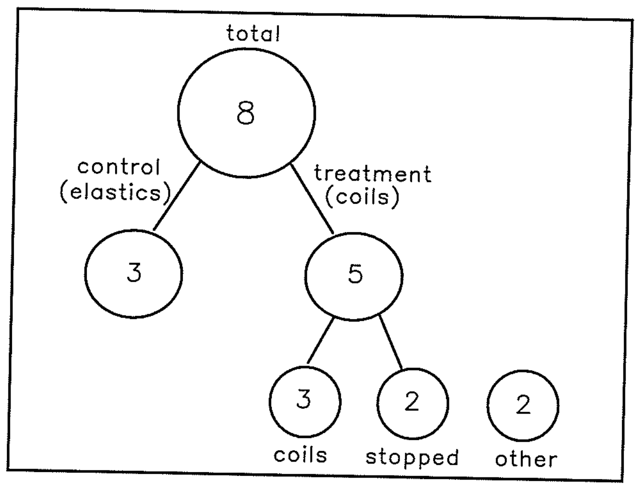
Different methods of ligation employed for attachment of interarch closed coil springs. Numbers refer to the chronological order of the different methods.

METHOD OF LIGATION						
		#1	#2	#3	#4	#5
CUSPID	bracket single tie	distal double tie	distal		disto-occlusal through eyelet	
	archwire			mesial		mesial
MOLAR	bracket	mesial single	mesial double	mesial not tied	mesial not tied	
	archwire					mesial

Appendix M

Distribution of Subjects to Treatment Groups

Randomization of 8 study subjects to the two treatment groups, subsequent exclusion of 2 subjects from the coil group, and recruitment of 2 additional participants for coil springs



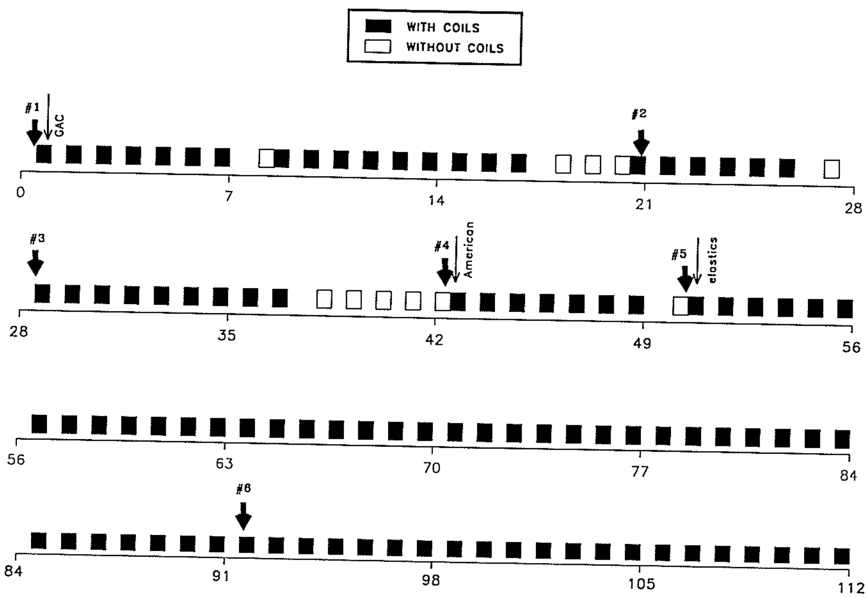
Appendix N

Pulse Diagrams for Subjects in the Coil Springs Group

Pulse diagrams indicating days in the presence (black squares) and absence (white squares) of coil springs; initiation of treatment with GAC coil springs, American coil springs and RMO elastics (small arrows); and timing of test sessions (large arrows); for subjects in the coil springs group: M.M. (A), M.D. (B) and L.K.(C).

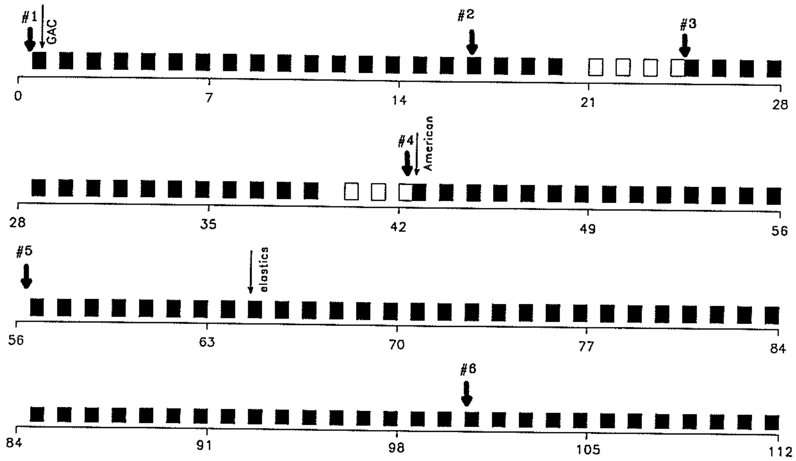
Pulse Diagram A

TIMING OF TREATMENT AND TEST SESSIONS
(subject M.M.)



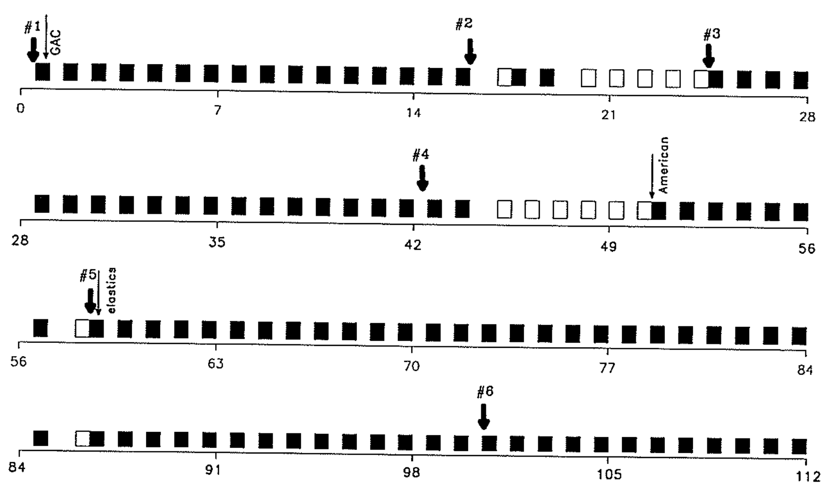
Pulse Diagram B

TIMING OF TREATMENT AND TEST SESSIONS
(subject M.D.)



Pulse Diagram C

TIMING OF TREATMENT AND TEST SESSIONS
(subject L.K.)

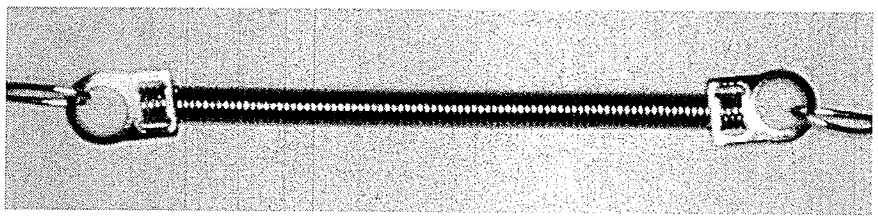


Appendix O

American Orthodontics Closed Coil Spring

The figures below illustrate the coil spring before usage (before) and after intraoral wear (after) showing plastic deformation of the coil spring. The coil spring was separated from the metal plate during removal from the patient. Of the six coils which were inserted, none actually broke.

Before



After