ARCH DIMENSION CHANGES WITH A PASSIVE SELF-LIGATING SYSTEM

JOHANNES JACOBUS VAN DEN BERG
BChD (Pret); Dip Odont (Ortho) (Pret)

2014

ARCH DIMENSION CHANGES WITH A PASSIVE SELF-LIGATING SYSTEM

by

JOHANNES JACOBUS VAN DEN BERG
BChD (Pret); Dip Odont (Ortho) (Pret)

Submitted in partial fulfilment of the
requirements for the degree of

MASTER IN DENTISTRY (ORTHODONTICS)

in the
Department of Orthodontics
at the
Faculty of Health Sciences
of the
University of Pretoria

Study Coordinator: Dr. S. Choonara

Supervisor: Prof. S.M. Dawjee

November 2014

" Commit your works to the Lord and
your plans will be established"

— Proverbs 16:3 —

DEDICATION

This dissertation is dedicated to my wife, Sylvia,
and my two children, Neill and Carla.
To my wife:
Thank you for your endless love, support, and understanding.
To my dear children:
You enrich my life.

ACKNOWLEDGEMENTS

My sincerest thanks to the following people who contributed to this dissertation:

Prof. S.M. Dawjee, my supervisor, for his time, constant support, motivation, and expert advice throughout this study. A special thank you for his help and support in our effort to gain ethical clearance for my previous proposed study.

Dr. S. Choonara, my study coordinator, for his guidance, advice and kind willingness to help. A special thank you goes to him for allowing me access to the patient records at his practice.

Prof. P.J. Becker of the Medical Research Council, for the statistical analysis, as well as his time and counsel on the interpretation of the results.

Ms Estee Oosthuizen, Dr Choonara's practice manger, for accommodating me in spite of her busy schedule regarding access to patient information and records

Dr. H. Swart, my fellow registrar for assisting with the re-measurement of the dental cast arch dimensions to determine the inter-examiner reliability of the measuring procedure.

DECLARATION

I, Johannes Jacobus van den Berg, declare that the dissertation I am herewith submitting for the degree MChD (Orthodontics) at the University of Pretoria, is my own work and has not previously been submitted for any other degree at any other university.

J.J. van den Berg
15 October 2014

CONTENTS

CHAPTER 1

INTRODUCTION

CHAPTER 2

REVIEW OF THE LITERATURE

CHAPTER 3

MATERIALS AND METHODS

CHAPTER 4

RESULTS

CHAPTER 5

DISCUSSION

CHAPTER 6

CONCLUSIONS

ADDENDA

SUMMARY

ARCH DIMENSION CHANGES WITH A PASSIVE SELF-LIGATING SYSTEM

by

Johannes Jacobus van den Berg
Department of Orthodontics
Faculty of Health Sciences
University of Pretoria

Study Coordinator: **Dr. S. Choonara**

Supervisor: **Prof. S.M. Dawjee**

Statistician: **Prof. P.J. Becker**

Department: **Orthodontics**
Degree: **MChD (Orthodontics)**

Recently, self-ligating brackets have gained popularity among clinicians around the world (Pandis et al., 2010, Berger, 2008). A passive self-ligating system utilizes a passive self-ligating slot, which is supposed to allow a low friction tooth movement environment (Harradine, 2008). The combination of thin super-elastic copper-nickel-titanium wires and 'low-friction systems' is claimed to be advantageous when leveling crowded dental arches (Tecco et al., 2009, Cattaneo et al., 2011). Some passive self-ligating systems even claim that there is less need for tooth extraction when using their system (Ormco, 2013, Scott et al., 2008). This raises the question of whether passive self-ligating systems achieve their results at the expense of overexpanded dental arches, which requires lifelong retention due to questionable stability.

The aim of this study was to evaluate the arch dimension changes that occur after treatment with a 0,022" slot passive self-ligating system, and to compare the results with those obtained after treatment with a 0,018" slot conventional bracket system.

Existing pre- and post treatment records of 31 anonymous patients (15 patients treated with passive self-ligating system, and 16 patients treated with a conventional bracket system) from a private orthodontic practice were subjected to examination and measurement. Dental casts were measured using a digital caliper up to a hundredth of a millimeter for changes in: intercanine-, interpremolar- and intermolar widths. Arch length was measured on a photocopied image (scale of 1:1) of the occlusal surfaces of the dental casts using the digital caliper. Results were compared between both the passive self-ligating system and conventional bracket system groups.

The results indicated statistically significant increase for nearly all measured dimensions between pre- and posttreatment measurements within each group. Only the maxillary arch length in the passive self-ligating group, and both the maxillary- and mandibular arch lengths in the conventional bracket system group did not show statistically significant increase.
When comparing the arch dimension changes between the two groups (after baseline correction), it was found that the passive self-ligating system showed statistically significantly more expansion than the conventional bracket system in the following dimensions: maxillary second interpremolar width, maxillary intermolar width, maxillary arch length, and mandibular intermolar width.

Since preservation of original archform is important for posttreatment stability, and since overexpansion of dental arches are more prone to relapse (de la Cruz et al., 1995, Nojima et al., 2001), the cases treated with the passive self-ligating system might be more prone to relapse.

However, no long-term studies on stability of passive self-ligating appliance systems are available at the present time. Until then, their implications on long-term stability will remain largely unknown.

Further studies to investigate the arch dimension changes between a 0,022: slot passive self-ligating appliance system and a 0,022" slot conventional appliance system are recommended to evaluate whether similar trends between the two groups exist. Also, further research on long-term stability of passive self-ligating appliance systems are recommended.

LIST OF FIGURES

LIST OF TABLES

LIST OF ABBREVIATIONS

CBS - Conventional bracket system

CSF - Circumferential supracrestal fiberotomy

CuNiTi - Copper nickel-titanium

Md1IPm - Mandibular first interpremolar

Md2IPm - Mandibular second interpremolar

MdA/L - Mandibular arch length

MdIC - Mandibular intercanine

Mx1IPm - Maxillary first interpremolar

Mx2IPm - Maxillary second interpremolar

MxA/L - Maxillary arch length

MxIC - Maxillary intercanine

NiTi - Nickel-titanium

PAOO - Periodontally accelerated osteogenic orthodontics

PSL - Passive self-ligating

PSLB - Passive self-ligating bracket

PSLS - Passive self-ligating system

SLB - Self-ligating bracket

SS - Stainless steel

CHAPTER 1

INTRODUCTION

1.1 BACKGROUND

Fixed orthodontic appliances, as we know it today, have been used for approximately a century to correct dental malocclusion. They are favoured for the treatment of most orthodontic cases. These appliance systems were developed in the USA at the turn of the 20th century and they have become progressively more sophisticated. Fixed orthodontic appliances are required for accurate tooth positioning. Contemporary fixed appliances consist of brackets, archwires and auxiliary components. They are responsible for mediating tooth movement which takes place at the tooth-bracket interface (Cobourne and DiBiase, 2010). The earliest fixed appliance systems, before enamel bonding was invented, consisted of four elements i.e. the archwire, the band, the bracket, and the ligature (Wahl, 2008).

Brackets are one of the most important passive components of fixed orthodontic appliances. Their main function is to merely hold the force producing agents, i.e. the archwires, into position (Tamizharasi and Kumar, 2010). According to Wahl (2008), the orthodontic bracket's sole purpose is to transmit forces from a traction device, usually an archwire, to the tooth.

The design of brackets has undergone continuous modification since fixed appliances were first used in orthodontics. The quest to improve treatment efficiency has culminated in many modern edgewise appliances (Ong et al., 2010). Self-ligating brackets (SLB) have gained popularity among clinicians recently, and they have experienced a resurgence in the last decade with almost all major orthodontic companies offering a self-ligating appliance (Cattaneo et al., 2011, Pandis et al., 2010).

By definition, a self-ligating bracket does not require an elastic or wire ligature but has an in-built mechanism that can be opened and closed to secure the archwire. In most of the designs, this mechanism is some form of metal labial face to the bracket slot that is opened and closed with a specific instrument or probe (Graber et al., 2012, Harradine, 2008).

The SLB concept is not new. Already in 1933 the Boyd band and the Ford lock bracket were introduced. However, it was with the SPEED® brackets in the 1970s and later on with the In-Ovation® bracket and the Damon SL® that the interest for SLBs increased, as they were promoted as a system rather than a bracket. This happened because of the claims of increased treatment efficiency and shorter chair time associated with SLBs, although these allegations were not unanimously accepted at the time (Cattaneo et al., 2011).

There are mainly two types of SLBs: active and passive. Active SLBs have a spring clip, which encroaches on the slot from the labial aspect, potentially generating an additional force on the tooth (e.g. SPEED®, In-Ovation®). Passive self-ligating brackets (PSLB) on the other hand, utilize a slide that closes to create a rigid labial surface to the slot with no ability to invade the slot (e.g. Damon®, Carierre®). In general, an active clip will generate higher archwire forces and increased resistance to tooth movement. The greater clearance between a given archwire and a passive slide will produce lower forces and may facilitate dissipation of the adverse binding forces and the ability of teeth to push each other aside as they align (Graber et al., 2012).

SLBs have caused much controversy. Advocates of SLB systems claim that low-friction SLBs coupled with light forces enhance the rate of tooth movement and decrease treatment time. Other reported advantages include decreased appointment times, improved oral hygiene, increased patient acceptance, and superior treatment results (Ong et al., 2010). One particular self-ligating system making use of passive self-ligation and superelastic nickel-titanium archwires claim less need for extraction and surgery, as well as freedom from headgear and other appliances (Ormco, 2013b). These low-friction self-ligating brackets are reported to induce (a significant) maxillary arch expansion during the initial therapy phase when superelastic nickel-titanium archwires are used (Tecco et al., 2009).

Stability is a major issue in orthodontics. Of the many objectives of orthodontic therapy, the triad of Jackson (1904, cited in Beukes et al., 2007) most aptly emphasizes the importance of "structural balance, functional efficiency and aesthetic harmony". Maintaining dental alignment after completion of orthodontic treatment has been a challenge in the past, and it continues to be a challenge to the orthodontic profession (Bondemark et al., 2007). Our concerns about the stability of orthodontic treatment still seem to be the same as those expressed by Calvin Case in 1920 (cited in Rinchuse et al., 2007) that pointed out the difficulties of retention because of the uncertainty of orthodontic stability.

The goal of orthodontic treatment is usually to produce a normal or ideal occlusion that is morphologically stable and aesthetically and functionally well adjusted (Bondemark et al., 2007). Follow-up studies of treated cases have shown that although improvement in the dentition can obviously be achieved, there is a tendency to return toward the original malocclusion many years posttreatment (Al Yami et al., 1999). The aetiology of this relapse is not fully understood, but relates to a number of factors, including periodontal and occlusal factors, soft tissue pressures and growth (Littlewood et al., 2006). Authors have shown that expansion of intercanine width and/or arch form during orthodontic treatment is highly unstable (Lee, 1999, Zachrisson, 1997, Little et al., 1981, Rinchuse et al., 2007). Apparently the greater the increase in dimensions during treatment, the greater the decrease in dimensions after treatment (Zachrisson, 1997).

Orthodontic treatment of severe malocclusion using a nonextraction approach may be at the expense of stability. This is because nonextraction treatment is often accompanied by dentoaleolar expansion (Tecco et al., 2009). The so-called expansion of dentures has been the basic form of treatment for the correction of malocclusion of the teeth, dating back as far as the year 1723, when Pierre Fauchard introduced the expansion arch (Strang, 1949, Kusy, 2002). The nonextraction theory is consistent with Angle's philosophy. Angle believed that everyone had the capacity to have 32 teeth in functional occlusion, and that bone would form in response to stress, according to Wolff's law (bone-growing theory). According to the "apical base" theory, however, the size and shape of the supporting bone are largely under genetic control, and there is a limit to expansion of a dental arch. Lundström (1925) proposed the term "apical base" to describe the limits of expansion of the dental arch and wrote extensively on this topic. He stated that the apical base limits the size of the dental arch. It is not changed after loss of teeth, nor is it influenced by orthodontic tooth movement or masticatory function. If the teeth are moved orthodontically beyond this limit, labial or buccal tipping of the teeth, periodontal problems, or an unstable treatment result could be expected (Ronay et al., 2008). Based on previous studies on relapse, it is generally agreed that post-orthodontic stability is enhanced through maintenance of the original mandibular intercanine width and preservation of the original arch form (Nojima et al., 2001).

1.2 MOTIVATION

A current trend in orthodontics is to "develop the dental arches" (grow bone) in cases that would conventionally require extractions as part of the treatment plan, using self-ligating bracket systems. Orthodontic extraction frequencies of near-zero have been reported for some North American and European practices, although it is known epidemiologically that 15%-25% of these populations display severe arch-length/tooth size discrepancies (Peck, 2012). These clinicians expand the dental arches in order to achieve the proper dental alignment, and then retain their result with life-long retention.

Since the preservation of the original arch form is important to enhance post-orthodontic occlusal stability (Nojima et al., 2001, Little et al., 1981, Rinchuse et al., 2007), it may be beneficial to study the arch dimension changes that occur after treatment with a passive self-ligating system (PSLS) and to compare it to arch dimension changes that occur after treatment with a conventional bracket system. Such a comparison would indicate whether there is any difference between arch dimension changes for both PSLS and conventional bracket system (CBS) groups. The results might assist the clinician upon selecting a bracket system that would be more advantageous to the patient in terms of expansion.

A retrospective audit is the evaluation of choice for this study, because it is suspected that the PSLS could cause overexpansion of dental arches. The findings of this study could be used to formulate a new hypothesis, i.e. that the treatment of dental arches with the PSLS is more prone to dental relapse.

1.3 PURPOSE

1. To evaluate arch dimension changes that occurs after treatment with a 0,022" slot passive self-ligating system and a 0,018" slot conventional bracket system respectively in terms of changes in:
    - Intercanine-, interpremolar-, and intermolar width
    - Arch length
2. To compare the changes that occur between the two groups

1.4 RESEARCH HYPOTHESIS

1.4.1 Null Hypothesis ($H_0 1$)

There are no significant arch dimension changes that occur after treatment with a 0,022" slot passive self-ligating system and a 0,018" slot conventional bracket system respectively.

1.4.2 Null Hypothesis ($H_0 2$)

There is no significant difference in arch dimension changes between the PSLS and CBS groups.

CHAPTER 2

LITERATURE REVIEW

2.1 THE EDGEWISE BRACKET SYSTEM

2.1.1 Introduction

Contemporary fixed appliances are predominantly variations of the edgewise appliance system that was developed by Angle in 1928. It is based around a bracket with a rectangular edgewise slot and an in-built prescription for each individual tooth position (Proffit and Fields, 2013, Cobourne and DiBiase, 2010). Edgewise brackets (also referred to as conventional brackets), makes use of elastomeric ligatures or steel ligature ties, to actively tie the archwire into the slot (Ormco, 2013a). Edgewise brackets are fabricated with a single archwire channel and two tie-wings (Figure 2.1), or more commonly as Siamese (or twin) brackets, which have four tie-wings (Figure 2.2). Siamese designs have an increased bracket width, which produces better control of tooth rotations and root position, whilst the presence of two separate tie-wings allows partial ligation of crowded teeth during initial alignment. However, the increased width of Siamese brackets results in a reduced interbracket span and some compromise in flexibility of the archwire during early alignment (Cobourne and DiBiase, 2010).

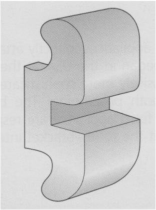


Figure 2.1: Edgewise Bracket (Cobourne and DiBiase, 2010)

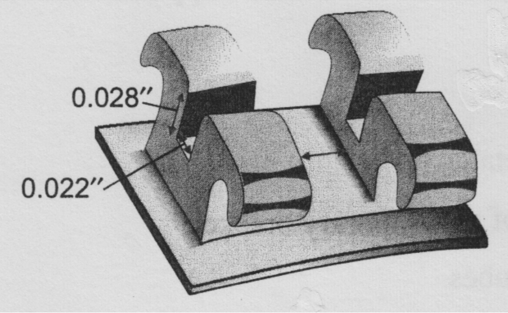


Figure 2.2: Siamese or Twin Bracket (Kharbanda, 2009)

Another group of fixed appliance light wire systems have also been developed, however, which allow much greater amounts of tooth tipping during the early stages of treatment (Cobourne and DiBiase, 2010). The Begg appliance is the only current fixed appliance system that does not use rectangular archwires in a rectangular slot. Practitioners using this appliance have recently shown renewed interest in rectangular archwires at the finishing stage as the original Begg appliance has transformed into the Tip-Edge appliance (Proffit and Fields, 2013).

Fixed orthodontic appliances consist of three main components:

- Brackets and molar tubes, which are bonded directly to the tooth crowns, or in the case of molar tubes, often welded to stainless steel bands that fit around the tooth. The bracket slot design and size have largely been governed by the ultimate desired tooth position at the end of orthodontic treatment, which in turn to a great extent is dictated by the concept of normal occlusion
- Archwires, which are attached to the brackets and pass through the molar tubes
- Auxiliaries, which will vary between appliance types, but include bracket ligatures, pins, elastics, uprighting and torquing springs, ligature wires and fixed devices for anchorage reinforcement or arch expansion (Cobourne and DiBiase, 2010, Kharbanda, 2009)

Brackets may be fabricated from metals, plastics and ceramics (Bishara, 2001). Brackets are either routinely cast, milled, sintered or injection-molded from stainless steel. In order to reduce the chance of allergic reaction, nickel-free brackets made from titanium or cobalt chromium are also available. Plastic brackets made in polyurethane or polycarbonate reinforced with ceramic or fiberglass fillers has been developed together with ceramic brackets to overcome the poor aesthetics of metallic brackets. Ceramic brackets were introduced in the 1980s and they are manufactured from aluminium oxide. These are described as either mono- or polycrystalline, depending on whether they are made from one or many crystals (Cobourne and DiBiase, 2010, Atack and Sandy, 2009).

2.1.2 History and Development of the Edgewise Appliance

Edward Hartley Angle (Figure 2.3) is regarded as the "father of modern orthodontics" due to not only his contributions to the classification and diagnosis of malocclusion, but also because of his creativity in developing new orthodontic appliances.

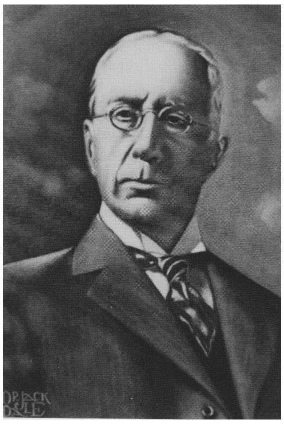


Figure 2.3: Edward H. Angle (Graber et al., 2012)

Motivated by obsession, Angle created the Angle System in 1888. The Angle System ultimately led to the development and introduction of the edgewise multibanded appliance, five years before Angle's death, which has been the progenitor of all modern fixed orthodontic appliances.

After graduation from dental school in 1878 and before his introduction of the Angle System in 1888, Angle experienced many technical problems and frustrations in patient treatment that motivated and inspired him to develop a standard appliance. He believed that an orthodontic appliance must have five properties:

i. Simplicity: it must push, pull, and rotate teeth.
ii. Stability: it must be fixed to the teeth.
iii. Efficiency: it must be based on Newton's third law and anchorage.
iv. Delicacy: it must be accepted by the tissues, and it must not cause inflammation and soreness.
v. Inconspicuousness: it must be is esthetically acceptable.

The Angle System was a standard appliance that consisted of a specific number of basic components. Angle had these components produced in large quantities so that they could be assembled into a simple, sturdy, efficient, delicate, and inconspicuous treatment device, without difficulty, in less time and with minimal pain and discomfort to the patient. This application enabled practitioners to treat more patients at a higher level of excellence and at less cost than they had done previously. This was the beginning of a relationship among manufacturers, suppliers, and orthodontists.

During his lifetime, Angle developed four major appliance systems:

- **E-Arch:** A typical orthodontic appliance of the late 1800s, depended on some sort of rigid framework to which the teeth were tied so that they could be expanded to the arch form dictated by the appliance. Angle's E-arch (his first appliance) (Figure 2.4), was an improvement on this basic design. Molar teeth were banded, and a heavy labial archwire extended around the arch. A nut placed at the threaded end of the arch allowed advancement of the archwire so that expansion could be achieved. Because of its simplicity, and despite the fact that it can deliver only heavy interrupted force, this appliance was still available as late as the 1980s.

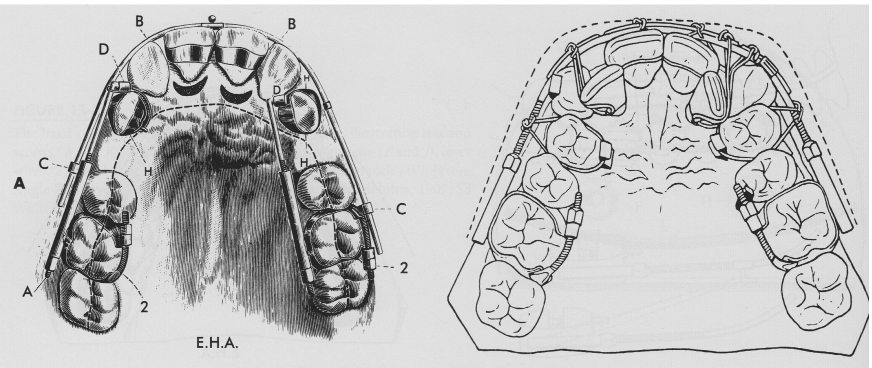


Figure 2.4: Angle's E-arch Appliance (Graber et al., 2005)

- **Pin and Tube:** The E-arch was only capable of tipping teeth to a new position. It was not able to produce precise individual tooth movement. To overcome this difficulty, Angle began to place bands on other teeth, and he used a vertical tube on each tooth into which a soldered pin from a smaller archwire was placed. Tooth movement was accomplished by repositioning the individual pins at each appointment. Unfortunately, this pin and tube appliance (Figure 2.5) proved impractical in clinical use, since an incredible degree of craftsmanship was involved in constructing and adjusting it, even though it was theoretically capable of great precision in tooth movement. It is said that only Angle himself and one of his students ever mastered the appliance.

The relatively heavy base arch meant that spring qualities were poor, and the problem therefore was compounded because many small adjustments were needed.

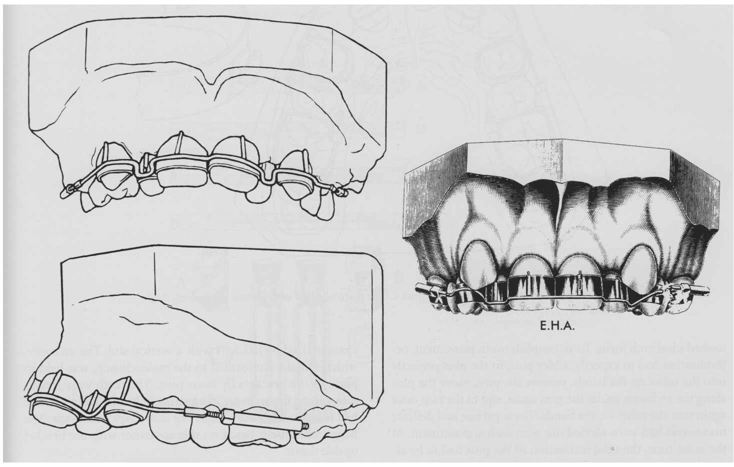


Figure 2.5: Angle's Pin and Tube Appliance (Graber et al., 2005)

- **Ribbon Arch:** This appliance modified the tube on each tooth to provide a vertically positioned rectangular slot behind the tube. A ribbon arch of 0,010 x 0,020 inch gold wire was placed into the slot and held with pins. The ribbon arch (Figure 2.6) was an immediate success, primarily because the archwire, unlike any of its predecessors, was small enough to have good spring qualities and was quite efficient in aligning malposed teeth. Although the ribbon arch could be twisted as it was inserted into its slot, the major weakness of the appliance was that it provided relatively poor control of root position. The resiliency of the ribbon archwire simply did not allow generation of the moments necessary to torque roots to a new position.

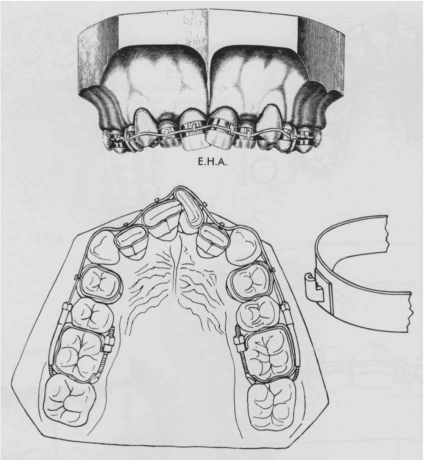


Figure 2.6: Angle's Ribbon Arch Appliance (Graber et al., 2005)

- **Edgewise:** The edgewise appliance (Figure 2.7) was the last and the most advanced of the several appliances invented by Dr. Edward Angle, and was introduced in 1928. It is a multibanded precision appliance consisting of a rectangular labial archwire fitted and ligated into horizontal slots in brackets and terminating in rectangular tubes on the second molar bands. Angle reoriented the slot from vertical to horizontal to overcome the deficiencies of the ribbon arch. The archwire (precious metal) originally was 0.022 x 0.028 inch, with the narrow dimension lying against the facial surfaces of the teeth. Because the wire was rotated 90° to the orientation it had with the ribbon arch, it was called "edgewise". Control in all directions is possible, and all individual teeth may be moved simultaneously in three directions. The edgewise bracket (Figure 2.1) is versatile since it will accept any shape of wire up to 0.022 inch in diameter. A series of progressively larger light twist and round wires are used initially to align, rotate, and tip the teeth and to level the occlusal plane, permitting the greatest movements with light forces yet allowing more easy insertion of the rectangular wire. Loops can be incorporated into the archwire to affect individual tooth and sectional arch movements. The modern edgewise mechanism is quite different from Angle's original appliance but its ingenious design enabled the adoption of many ideas from other multibanded systems. The idea that each tooth has a proper position and angulation within an ideally shaped arch in order to achieve an ideal coordinated occlusal relationship with teeth of the opposing arch is an important concept, if used in treatment with edgewise appliances. The edgewise appliance was a breakthrough in orthodontics, since it provided tip-, torque- and labio-lingual control of tooth position. It facilitates first-, second- and third-order control, which was not previously possible. Angle had only two years of his life to perfect its design and its use. Though difficult to master, the edgewise mechanism is the most popular because of its versatility. Several systems of treatment (e.g. Tweed, Straightwire, Bioprogressive) are based on use of the edgewise mechanism. Though the brackets are similar, the steps of treatment, means of obtaining anchorage, methods of delivering torque, etc., differ (Proffit, 2013, Proffit and Fields, 2013, Moyers et al., 1988, Wahl, 2008, Cross, 1996, Proffit et al., 2007, Wahl, 2005a, Wahl, 2005b).

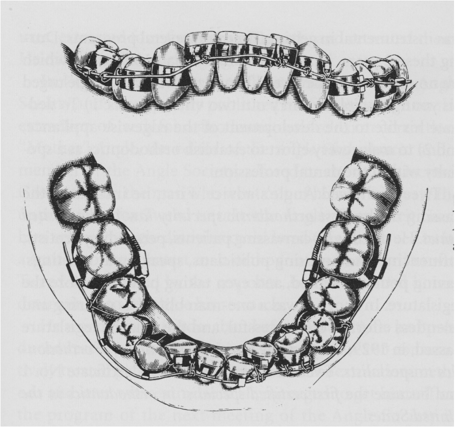


Figure 2.7: Angle's Edgewise Appliance (Graber et al., 2005)

2.1.3 Contemporary Edgewise Bracket System

For many years orthodontists used the standard edgewise and Begg systems with great success. The Begg appliance became widely popular in the 1960s because it was more efficient than the edgewise appliance of that era, in the sense that equivalent results could be produced with less investment of the clinician's time. Developments since then have reversed the balance: the contemporary edgewise appliance has evolved far beyond the original design while retaining the basic principle of a rectangular wire in a rectangular slot, and now is more efficient than the Begg appliance, which is the reason for its almost universal use now. Major steps in the evolution of the edgewise appliance include:

- **Automatic rotational control:** In the original appliance, Angle soldered eyelets to the corners of the bands, so that a separate ligature tie could be used as needed to correct rotations or control the tendency for a tooth to rotate as it was moved. By using either twin brackets or single brackets with extension wings that contact the underside of the archwire (Lewis or Lang brackets), rotational control is now achieved without the necessity for an additional ligature to make it easier to obtain the necessary moment in the rotational plane of space.
- **Alteration in bracket slot dimensions:** The original dimensions of the bracket slot was 0.022 inches vertically and 0.028 inches horizontally to accommodate gold archwires, which were quite soft. Once stiffer stainless steel archwires were introduced, slot size was reduced to 0.018 inches vertically and 0.025 inches horizontally. However, with greater uptake of preadjusted edgewise systems, there has been a move back to the original slot dimension. This allows increased dimensions of the working archwire and provides better overbite and torque control during space closure with sliding mechanics.
- **Straight-wire prescriptions:** Angle used the same bracket on all teeth, as did the other appliance systems (standard edgewise appliance system). In the 1980s, Andrews developed bracket modifications for specific teeth to eliminate the many repetitive bends in archwires that were necessary to compensate for differences in tooth anatomy, and bonding made it much easier to have different brackets for each tooth. The result was the "straight-wire" appliance (preadjusted appliance system). This was the key step in improving the efficiency of the edgewise appliance, and these modifications were based on Andrews' "six

keys to normal occlusion" which were characteristics observed in a study of 120 casts of non-orthodontic patients with normal occlusion. In the original edgewise appliance, faciolingual bends in the archwires (first-order, or in-out bends) were necessary to compensate for variations in the contour of labial surfaces of individual teeth. In the contemporary appliance, this compensation is built into the base of the bracket itself. This reduces the need for compensating bends but does not eliminate them because of individual variations in tooth thickness. Angulation of brackets relative to the long axis of the tooth is necessary to achieve proper positioning of the roots of most teeth. Originally, this mesiodistal root positioning required angled bends in the archwire, called second-order, or tip, bends. Angulating the bracket or bracket slot decreases or removes the necessity for these bends. Because of the facial surface of individual teeth varies markedly in inclination to the true vertical, in the original edgewise appliance it was necessary to place a varying twist (referred to as third-order, or torque, bends) in segments of each rectangular archwire, in order to make the wire fit passively. Torque bends were required for every patient in every rectangular archwire, not just when roots needed to be moved facially or lingually, in order to avoid inadvertent movements of properly positioned teeth. The bracket slots in the contemporary edgewise appliance are inclined to compensate for the inclination of the facial surface, so that third-order bends are less necessary.

The angulation and torque values built into the bracket are referred to as the appliance prescription. In 1976 Dr. Ronald Roth introduced the "Roth Prescription" which had a lot of overcorrection built into the appliance in order to have the teeth finish in their desired positions (Roth, 1976, Roth, 1987). It quickly became the most popular straight-wire prescription all around the world. Figure 2.8 depicts a set of extracted teeth with the Roth prescription straight-wire appliance brackets and full-size rectangular wire, showing the amount of overcorrection built into the brackets.

Any prescription that is based on a group average would precisely position only the average tooth, and would not be correct for outliers in a normal population. It is because of this reason, as well as individual variability that a great number of clinicians came out with small variations to either the Andrews prescription or the Roth prescription (e.g. Alexander, MBT, etc.) (McLaughlin and Bennett, 1989). The edgewise appliance continues to evolve. (Cobourne and DiBiase, 2010, Proffit and Fields, 2013, Andrews, 1972, Andrews, 1979, Proffit, 2013)

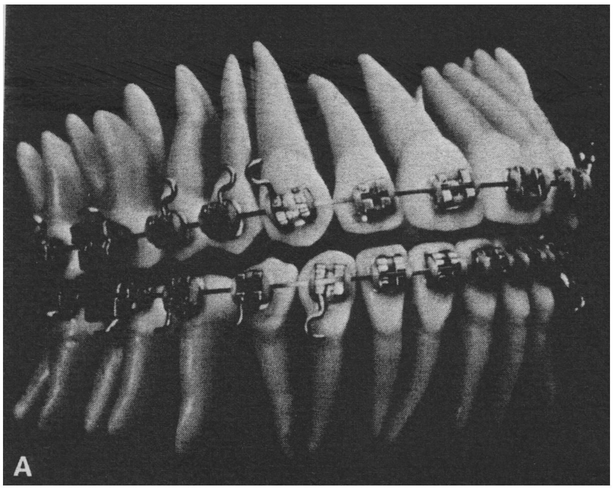


Figure 2.8: Extracted teeth with Roth Prescription Brackets (Roth, 1987)

2.2 THE SELF-LIGATING BRACKET SYSTEM

2.2.1 Definition and History

Self-ligating brackets do not require an elastic or wire ligature, but have an inbuilt mechanism that can be opened and closed to secure the archwire. In the overwhelming majority of designs, this mechanism is a metal face to the bracket slot that is opened and closed with an instrument or fingertip (Harradine, 2008, Harradine, 2003). Figure 2.9 shows an example of a SLB: the In-Ovation® Bracket -Subsequently In-Ovation R® and then System R® with Reduced Size and Minor Modifications.

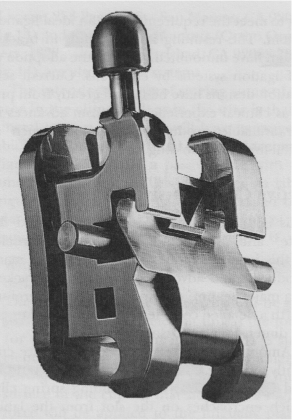


Figure 2.9: Example of a Self-Ligating Bracket (Harradine, 2008)

Brackets incorporating their own ligation system have existed for a surprisingly long time in orthodontics. The first, "Russel Lock" edgewise attachment was described in 1935 by Stolzenberg. Many designs have been patented, although only a minority have become commercially available (Harradine, 2001). The first self-ligating appliances did not gain much popularity at the time due to skepticism in the orthodontic society, lack of promotion, problems with design, and technical difficulties with the appliances.

Self-ligating brackets reappeared in the mid 1970s as Strite Ltd. marketed the SPEED® system (Figure 2.10). Their advantage was that unlike conventional ligation, friction was purportedly reduced —but most importantly, friction became more reproducible (Kusy, 2002, Kusy and Whitley, 1997).

Much of the initial difficulties with self-ligating brackets have been overcome, with simplified use of their application, and refinement of the appliances itself. This caused a recent increase in the use of self-ligating bracket systems over the last two decades, with claims of significant reduction in the level of friction, in addition to shorter treatment time and chairtime, when compared with conventional bracket systems (Shivapuja and Berger, 1994, Harradine, 2013).

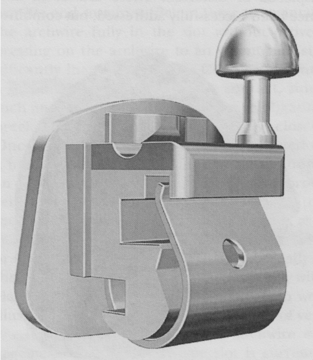


Figure 2.10: SPEED® Bracket (Berger, 2008)

The claim of reduced friction with self-ligating brackets is often cited as a primary advantage over conventional brackets. This occurs because the usual steel or elastomeric ligatures are not necessary, and it is claimed that passive self-ligating bracket designs generate even less friction than active ones. With reduced friction and hence less force needed to produce tooth movement, self-ligating brackets are proposed to have the potential advantages of producing more physiologically harmonious tooth movement by not overpowering the musculature and interrupting the periodontal vascular supply. Therefore, more alveolar bone generation, greater amounts of expansion, less proclination of anterior teeth, and less need for extractions are claimed to be possible. Other claimed advantages include full and secure wire ligation, better sliding mechanics and possible anchorage conservation, decreased treatment time, longer treatment intervals with fewer appointments, chair time savings, less chair-side assistance and improved ergonomics, better infection control, less patient discomfort, and improved oral hygiene (Chen et al., 2010, Mavreas, 2008). However, most advantages of self-ligation remain largely presumptive (Pandis et al., 2007, Fleming and O'Brien, 2013, Celar et al., 2013). It is fair to say that, as with several popular orthodontic products such as preadjusted brackets and superelastic wires, the clinical popularity of self-ligating systems has run ahead of the evidence to firmly support all the proposed advantages (Harradine, 2008).

Self-ligating brackets also have some disadvantages, including higher cost, possible breakage of the clip or the slide, higher profile because of the complicated mechanical design, potentially more occlusal interferences and lip discomfort, and difficulty in finishing due to incomplete expression of the archwires (Chen et al., 2010).

The principal aim behind the development of earlier self-ligating brackets was faster ligation. With the introduction of elastomeric ligatures, this incentive greatly diminished. Recent designs have been driven by a wish to harness the combination of two other claimed advantages of this type of bracket — low friction and archwire engagement which is secure and complete (Harradine, 2001).

2.2.2 Types

There are 3 types of self-ligating bracket systems being used in contemporary orthodontic practices:

a. Systems that are completely *active* throughout all stages of treatment,

b. Systems that are completely *passive* throughout all stages of treatment, and
c. Systems that are *interactive*, that is, they can exhibit either passive or active properties during any stage of treatment at the discretion and direction of the clinician.

Active self-ligating brackets have a spring clip that stores energy to press against the archwire for rotation and torque control. These brackets exhibit a spring clip, which encroaches on the slot from the labial aspect, potentially generating an additional force on the tooth. Examples of active self-ligating bracket systems are, SPEED®, System R® (In-Ovation), and Forestadent Quick® (Figure 2.11) brackets.

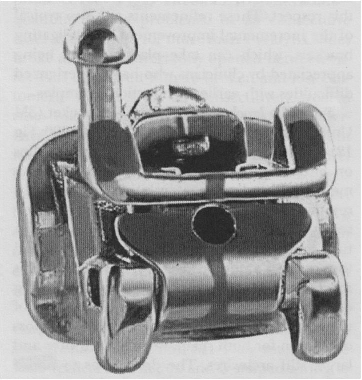


Figure 2.11: Quick® Bracket (Harradine, 2008)

Passive self-ligating brackets usually have a slide that can be closed which does not encroach on the slot lumen, thus exerting no active force on the archwire. The slide closes to create a rigid labial surface to the slot with no intention or ability to invade the slot and store force by deflection of a metal clip. Damon® (Figure 2.12), SmartClip® (Figure 2.13), and Carriere LX® are examples of passive systems (Chen et al., 2010, Graber et al., 2012).

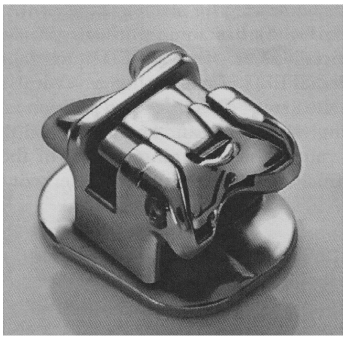


Figure 2.12: Damon® 3 Bracket (Birnie, 2008)

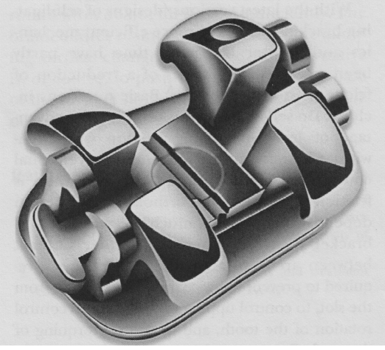


Figure 2.13: SmartClip® Bracket (Graber et al., 2012)

Interactive self-ligating brackets exhibit both integrated passive and active elements and may be described as a "hybrid" self-ligating bracket system. This system provides minimal force and friction (passive) in the early stage of treatment, and torque and rotational control (active) in the middle and finishing stages of treatment. The Time® appliance (Figure 2.14) is an example of an interactive system. The clip of Time® brackets is very similar to the spring clip of the active self-ligating brackets (e.g. SPEED®, System R®, and Quick®), but for closure it rotates around a tie wing rather than slides into place (Valant, 2008).

The following table contains the majority of self-ligating bracket types that have been available for clinical use as well as their year of introduction:

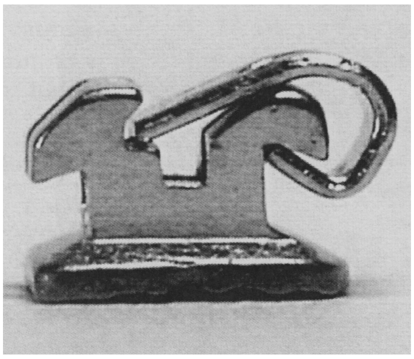


Figure 2.14: The Time® Interactive Self-Ligating Bracket (Valant, 2008)

TABLE 2.1: Self-ligating Brackets by Year of Manufacture

BRACKET	***YEAR***
Russel Lock	1935
Ormco Edgelok	1972
Forestadent Mobil-Lock	1980
Forestadent Begg	1980
Strite Industries SPEED	1980
"A" Company Activa	1986
Adenta Time	1996
"A" Company Damon SL	1996
Ormco TwinLock	1998
Ormco / "A" Co. Damon 2	2000
GAC In-Ovation	2000
Gestenco Oyster	2001
GAC In-Ovation R	2002
Adenta Evolution LT	2002
Ultradent OPAL	2004
Ormco Damon 3	2004
3 M Unitek SmartClip	2004
Ormco Damon 3 MX	2005
Ultradent OPAL metal	2006
Forestadent Quick	2006
Lancer Praxis Glide	2006
Class 1 / Ortho Organisers Carriere LX	2006
GAC In-Ovation C	2006
3M Unitek Clarity SL	2007
American Orthodontics Vision LP	2007
Dentaurum Discovery SLB	2007
Ortho Technology Lotus	2008
OrthoClassic Axis	2009

Damon Q	2009
Damon Clear	2010

(Harradine, 2008, Graber et al., 2012)

Most of the self-ligating bracket systems consist of self-ligating brackets only, and do not require a specific archwire or archwire sequence to be used with their system. A few systems (e.g. SPEED® and Damon®), however, manufacture their own archwires and auxiliaries in addition to the brackets. Although the edgewise slot of any self-ligating bracket will accommodate virtually any size or configuration of archwire, some systems recommend the use of their brackets together with their own archwires and auxiliaries for best results. Archwires from the SPEED® system include: Supercable, Hills Dual-Geometry, and SPEED® finishing archwires. The Damon® system requires the use of their own series of archwires in a certain sequence for best results (Berger, 2008, Birnie, 2008).

2.3 HISTORY OF THE DEVELOPMENT OF THE CORE BRACKET SYSTEMS IN ORTHODONTICS

Herewith a summary (in table format) of the different core bracket systems and how they evolved:

TABLE 2.2: Development of the Major Types of Bracket Systems

DATE	***BRACKET SYSTEM***	
1928	Standard Edgewise Appliance	Dr. Edward Angle (father of modern orthodontics) devised the edgewise system, which has served as the blueprint for all subsequent edgewise bracket systems. Problems with high friction lead to a high demand upon anchorage, and

		the lack of prescription in the brackets (no tip, torque or in-out) meant that final detailing of tooth position in rectangular wires was dependent upon many bends being placed within the archwire for each individual tooth. This was time consuming and required significant operator skill
1935	Russel Lock (First Self-Ligating Appliance)	Stolzenberg introduced the first self-ligating appliance. The appliance did not gain much popularity at the time due to skepticism in the orthodontic society, lack of promotion, and technical difficulties with the appliance
1956	Begg / Light Wire Appliance	In an effort to overcome the high anchorage demand associated with the standard edgewise appliance, Dr. Raymond Begg developed a light wire fixed appliance system where tooth movement was based around the concept of differential force. The original Begg appliance has morphed into the Tip-Edge appliance, where rectangular archwires may be employed during the finishing stages of treatment
1970	Straight-Wire Appliance / Preadjusted Edgewise Appliance	This appliance system has revolutionized fixed appliance orthodontics, and was introduced by Dr. Lawrence Andrews. Contemporary edgewise brackets are based on its design, and it is the most popular fixed appliance system in use today. Unlike standard edgewise brackets which are identical for each tooth, each tooth in the preadjusted edgewise system

		has a customized bracket. This built-in prescription was based around Andrews' measurement from the untreated sample of ideal occlusions he studied, and included a number of features to position each tooth individually in three dimensions, generating mesiodistal tip, torque and in/out positioning
1980	SPEED® Appliance (Self-Ligating Appliance)	Self-ligating or ligatureless brackets reappeared in 1977, and in 1980 they became commercially available as Strite Ltd. marketed them. The appliance was designed by Dr Hanson to improve operator efficiency. These brackets had a stainless steel body and a positive-locking, spring-clip mechanism. Their advantage was that unlike conventional ligation, friction was purportedly reduced - but most importantly friction became more reproducible. During the past 2 decades, there has been a boost in the manufacturing and release of self-ligating appliances with active and passive modes. This is because the initial clinical handling difficulties associated with the use of self-ligating appliances have been overcome, application of these appliances has been simplified, and due to refinement of the appliances itself.

(Cobourne and DiBiase, 2010, Pandis et al., 2007, Kusy, 2002, Andrews, 1976, Harradine, 2001, Chen et al., 2010, Berger, 2008, Begg, 1956)

2.4 METHODS OF LIGATION

The core difference between a self-ligating bracket system and an edgewise bracket system is their method of retaining the archwire in the bracket slot. This requires us to take a closer look at the different methods of ligation in orthodontics.

Most fixed appliance systems store tooth-moving forces in archwires, which are deformed within their elastic limit. In order for this force to be transmitted to a tooth, the wire needs a form of connection to the bracket. This connection between an archwire and a bracket is called "ligation" because the early forms of connection were most frequently a type of ligature. There are three major types of ligation — steel ligatures, elastomeric ligatures, and self-ligation. Conventional edgewise bracket systems make use of steel and elastomeric ligatures, whereas self-ligating brackets make use of an inbuilt clip or slide. Another method of ligation is through the use of brass pins in the Begg technique, but it won't be discussed here since it has no relevance to this discussion (Graber et al., 2012).

2.4.1 Stainless Steel Ligatures

Stainless steel became available in the early 1930s. At the time it became universally adopted as the method of ligation. Stainless steel ligatures have several benefits. They are cheap, robust, and essentially free from deformation and degradation, and to an extent they can be applied tightly or loosely to the archwire. Long stainless steel ligatures can be employed to create anchor units by tying teeth together in a "figure-of-eight" fashion (Tweed, 1941). They also permit ligation if the archwire is not positioned in the bracket slot. This is especially useful if the appliance tends to employ high forces from the archwires, because this high force prevents full archwire engagement with significantly irregular teeth. Despite these good qualities and their widespread use over many decades, wire ligatures have substantial drawbacks, and the most immediately apparent of these are the length of time required to place and remove the ligatures. Shivapuja and Berger (1994) found that an additional 11 minutes was needed to remove and replace two archwires if wire ligatures were used rather than elastomeric ligatures. Additional potential hazards include those arising from puncture wounds from the ligature ends and trauma to the patients' mucosa if the ligature end becomes displaced (Graber et al., 2012, Kusy, 2002, Shivapuja and Berger, 1994, Alpern, 2008, Geron, 2008).

2.4.2 Elastomeric Ligatures

Elastomeric ligatures became available in the late 1960s and rapidly became the most common method of ligation, almost entirely because of the greatly reduced time required to place and remove them when compared with stainless steel ligatures. New clinicians and staff greatly preferred elastomerics, because it was easier to learn the skills required to place these ligatures. Intermaxillary elastics had been employed since the late nineteenth century, pioneered by well-known orthodontists such as Calvin Case and H. A. Baker. Initially these elastic bands were made from natural rubber, but production of elastomeric chains and ligatures followed the ability to produce synthetic elastics from polyester or polyether urethanes. Because of the ease of use and speed of placement of elastomeric ligatures, other disadvantages had been generally overlooked. Elastomerics frequently fail to fully engage an archwire when full engagement is intended. Twin brackets with the ability to "figure-of-eight" the elastomerics are a significant help in this respect but at the cost of greatly increased friction. Khambay et al. (2004, cited in Graber et al., 2012) quantified the potential seating forces with wire and elastic ligatures and clearly showed the much higher archwire seating forces available with tight wire ligatures.

A second and well-documented drawback with elastomerics is the degradation of their mechanical properties in the oral environment. A comprehensive literature review of elastomeric chains gave a good account of the relevant data. Typically elastomeric chains and ligatures undergo greater than 50% degradation in force in the first 24 hours when tested under in vitro experimental environments. The higher temperature in the mouth, enzymatic activity, and lipid absorption by polyurethanes are all reported as in vivo sources of force relaxation. This leads to the potential for elastomeric ligatures to fail to achieve or to maintain full archwire engagement in the bracket slot. Loss of rotational control of canines during space closure is a well-known example of this. Twin brackets with the ability to "figure-of-eight" the elastomerics may help in this respect but certainly is not a complete answer. A further factor of potential clinical importance is the variability in mechanical properties of elastomerics. This is well described by Lam et al., (2002, cited in Graber et al., 2012) who reported substantial variation in the range and tensile strength of elastomerics from different manufacturers and for different colours of elastomeric from the same manufacturer.

Lastly, there is a large body of literature to demonstrate the much higher friction between bracket and archwire with elastomeric ligation compared with wire ligatures. Interestingly, this had been proposed as a factor of clinical significance more than 30 years ago but was largely disregarded until more recently. The great popularity of elastomeric ligation in the last 40 years was achieved despite these substantial deficiencies in relation to wire ligatures. Speed and ease of use were the overriding assets of elastomerics, and it is no surprise that the strongest motivation behind the early efforts to produce a satisfactory self-ligating bracket was a desire to have all the benefits of wire ligation but in addition to have a system that was quick and easy to use (Graber et al., 2012).

2.4.3 Self-Ligation

The cardinal feature of a self-ligating bracket is an inbuilt metal labial face to the bracket slot, which is referred to as a clip or slide (Harradine, 2001). Self-ligating brackets have a relatively long history, but their development should be viewed against the background of an almost universal use of elastomeric ligatures despite the known advantages of wire ligatures —and in a different context— of brass Begg pins. Elastomeric ligation gives unreliable archwire control, high friction, and perhaps an added oral hygiene challenge. It creates friction by pressing the archwire into the slot, and according to Meling et al. (1997, cited in Trevisi & Bergstrand, 2008) use of an elastomeric module results in a force of approximately 50 g of friction per bracket. Wire ligation is better in every respect, with stainless steel ligature wires producing lower amounts of classical friction than do elastomeric ligatures. However, wire ligation is very slow, highly inconsistent in its force application and the wire ends can cause trauma to patient and operator. Orthodontists accommodated these shortcomings for several decades. Self-ligation has always offered the potential for very substantial improvements in relation to all of these drawbacks, but for many years remained the choice of a small minority of clinicians because of several factors that hindered the adoption of the appliance (Trevisi and Bergstrand, 2008, Graber et al., 2012).

2.5 TREATMENT STABILITY IN ORTHODONTICS

Long-term post-treatment stability is an issue of great concern to all orthodontists (BeGole and Sadowsky, 1999, Burke et al., 1998). Maintaining dental alignment after orthodontic treatment has been and continues to be a challenge to the orthodontic profession (Bondemark et al., 2007).

The goal of orthodontic treatment is usually to produce a normal or ideal occlusion that is morphologically stable and aesthetically and functionally well adjusted (Bondemark et al., 2007). Follow-up studies of treated cases have shown that although improvement in the dentition can obviously be achieved, there is a tendency to return toward the original malocclusion many years posttreatment (Al Yami et al., 1999). The aetiology of this relapse is not fully understood, but relates to a number of factors, including periodontal and occlusal factors, soft tissue pressures and growth (Littlewood et al., 2006).

Retention is the phase of orthodontic treatment that attempts to maintain teeth in their corrected positions after active tooth movement. Post-orthodontic retention is one of the most controversial areas in clinical orthodontic practice. Although retention potentially affects every patient, there is minimal agreement as to the most appropriate approach to adopt in an individual case. Attitudes to the use of retention have changed over the years, but it has been suggested that there is a shortage of reliable evidence to apply clinically (Littlewood et al., 2006). The proposed basis for holding the teeth in their treated position is to: allow for periodontal and gingival reorganization; to minimize changes from growth; to permit neuromuscular adaptation to the corrected tooth position; and to maintain unstable tooth position, if such positioning is required for reasons of compromised aesthetics (Blake and Bibby, 1998). Retention can be achieved by placing removable or fixed retainers. It has been shown that, at least in relation to periodontal factors, it takes, on average, a minimum of 232 days for fibres around the teeth to remodel to the new position. However, even if the teeth are held in position during this period, in the long-term they can show relapse. Some clinicians, therefore, prefer to retain for longer periods, sometimes indefinitely (Littlewood et al., 2006).

The mandibular anterior region is the most common area for post-treatment relapse and crowding (Zachrisson, 1997). Mandibular anterior malalignment is considered to be the most significant problem in patients having orthodontic treatment. Clinically significant incisor irregularity occurs in approximately 40% of the untreated population between 15 and 50 years of age, with approximately 17% exhibiting severe amounts (≥7mm) of mandibular irregularity. Since patients want to maintain straight teeth, a primary objective of the orthodontist must be long-term stability (Myser et al., 2013). Without it, ideal function, optimum aesthetics, or both may be lost (Graber et al., 2012).

2.5.1 Definitions of Terms

- ***Stability:*** Stability is the condition of maintaining equilibrium. This refers to the quality or condition of being stable; the fixity of position in space or the capacity for resistance to displacement. Stability is not retention (Rossouw, 1999).
- ***Retention:*** It is defined as the action or fact of holding or keeping in a place or position; retaining in a fixed position. Retention is accomplished by a variety of mechanical appliances (Rossouw, 1999).
- ***Relapse:*** Relapse means an undesirable return to a previously corrected malocclusion. Minor changes are to be expected, and there are categories of acceptability, but it is the major unacceptable reversions that should be termed the true relapse (Rossouw, 1999).

2.5.2 Normal Development

The stability of orthodontic treatment must be judged against the background of naturally occurring changes in the untreated dentition (Richardson, 1999). Physiologic dentoalveolar adaptation may affect posttreatment changes in the dentition (Blake and Bibby, 1998). It is generally recognized that the human dentition is in a dynamic state, continually changing throughout life. During normal development a moderate increase in arch width is seen until permanent cuspid eruption, followed by a reduction of intercanine width. The intermolar width remains stable from 13 to 20 years, and there is a reduction in the antero-posterior dimension of the mandibular arch with time (Blake and Bibby, 1998, Ahn et al., 2012).

2.5.3 Potential Causative Factors for Posttreatment Crowding

There are numerous causes attributed to relapse. No single factor can be said to be the sole cause of relapse. In most cases relapse occurs due to a combination of causes (Bhalajhi, 2009).

- ***Apical Base:*** In the middle 1920's Lundström suggested that the apical base was one of the most important factors in the correction of malocclusion and maintenance of a correct occlusion. McCauley (1944, cited in Graber et al., 2012) suggested that intercanine width and intermolar width should be maintained as originally presented to minimize retention problems.
- ***Patient Age:*** Corrections carried out during periods of growth are less likely to relapse (Little et al., 1981).
- ***Length of Retention:*** The longer the retention period, the better the postretention stability (Little et al., 1981).
- ***Incisors Upright Over Basal Bone:*** According to Graber, Grieve and Tweed suggested that the mandibular incisors must be placed and kept upright and over basal bone (Graber et al., 2012).
- ***Posttreatment Growth:*** Prolonged retention is indicated until active growth is completed (Bhalajhi, 2009). In Class III malocclusion, mandibular growth can result in the reappearance of a reverse overbite following early correction (Cobourne and DiBiase, 2010).
- ***Third Molars:*** The pressure exerted by the erupting third molars is believed to cause late anterior crowding by some authors, predisposing to relapse (Bhalajhi, 2009). Other investigators,

however, have published data suggesting that third molars play little, if any, role in long-term mandibular arch changes (Ades et al., 1990).

- ***Periodontal and Gingival Tissues:*** Following orthodontic tooth movement, the tissues of the periodontal ligament and gingivae remodel to the new position of the tooth. While collagen fibres in the periodontal ligament take between three to four months to remodel, those in the gingival tissues take slightly longer, at around six months. The slowest turnaround occurs in the elastic supracrestal fibres, which take up to one year. This has important implications for teeth that were rotated, as this slow remodelling is implicated in the very high relapse rate for rotational correction (Cobourne and DiBiase, 2010).
- ***Oral Habits:*** Stability is not achievable without elimination of the initial cause of the malocclusion, particularly if habit related (Cobourne and DiBiase, 2010).
- ***Occlusion:*** Kingsley (1880, cited in Graber et al., 2012) stated, "The occlusion of the teeth is the most potent factor in determining the stability in a new position". Many early writers agreed that proper occlusion was of primary importance in retention. Teeth retained by the occlusion are often stable. Mihalik et al. (2003) evaluated the long-term occlusal stability and treatment outcomes in 31 adults who had been treated with orthodontics alone for Class II malocclusion correction, and compared them to similar data for long-term outcomes in patients with more severe Class II problems who had surgical correction. They reported that despite the initial differences between the two groups, jaw relationships and dental occlusion were similar at the end of treatment. The camouflage group showed good stability of the occlusal result at long-term recall.
- ***Soft Tissues:*** Muscle imbalance at the end of the orthodontic therapy can result in reappearance of the malocclusion (Bhalajhi,

2009). To a large extent the soft tissues define the limitations of orthodontic tooth movement. Any change in the position of the teeth can move them out of the zone of soft tissue balance and increase the chance of relapse.

- ***Mandibular Incisor Dimensions****:* Peck and Peck advocated reduction of mandibular incisors to a given faciolingual/mesiodistal ratio to increase stability (Kuftinec and Stom, 1975, Peck and Peck, 1972). Boese (1980) introduced the concept of lower incisor reproximation to provide broader contact points and increase the available arch space in the mandibular anterior region. Lower incisors with broader contacts and near parallel sides are thought to maintain their alignment more readily than triangular shaped incisors.
- ***Failure to Eliminate the Original Cause:*** Failure to remove the aetiology can result in relapse (Bhalajhi, 2009).
- ***Normal Decrease in Arch Dimension with Time:*** The normal developmental maturation process of decreasing arch dimensions inevitably results in crowding (Little et al., 1981).
- ***Bone Adaptation:*** Teeth that have been moved recently are surrounded by lightly calcified osteoid bone. Thus the teeth are not adequately stabilized and have a tendency to move to their original position. Only during the retention phase do they become stabilized (Bhalajhi, 2009).
- ***Unknown Factors***

2.5.4 Long-Term Retention Studies on Stability

Based on extensive research conducted at the University of Washington, Little and colleagues (1990) concluded that orthodontic results are more likely to be unstable than to be stable. For more than 35 years, research in the Department of Orthodontics at the University of Washington has focused on a growing collection of over 600 sets of patient records to assess stability and failure of orthodontic treatment.

All had completed treatment a decade or more prior to the last set of data. Evaluation of treated premolar extraction cases, treated non-extraction cases with generalized spacing, cases treated by arch enlargement strategies, and untreated normal occlusions demonstrate similar physiological changes:

a. Arch length reduces following orthodontic treatment, but also does so in untreated normal occlusions
b. Arch width measured across the mandibular canine teeth typically reduces post-treatment whether the case was expanded during treatment or not
c. Mandibular anterior crowding during the post-treatment phase is a continuing phenomenon well into the 20-40 age bracket and likely beyond
d. Third molar absence or presence, impacted or fully erupted, seems to have little effect on the occurrence or degree of relapse
e. The degree of post-retention anterior crowding is both unpredictable and variable and no pretreatment variables either from clinical findings, casts, or cephalometric radiographs before or after treatment seem to be useful predictors

In these authors' opinion, the only way to ensure continued satisfactory alignment after treatment would be to provide retention for life (Little, 1990).

2.5.5 Arch Perimeter and Intercanine Width

The main reason for a relapse of crowding is the tendency for dental arch perimeter or length and intercanine width to decrease and constrict over time (Rinchuse et al., 2007).

Mandibular intercuspid width:

Many authors have demonstrated the importance of avoiding an increase in "normal" mandibular intercuspid width (24-26 mm) during orthodontic treatment (Zachrisson, 1997). Gianelly (2003, cited in Rinchuse et al., 2007) and others have argued that the stability of orthodontic treatment can be improved by preserving mandibular intercanine width. This means that any increase in mandibular intercanine dimension is inherently unstable.

Mandibular archform:

Changes in mandibular archform during orthodontic treatment leads to relapse toward their original shape (Zachrisson, 1997). According to Franklin et al. (1995, cited in Zachrisson, 1997), sound treatment principles including maintenance of the original mandibular archform, is claimed to be essential in achieving satisfactory long-term stability. Ronay et al. (2008) found the WALA points to be a useful representation of the apical base, and helpful in the predetermination of an individualized dental arch form. Andrews and Andrews (2000, cited in Ronay et al., 2008) defined the WALA ridge as the most prominent point on the soft-tissue ridge immediately occlusal to the mucogingival junction. It is located at or nearly at the same vertical level as the horizontal center of rotation of each tooth.

Maxillary archform:

Although minimal alteration of archform may be important for stability, there are certain situations when maxillary archform should be purposely changed by orthodontic treatment. A good example is a patient with a Class II, division 1 malocclusion, in whom it may be necessary to coordinate the maxillary archform with the mandibular arch (Zachrisson, 1997).

2.5.6 Minimising Relapse

Stability starts with proper diagnosis (Vanarsdall, 1999). Atack and Sandy (2009) recommend the following measures in order to keep dental relapse to a minimum:

Pre-treatment:

- Consider extractions of very displaced/rotated teeth

During treatment:

- Maintain the existing arch form (except for certain exceptions e.g. Class II division 1 malocclusion where it may be necessary to coordinate the maxillary archform with the mandibular arch)
- Maintain the intercanine width
- Do not alter the antero-posterior position of the lower labial segment (teeth in position of equilibrium with "extrinsic" and "intrinsic" forces)
- Correct rotations early in treatment (and overcorrect if using the Begg technique) - carry out circumferential supracrestal fiberotomy (CSF) prior to debond
- Consider interproximal enamel reduction for triangular teeth to increase the area of interproximal contact
- Active retention for skeletal discrepancies throughout growth
- Labial frenectomy prior to debond produces scar tissue which minimises chances of diastema re-opening
- Obtain an adequate edge/centroid relationship
- Move upper incisors to within lower lip control
- Maximize interdigitation

Pre-debond:

- Carry out CSF
- Consider interproximal enamel reduction for triangular teeth to increase the area of interproximal contact
- Labial frenectomy prior to debond produces scar tissue which minimises chances of diastema re-opening

During retention

- Active retention for skeletal discrepancies throughout growth
- Bonded retainers

Recent preliminary studies on stability of the mandibular dental arch following periodontally accelerated osteogenic orthodontics (PAOO) therapy reported that the mandibular dental arch is more stable after

PAOO therapy in comparison to traditional orthodontics without PAOO therapy. Ferguson et al. (2014) found retrospectively that mandibular intercanine and inter-first-molar arch widths, while expanded during active orthodontic treatment, did not decrease following alveolar decortication and augmentation grafting during five years post-orthodontic treatment. The authors surmised that the remarkable stability following PAOO is due to substantial "memory" loss of periodontal tissues and increased cortical bone thickness due to alveolar augmentation (Ferguson et al., 2014). At the present time the credibility of their results must be questioned, however, because their study suffered from research design problems and this was a preliminary study only.

CHAPTER 3

MATERIALS AND METHODS

3.1 ETHICAL CONSIDERATIONS

Ethical clearance for conduction of the study was obtained from the Ethics committee of the University of Pretoria (Addendum I). The identity of all subjects whose records have been used for this investigation has not been disclosed and subjects will remain anonymous due to ethical concerns.

3.2 SAMPLE

General information of the subjects comprising the total sample, together with irregularity index values for each subject as well as their treatment duration may be viewed in Table 3.1. The sample for the study consisted of 31 nonextraction patients (19 females, 12 males) with a pretreatment mean age of 13 years 2 months, consecutively treated by a single private orthodontic practitioner that used both PSLS and CBS techniques in the treatment of patients between the period January 2009 and December 2013. The study material consisted of pre- and posttreatment dental casts of those 31 consecutively treated anonymous patients that were divided into two groups: 15 patients treated with PSLS (group 1), and 16 patients treated with CBS (group 2).

The inclusion criteria for the study were:

- Permanent dentition
- Non-extraction treatment
- Between ages 10,5 to 16 years old

- Eruption of all permanent teeth mesial to and including 1st permanent molar to first permanent molar in both maxillary and mandibular dental arches
- Irregularity index of 4 mm or more for the maxillary arch
- Irregularity index of at least 2 mm for the mandibular arch
- Treatment duration of at least 18 months

The exclusion criteria:

- Interproximal enamel reduction
- Spacing or diastemas
- Missing or extracted permanent teeth mesial to and/or including 1st permanent molar to first permanent molar in both maxillary and mandibular dental arches
- Malformed teeth e.g. peg-shape upper lateral incisors
- Presence of primary teeth
- Adjunctive therapeutic intervention involving lip bumpers, maxillary expansion appliances or headgear
- Previous first phase treatment

The plaster models, prepared from alginate impressions were taken at T0 (immediately before treatment) and at T1 (immediately after treatment) for both groups one and two.

Group 1 represented the 15 patients treated with the PSLS, Damon Q® (Ormco, Glendora, California, USA), 0,022" slot appliances. Only archwires prescribed for this particular PSLS were used during treatment. Archwire sizes used for this group were: 0,013" Damon® CuNiTi (copper nickel-titanium), 0,014" Damon® CuNiTi, 0,016" Damon® CuNiTi, 0,018" Damon® CuNiTi, 0,014" x 0,025" Damon® CuNiTi, 0,016" x 0,025" Damon® CuNiTi, 0,018" x 0,025" Damon® CuNiTi, and 0,019" x 0,025" Damon® SS (stainless steel) arch-wires.

Figure 3.1 depicts the shape of all the rectangular Damon® archwires used. The Damon® system only has one shape of archwire and does not make distinction between maxillary and mandibular archwires. They use the same archwire for either upper or lower jaw.

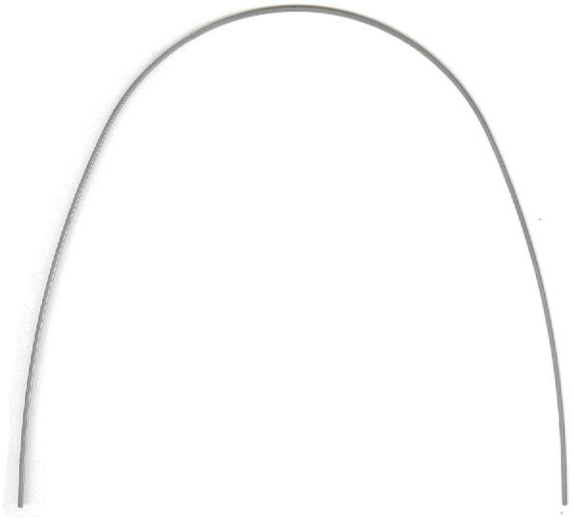


Figure 3.1: Shape of a 0,016" x 0,025" Damon® CuNiTi Arch-Wire

Group 2 represented the 16 patients treated with the CBS, UltiMIM® (Ortho Classic, McMinnville, Oregon), 0,018" slot appliances, Roth prescription. Conventional ligation and NiTi archwires (FlexArch Trueform® I archform, FlexMedics, Franklin, IN) were used during the treatment period for this group. Archwire sizes used for this group included: 0,014" NiTi (nickel-titanium), 0,016" NiTi, 0,016" x 0,022" NiTi, 0,017" x 0,025" NiTi, and 0,017" x 0,025" SS arch-wires.

Figure 3.2 depicts this shape for both upper (Fig 3.2 a) and lower (Fig 3.2 b) arch-wires.

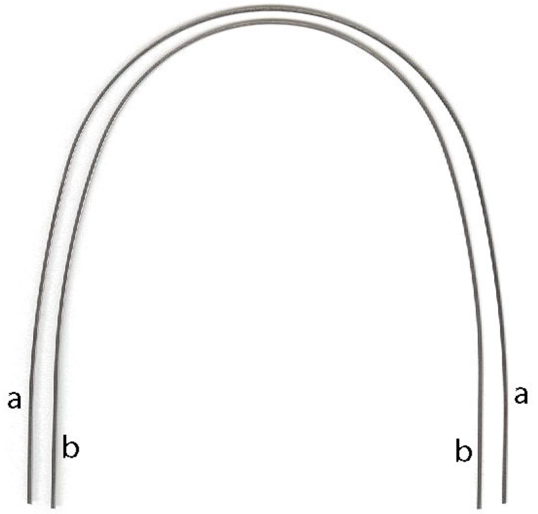


Figure 3.2: Shape of (a) an Upper 0,016" x 0,022" NiTi Arch-Wire, and (b) a Lower 0,016" x 0,022" NiTi Arch-Wire

The amount of crowding of the upper and lower anterior dentition were assessed using Little's irregularity index (1975). The irregularity index is not synonymous with crowding and arch length deficiency. The irregularity index measures displaced anatomic contact points (in millimeters) of the teeth from canine to canine, and give an objective value to subjective crowding of the case.

Table 3.1: General Information of the Study Sample (n = 31)

Subject number	Sex	Age at T0	Age at T1	Maxillary Irregularity Index (mm)	Mandibular Irregularity Index (mm)	Treatment Duration (months)
1	♀	15y1m	17y2m	10,35	4,18	25
2	♂	12y3m	14y10m	7,47	4,62	31
3	♀	10y11m	13y5m	10,72	4,33	30
4	♀	12y9m	15y2m	16,79	6,75	29
5	♂	13y4m	16y2m	9,11	6,67	34
6	♀	11y5m	13y8m	12,75	3,96	27
7	♂	12y1m	14y6m	9,02	5,35	29
8	♀	14y0m	15y10m	7,26	2,08	22

9	♀	13y5m	15y4m	11,92	10,84	23
10	♂	13y2m	15y4m	6,17	5,80	26
11	♂	13y8m	15y6m	6,66	4,68	22
12	♂	12y5m	14y6m	4,27	4,60	25
13	♀	13y11m	16y1m	5,58	7,89	26
14	♂	15y3m	17y9m	9,25	13,18	30
15	♀	13y0m	14y7m	4,09	5,57	19
16	♀	14y5m	16y3m	5,39	4,80	22
17	♂	12y4m	14y6m	5,98	3,07	26
18	♀	14y2m	16y1m	6,21	10,22	23
19	♀	14y8m	16y4m	8,20	5,10	20
20	♀	13y0m	15y7m	6,27	5,62	31
21	♂	11y10m	13y5m	8,11	5,47	19
22	♂	15y1m	16y11m	6,61	2,30	22
23	♀	13y6m	16y3m	4,22	6,23	33
24	♀	14y0m	16y2m	8,75	8,39	26
25	♀	12y8m	14y4m	8,32	8,85	20
26	♀	12y1m	13y10m	10,70	10,68	21
27	♂	12y8m	14y11m	14,02	5,84	27
28	♂	12y11m	14y8m	8,04	5,96	21
29	♀	13y3m	15y0m	4,57	2,86	21
30	♀	11y1m	12y8m	11,81	4,30	19
31	♀	12y5m	14y7m	7,60	4,19	26

Irregularity Index measured in millimeters (mm); Treatment Duration in months

The mean age for the sample at T0 was 13 years 2 months (158 months) with an age range of 10 years 11 months (131 months) to 15 years 3 months (183 months). The mean age for the study sample at T1 was 15 years 3 months (183 months) with a range of 12 years 8 months (152 months) to 17 years 9 months (213 months).

The treatment duration varied between 19 months and 34 months with a mean of 26,5 months.

The irregularity index for the maxillary anterior teeth varied between 4,09 mm and 16,79 mm, with an average of 8,26 mm. Irregularity index for the mandibular anterior teeth varied between 2,08 mm and 13,18 mm, with an average of 5,95 mm.

3.3 MEASUREMENT OF ARCH DIMENSIONS

All measurements except arch length measurement were made on the pre- and posttreatment casts at T0 and T1 by the same operator using a fine-tip Vernier digital caliper up to a hundredth of a millimeter (Figure 3.3).

The vernier digital caliper allows for very accurate measurement, and were also used to measure arch dimensions in studies conducted by Scott et al. (2008), Fleming et al. (2009), Tecco et al. (2009), Pandis et al. (2010), and many others.

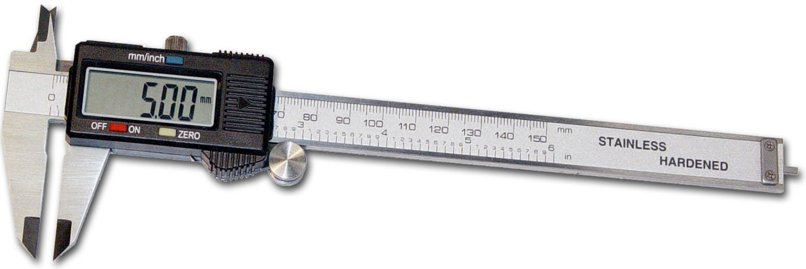


Figure 3.3: Vernier Digital Caliper

Arch length was measured on a photocopied image (scale 1:1) of the occlusal surfaces of the dental casts using the digital caliper. In order to attain standardization, dental casts were properly trimmed and then positioned so that the occlusal surfaces of the casts laid flat on the photocopier, having only the teeth making contact with the surface of the photocopier (no interferences). The occlusal plane was therefore parallel to the horizontal plane (or as close as possible in the presence of severe malocclusion). Even in the presence of severe malocclusion, however, the copied image of the occlusal surface was found to be reproducible. A 100 mm ruler was also included in the photocopy to assure a 1:1 ratio.

The following measurements were recorded for the maxillary arch (Fig 3.4):

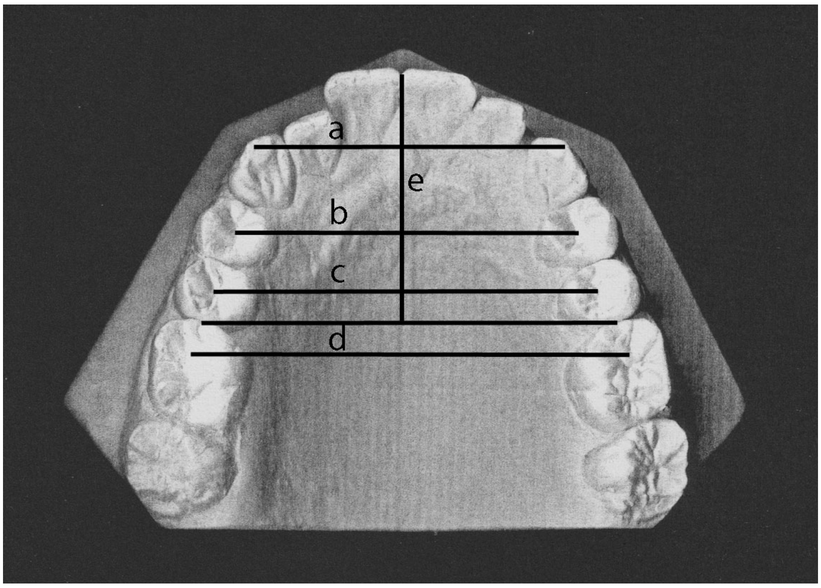


Figure 3.4: Measurements for the Maxillary Arch

- Maxillary intercanine (MxIC) width: the distance between the canine tips or between the centers of the surfaces in case of worn cusps (Fig 3.4 a)
- Maxillary first interpremolar (Mx1IPm) width: distance between the central fossae on the occlusal surfaces of the first premolars (Fig 3.4 b)
- Maxillary second interpremolar (Mx2IPm) width: distance between the central fossae on the occlusal surfaces of the second premolars (Fig 3.4 c)
- Maxillary intermolar (MxIM) width: distance between the mesial ends of the central fissures on the occlusal surfaces of the first molars (Fig 3.4 d)

- Maxillary arch length (MxA/L): distance from a line perpendicular to the tangent that connects the mesial aspects of the 1st permanent molars and the contact point between the central incisors (Fig 3.4 e)

The following measurements were recorded for the mandibular arch (Fig 3.5):

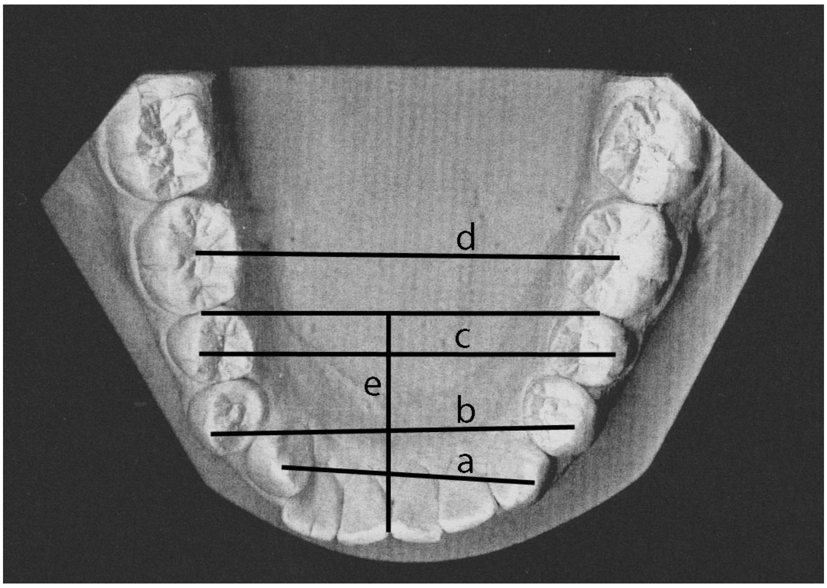


Figure 3.5: Measurements for the Mandibular Arch

- Mandibular intercanine (MdIC) width: the distance between the canine tips or between the centers of the surfaces in case of worn cusps (Fig 3.5 a)
- Mandibular first interpremolar (Md1IPm) width: distance between the tips of the buccal cusps or between the centers of the surfaces of first premolars in case of worn cusps (Fig 3.5 b)
- Mandibular second interpremolar (Md2IPm) width: distance between the tips of the buccal cusps or between the centers of the surfaces of second premolars in case of worn cusps (Fig 3.5 c)

- Mandibular intermolar (MdIM) width: distance between the central fossae on the occlusal surfaces of the first molars (Fig 3.5 d)
- Mandibular arch length (MdA/L): distance from a line perpendicular to the tangent that connects the mesial aspects of the 1st permanent molars and the contact point between the central incisors (Fig 3.5 e)

3.4 DATA ANALYSIS

Intra- and inter-operator repeatability was assessed for all ten measurements, for maxilla (intercanine width, first interpremolar width, second interpremolar width, intermolar width and arch length) and for mandible (intercanine width, first interpremolar width, second interpremolar width, intermolar width and arch length), using the intra-class correlation coefficient (ICC) and the limits of agreement from the Bland and Altman method.

The ten measurements for the PSLS and CBS groups were summarized by time (pre- and posttreatment) using mean and standard deviation. Within group comparisons between time points, with respect to each of the ten measurements, paired t-test was employed to assess whether change from pre- to posttreatment differed significantly from zero (Tables 4.2 and 4.3). Furthermore, group comparisons were done for change from pre- to posttreatment, with respect to each of the ten measurements, using analysis of covariance (ANCOVA) with pre-treatment values and covariates (Table 4.4).

The data for change of Mx2IPm slightly deviated from normality (normal probability plot). The reported result using a parametric ANCOVA was confirmed using a nonparametric ANCOVA. In fact the p-values differed in the third decimal only.

The percentage change from pre- to posttreatment is illustrated pictorially between groups for each of the ten measurements (Figure 4.7 and 4.8).

A composite table (4.5) with the results of Table 4.2, 4.3 and 4.4 was constructed to assist reading of discussion in chapter 5.

Testing was done at the 0,05 level of significance.

CHAPTER 4

RESULTS

4.1 INTRACLASS REPEATABILITY, INTERCLASS RELIABILITY AND BLAND & ALTMAN LIMITS OF AGREEMENT

In order to avoid interoperator error, a single operator carried out all measurements. The repeatability of the operator had to be tested in order to confirm a high correlation with the original measurements. This was achieved by having the same operator (intraclass) remeasure 10 randomly selected plaster models 12 weeks after the initial measurements were taken, and then compare those measurements to the original ones. To assess reliability of the measurements, another examiner (interclass) measured those same 10 plaster models. The reliability of the measurements was investigated, by comparing the second investigators measurements to the original ones. A high correlation is imperative before the data can be used for statistical analysis.

The Bland & Altman limits of agreement indicate the upper and lower end of the greatest difference measured in millimetres for each paramater/measurement. These were also found to be quite acceptable. The intraclass correlation (ICC) coefficient for intra- and interexaminer observer agreement, as well as the Bland & Altman limits of agreement are summarized in table 4.1.

A correlation coefficient of 1 indicate perfect correlation. As can be interpreted from table 4.1, the results from the repeatability and reliability tests confirmed that both the intraclass repeatability and the interclass reliability of all measurements were high. There was a high intra and interclass examiner correlation indicating that the accuracy of the measurements was acceptable for statistical inferences.

Table 4.1: Intraclass Correlation and Bland & Altman Limits of Agreement

Measurement	Observer Agreement	Intraclass Correlation	Bland & Altman Limits of Agreement
MxIC	Intra	0,9995	(-0,212 ; 0,064)
	Inter	0,9989	(-0,334 ; 0,234)
Mx1IPm	Intra	0,9965	(-0,444 ; 0,232)
	Inter	0,9937	(-0,474 ; 0,038)
Mx2IPm	Intra	0,9842	(-0,520 ; 0,412)
	Inter	0,9847	(-0,437 ; 0,045)
MxIM	Intra	0,9860	(-0,512 ; 0,556)
	Inter	0,9726	(-0,691 ; 0,787)
MxA/L	Intra	0,9923	(-0,827 ; 0,603)
	Inter	0,9973	(-0,293 ; 0,501)
MdIC	Intra	0,9502	(-0,312 ; 0,352)
	Inter	0,8783	(-0,540 ; 0,700)
Md1IPm	Intra	0,9961	(-0,329 ; 0,281)
	Inter	0,9783	(-0,812 ; 0,752)
Md2IPm	Intra	0,9901	(-0,589 ; 0,709)
	Inter	0,9785	(-0,599 ; 1,079)
MdIM	Intra	0,9912	(-0,270 ; 0,258)
	Inter	0,9680	(-0,486 ; 0,134)
MdA/L	Intra	0,9710	(-0,217 ; 0,965)
	Inter	0,9556	(-0,905 ; 1,329)

4.2 ARCH DIMENSION CHANGES FOR GROUP 1 (PSLS)

Measurements for Group 1 at T0 and T1 are summarized in table 4.2. On average, all measurements increased statistically significantly from T0 to T1 except for the maxillary arch length (MxA/L). This indicates significant expansion of almost all arch dimensions measured when comparing pre- with posttreatment change. The purple lines in figures 4.1 and 4.2 indicate the dimensions that showed significant increase.

Table 4.2: Mean (SD) for observed measurements, pre- to posttreatment within Group 1 (PSLS) and the test for change in outcome

Measurement	Mean (SD)			
	T0	T1	Δ_1	P
MxIC	34,96 (2,26)	36,71 (1,86)	1,75 (2,69)	0.025
Mx1IPm	34,26 (2,43)	39,05 (1,35)	4,79 (1,69)	<0,001
Mx2IPm	39,96 (3,41)	43,65 (1,67)	3,69 (2,41)	<0,001
MxIM	45,48 (2,75)	47,14 (2,45)	1,65 (1,21)	<0,001
MxA/L	27,63 (2,60)	28,29 (1,65)	0,66 (1,66)	0,144
MdIC	26,28 (2,17)	28,10 (1,24)	1,82 (2,07)	0,004
Md1IPm	33,26 (2,40)	37,01 (1,61)	3,75 (2,03)	<0,001
Md2IPm	38,52 (4,67)	42,62 (2,11)	4,10 (3,34)	<0,001
MdIM	41,07 (3,16)	43,25 (2,38)	2,18 (1,51)	<0,001
MdA/L	23,04 (1,77)	23,80 (1,56)	0,76 (1,26)	0,036

SD, standard deviation; Δ, difference; P, level of significance
All measurements made in mm (millimeters)

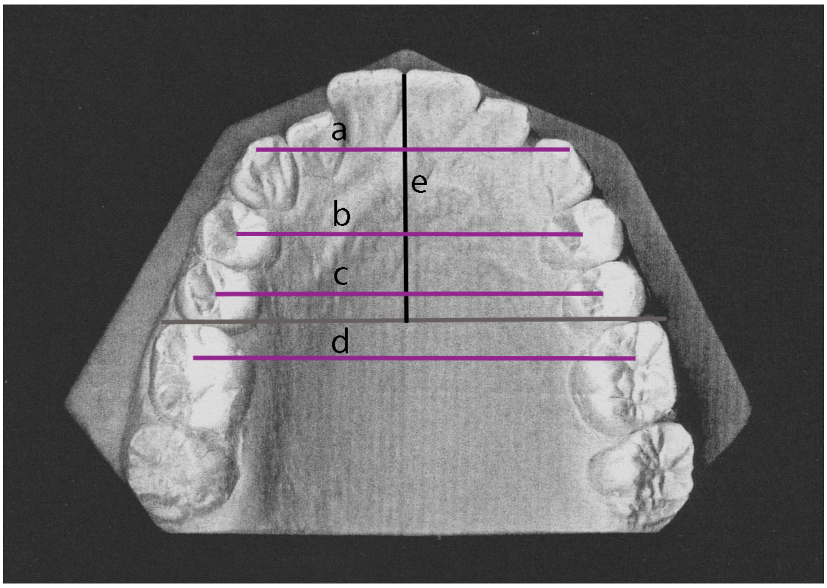


Figure 4.1: Maxillary Dimensions that showed Significant Increase for Group 1

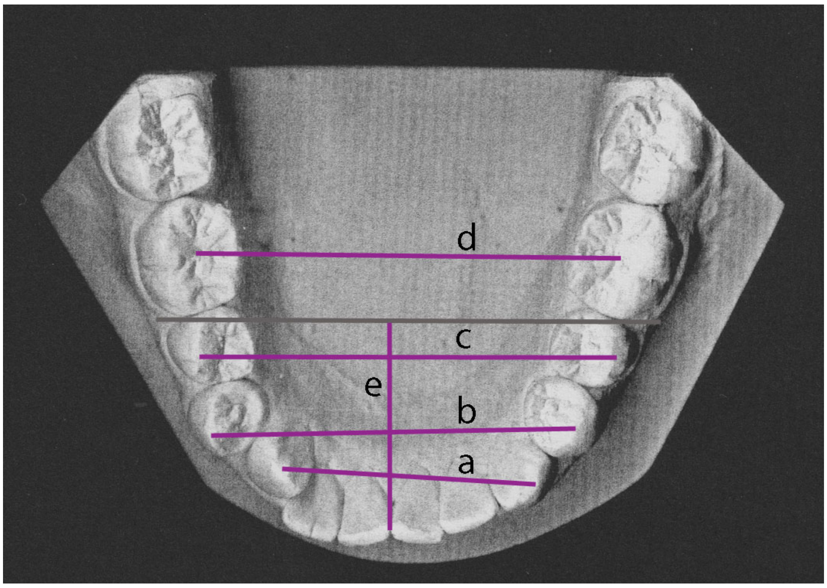


Figure 4.2: Mandibular Dimensions that showed Significant Increase for Group 1

From T0 to T1, the maxillary intercanine width showed a significant increase of 1,75 ± 2,69 mm (5%), while the mandibular intercanine width increased significantly by 1,82 ± 2,07 mm (6,9%).

The maxillary first interpremolar width increased significantly with 4,79 ± 1,69 mm (14%), whereas the mandibular first interpremolar width increased significantly with 3,75 ± 2,03 mm (11,3%).

Similarly, the second interpremolar width increased significantly by 3,69 ± 2,41 mm (9,2%), while in the mandibular arch it increased by 4,1 ± 3,34 mm (10,6%).

Maxillary- and mandibular intermolar widths showed significant increase of 1,65 ± 1,21 mm (3,6%) and 2,18 ± 1,51 mm (5,3%) respectively.

Maxillary arch length showed an increase of 0,66 ± 1,66 mm (2,4%), whereas mandibular arch length increased significantly by 0,76 ± 1,26 mm (3,3%).

Conclusion: All interarch dimensional changes of cases treated with the passive self-ligating system increased significantly except for maxillary arch length (MxA/L).

4.3 ARCH DIMENSION CHANGES FOR GROUP 2 (CBS)

Measurements for Group 2 at T0 and T1 are summarized in table 4.3. On average, all measurements increased statistically significantly from T0 to T1 except for the maxillary arch length (MxA/L) and mandibular arch length (MdA/L). Similarly to group 1, this indicates significant expansion of almost all arch dimensions measured when comparing pre- with posttreatment change. The blue lines in figures 4.3 and 4.4 indicate the dimensions that showed significant increase.

From T0 to T1, both maxillary- and mandibular intercanine widths showed similar percentage of increase of 5,6%. Maxillary intercanine width increased significantly with 1,9 ± 1,21 mm, while mandibular intercanine width increased significantly with 1,47 ± 26,14 mm.

The maxillary first interpremolar width increased significantly by 3,74 ± 1,31 mm (10,6%), where the mandibular first interpremolar width increased significantly by 3,15 ± 1,77 mm (9,4%).

Maxillary- and mandibular second interpremolar widths increased significantly by 2,2 ± 1,54 mm (5,4%) and 2,9 ± 2,3 mm (7,4%) respectively.

The maxillary intermolar width showed significant increase of 0,76 ± 1,25 mm (1,7%), while mandibular intermolar width increased significantly by 0,83 ± 1,31 mm (2%).

Maxillary arch length increased minimally by 0,05 ± 0,93 mm (0,2%), whereas mandibular arch length increased by a mere 0,43 ± 0,97 mm (1,9%).

Conclusion: All interarch dimensional changes of cases treated with the conventional bracket system increased significantly except for maxillary (MxA/L) and mandibular arch length (MdA/L).

Table 4.3: Mean (SD) for observed measurements, pre- to posttreatment within Group 2 (CBS) and the test for change in outcome

Measurement	Mean (SD)			
	T0	T1	Δ_2	P
MxIC	34,20 (2,01)	36,10 (1,53)	1,90 (1,21)	<0.001
Mx1IPm	35,16 (1,26)	38,90 (1,47)	3,74 (1,31)	<0,001
Mx2IPm	40,68 (1,78)	42,88 (1,64)	2,20 (1,54)	<0,001
MxIM	45,43 (2,15)	46,19 (2,06)	0,76 (1,25)	0,027
MxA/L	27,10 (1,65)	27,15 (1,28)	0,05 (0,93)	0,832
MdIC	26,14 (2,31)	27,61 (1,48)	1,47 (1,72)	0,004

Md1IPm	33,46 (1,99)	36,61 (1,25)	3,15 (1,77)	<0,001
Md2IPm	39,12 (2,47)	42,03 (1,90)	2,90 (2,30)	<0,001
MdIM	40,97 (2,31)	41,80 (2,49)	0,83 (1,31)	0,024
MdA/L	22,24 (1,52)	22,67 (1,17)	0,43 (0,97)	0,093

SD, stanSD, standard deviation; Δ, difference; P, level of significance
All measurements made in mm (millimeters)

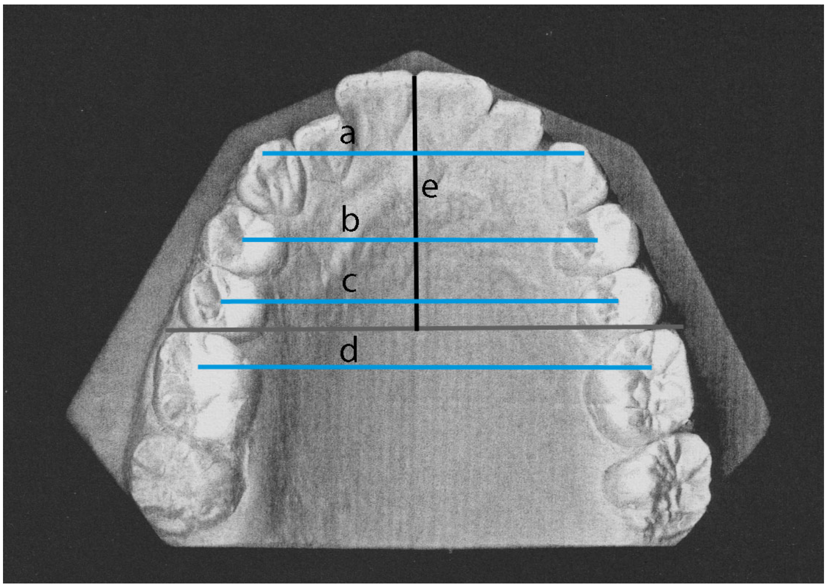


Figure 4.3: Maxillary Dimensions that showed Significant Increase for Group 2

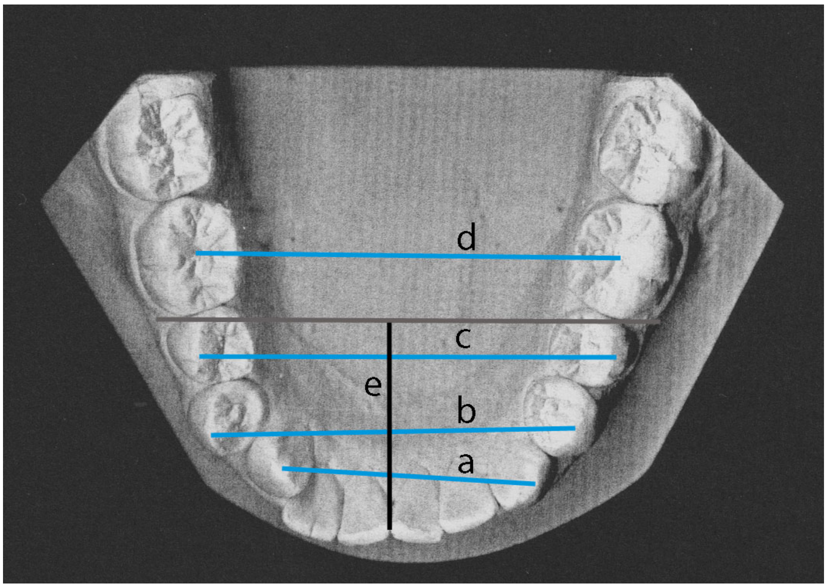


Figure 4.4: Mandibular Dimensions that showed Significant Increase for Group 2

4.4 INTERGROUP COMPARISONS FOR ARCH DIMENSION CHANGES

Arch dimension group comparisons are summarized in table 4.4. Both groups one and two showed increase in all the dimensions measured, however, group 1 (PSLS) showed significantly larger increases over group 2 (CBS) in terms of the following dimensions: maxillary second interpremolar width (Mx2IPm), maxillary intermolar width (MxIM), maxillary arch length (MxA/L), and mandibular intermolar width (MdIM). The red lines depicted in figures 4.5 and 4.6 indicate the arch dimensions that showed significant increase of group 1 over group 2 when comparing the two groups to each other.

Table 4.4: Group Comparison with Respect to Arch Dimension Change from Baseline

Measurement	Mean (SD)			
	Group 1 (PSLS)	Group 2 (CBS)	Δ_1 - Δ_2	P
MxIC	1,75 (2,69)	1,90 (1,21)	-0,15	0.548
Mx1IPm	4,79 (1,69)	3,74 (1,31)	1,05	0,182
Mx2IPm	3,69 (2,41)	2,20 (1,54)	1,49	0,027
MxIM	1,65 (1,21)	0,76 (1,25)	0,89	0,037
MxA/L	0,66 (1,66)	0,05 (0,93)	0,61	0,015
MdIC	1,82 (2,07)	1,47 (1,72)	0,34	0,308
Md1IPm	3,75 (2,03)	3,15 (1,77)	0,60	0,307
Md2IPm	4,10 (3,34)	2,90 (2,30)	1,19	0,161
MdIM	2,18 (1,51)	0,83 (1,31)	1,35	0,005
MdA/L	0,76 (1,26)	0,43 (0,97)	0,32	0,082

SD, standard deviation; Δ, difference; P, level of significance
All measurements made in mm (millimeters)

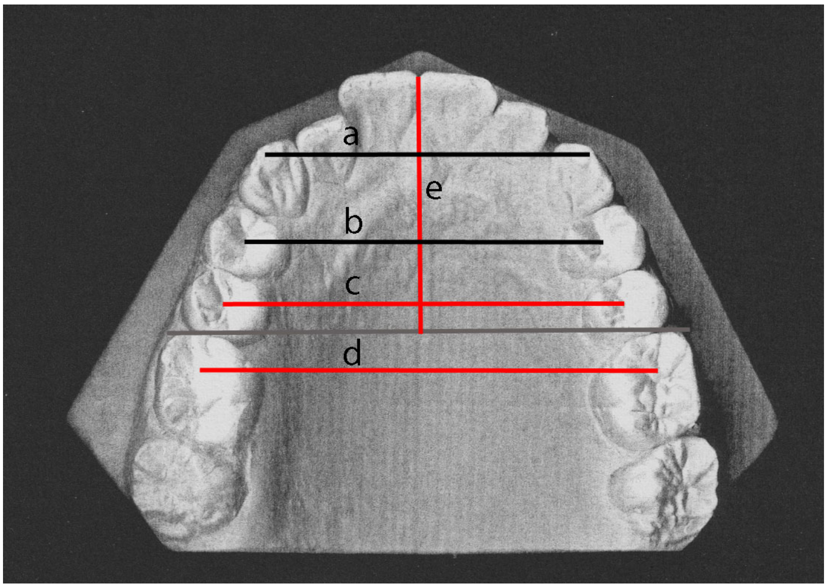


Figure 4.5: Maxillary Dimensions of Group 1 that showed Significantly Greater Increase than Group 2

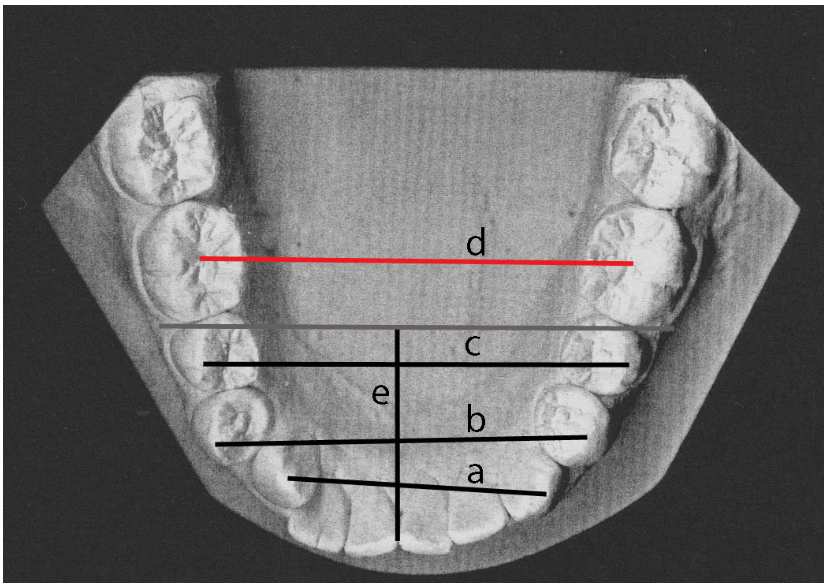


Figure 4.6: Mandibular Dimensions of Group 1 that showed Significantly Greater Increase than Group 2

Comparison between the two groups for percentage of increase for maxillary arch dimensions can be viewed in figure 4.7.

From T0 to T1, the maxillary intercanine width showed a significant increase of 1,75 ± 2,69 mm (5%) and 1,9 ± 1,21 mm (5,6%) in group 1 and group 2, respectively. The difference between the two groups was not significant (p = 0,55).

The maxillary first interpremolar width increased significantly by 4,79 ± 1,69 (14%) and 3,74 ± 1,31 mm (10,6%) in the first and second groups, respectively. The difference between the two groups was not significant (p = 0,18).

The maxillary second interpremolar width increased significantly by 3,69 ± 2,41 mm (9,2%) and 2,2 ± 1,54 mm (5,4%) in group 1 and group 2, respectively. In group 1 it increased statistically significantly more than in group 2 (p = 0,027).

The changes in maxillary intermolar width showed significant increases of 1,65 ± 1,21 (3,6%) and 0,76 ± 1,25 mm (1,7%) in the first and second groups, respectively. In group 1 it increased statistically significantly more than in group 2 (p = 0,037).

The changes in maxillary arch length were 0,66 ± 1,66 mm (2,4%) and 0,05 ± 0,93 mm (0,2%) for group 1 and group 2, respectively. The difference between the two groups was statistically significant (p = 0,015).

Comparison between the two groups for percentage of increase for mandibular arch dimensions can be viewed in figure 4.8.

From T0 to T1, the mandibular intercanine width showed a significant increase of 1,82 ± 2,07 mm (6,9%) and 1,47 ± 1,72 mm (5,6%) in group 1 and group 2, respectively. The difference between the two groups was not significant (p = 0,31).

The mandibular first interpremolar width increased significantly by 3,75 ± 2,03 (11,3%) and 3,15 ± 1,77 mm (9,4%) in the first and second groups, respectively. The difference between the two groups was not significant (p = 0,31).

The mandibular second interpremolar width increased significantly by 4,1 ± 3,34 mm (10,6%) and 2,9 ± 2,3 mm (7,4%) in group 1 and group 2, respectively. The difference between the two groups was not significant (p = 0,16).

The changes in mandibular intermolar width showed significant increases of 2,18 ± 1,51 (5,3%) and 0,83 ± 1,31 mm (2%) in the first and second groups, respectively. In group 1 it increased statistically significantly more than in group 2 (p = 0,005).

The changes in mandibular arch length were significant for group 1 that showed an increase of 0,76 ± 1,26 mm (3,3%), but not for group 2 that showed an increase of 0,43 ± 0,97 mm (1,9%). The difference between the two groups was not significant (p = 0,08).

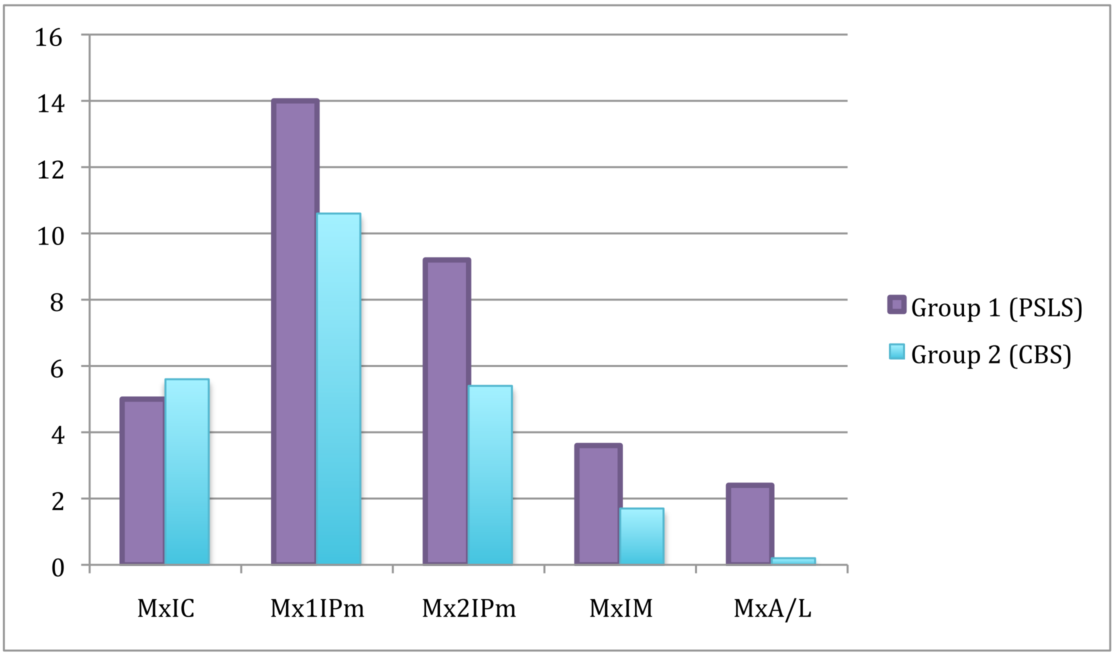


Figure 4.7: Comparison of maxillary arch dimension changes in terms of percentage increase from baseline for groups one and two

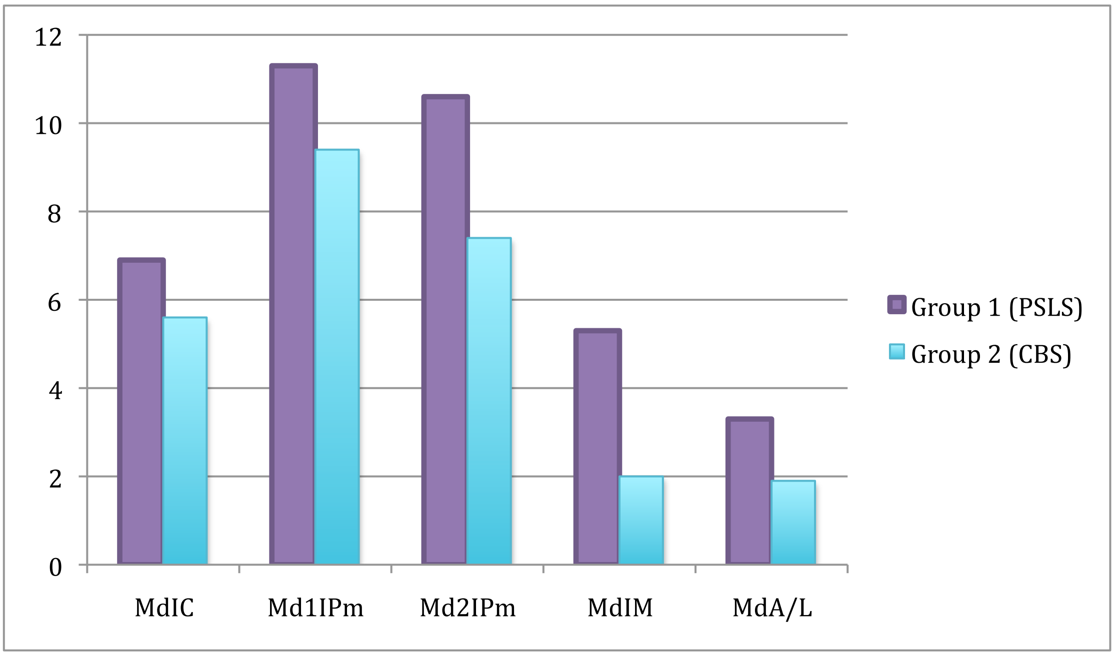


Figure 4.8: Comparison of mandibular arch dimension changes in terms of percentage increase from baseline for groups one and two

In conclusion, the interarch dimensional changes of cases treated with the passive self-ligating system were significantly larger than those cases treated with the conventional bracket system for the maxillary second interpremolar width (Mx2IPm), maxillary intermolar width (MxIM), maxillary arch length (MxA/L), and mandibular intermolar width (MdIM).

Table 4.5: Composite of Tables 4.2-4.3 Results

	Group 1 (PSLS)				Group 2 (CBS)				
	Mean (SD)				Mean (SD)				
Measurement	T0	T1	Δ_1	P-value^1	T0	T1	Δ_2	P-value^1	P-value^2
MxIC	34,96 (2,26)	36,71 (1,86)	1,75 (2,69)	0.025	34,2 (2,01)	36,10 (1,53)	1,90 (1,21)	<0.001	0.548
Mx1IPm	34,26 (2,43)	39,05 (1,35)	4,79 (1,69)	<0,001	35,16 (1,26)	38,90 (1,47)	3,74 (1,31)	<0,001	0,182
Mx2IPm	39,96 (3,41)	43,65 (1,67)	3,69 (2,41)	<0,001	40,68 (1,78)	42,88 (1,64)	2,20 (1,54)	<0,001	0,027
MxIM	45,48 (2,75)	47,14 (2,45)	1,65 (1,21)	<0,001	45,43 (2,15)	46,19 (2,06)	0,76 (1,25)	0,027	0,037
MxA/L	27,63 (2,60)	28,29 (1,65)	0,66 (1,66)	0,144	27,10 (1,65)	27,15 (1,28)	0,05 (0,93)	0,832	0,015
MdIC	26,28 (2,17)	28,10 (1,24)	1,82 (2,07)	0,004	26,14 (2,31)	27,61 (1,48)	1,47 (1,72)	0,004	0,308
Md1IPm	33,26 (2,40)	37,01 (1,61)	3,75 (2,03)	<0,001	33,46 (1,99)	36,61 (1,25)	3,15 (1,77)	<0,001	0,307
Md2IPm	38,52 (4,67)	42,62 (2,11)	4,10 (3,34)	<0,001	39,12 (2,47)	42,03 (1,90)	2,90 (2,30)	<0,001	0,161
MdIM	41,07 (3,16)	43,25 (2,38)	2,18 (1,51)	<0,001	40,97 (2,31)	41,80 (2,49)	0,83 (1,31)	0,024	0,005
MdA/L	23,04 (1,77)	23,80 (1,56)	0,76 (1,26)	0,036	22,24 (1,52)	22,67 (1,17)	0,43 (0,97)	0,093	0,082

SD, standard deviation; Δ, difference; P, level of significance; All measurements made in mm (millimeters)
1- Paired t-test p-value; 2- ANCOVA for changes in P-values

CHAPTER 5

DISCUSSION

The present study evaluated the transverse dimensions and arch lengths of both maxillary and mandibular dental arches induced by fixed passive self-ligating and traditional straight-wire appliances during orthodontic therapy.

It compared arch dimensional changes between 15 patients treated with a 0,022" slot PSLS (Damon Q® Ormco) and 16 patients treated with a 0,018" slot CBS (UltiMIM® Ortho Classic). The reason why a 0,022" slot system was compared to a 0,018" slot system was because we wanted to see how the two systems as a whole compared to each other (despite having different slot sizes), as each system utilizes different archwires, auxilliaries and treatment techniques. Even if a 0,022" slot CBS was compared to the 0,022" slot PSLS, any change between the two groups could still not be ascribed to the different types of brackets alone. There are too many other variables that would make standardization between the two groups impossible. In essence the PSLS and CBS groups constitute two different treatment techniques, and we wanted to compare the two techniques as a whole to each other. That is also why we preferred a single operator carrying out all the treatment (in order to eliminate inter-operator error).

All the available resources gathered for sample collection were depleted during data collection. Over 170 patients were evaluated for the study, however only 31 patients fitted the strict inclusion and exclusion criteria.

In nonextraction treatment protocols of a crowded dental arch without tooth size reduction, arch development is a therapeutic effect of fixed appliances (Kim and Gianelly, 2003, BeGole et al., 1998, Bishara et al., 1997, Paquette et al., 1992, Isik et al., 2005). To allow resolution of crowding and achievement of optimum arch alignment and leveling requires an increase in arch perimeter. Without active distal movement, one would expect to find both transverse expansion and proclination (Fleming et al., 2009, Weinberg and Sadowsky, 1996). These expected changes were confirmed for both groups in the study. All measured dimensions in PSLS and CBS groups increased from pre- to posttreatment. The first null hypothesis that stated no significant arch dimension changes from T0 to T1 within each group (H_01) was therefore rejected.

For the PSLS group, all the measured dimensions, except for the maxillary arch length (MxA/L), increased statistically significantly from T0 to T1. The MxA/L on average increased by only 0,66 ± 1,66 mm (2,4%).

The greatest increase took place in the premolar areas in both upper and lower jaws. The maxillary first (Mx1IPm) and maxillary second interpremolar (Mx2IPm) widths increased statistically significant by 4,79 ± 1,69 mm (14%) and 3,69 ±2,41 mm (9,2%) respectively, while the mandibular first (Md1IPm) and mandibular second interpremolar (Md2IPm) widths increased statistically significant by 3,75 ± 2,03 mm (11,3%) and 4,1 ± 3,34 mm (10,6%) respectively. These results compare favourably with those from the study by Tecco et al. (2009), Cattaneo et al. (2011), and Fleming et al. (2013) for the maxillary arch treated with passive self-ligating bracket system appliances.

Tecco et al. (2009) evaluated the transverse dimensions of the maxillary arch produced by fixed self-ligating and conventional bracket system appliances during orthodontic therapy. They also recorded the greatest expansion for the premolars (14,3% for Mx1IPm and 11,6% for Mx2IPm widths).

Similarly, Cattaneo et al. (2011) found that expansion was most pronounced in the premolar regions when assessing transversal maxillary tooth movements and dento-alveolar changes in patients treated with active and passive self-ligating brackets in a randomized clinical trial using cone beam computed tomography (CBCT). They found an increase of 11,5% for the Mx1IPm width and an increase of 9,4% for the Mx2IPm width.

The study by Fleming et al. (2013) again confirmed this finding in a randomized controlled trial where they compared maxillary arch dimensional changes with passive and active self-ligation and conventional brackets in the permanent dentition. They reported an increase of 11,8% for the Mx1IPm width and an increase of 8,8% for the Mx2IPm width.

The mandibular intercanine and mandibular intermolar widths in the PSLS group compared favourably with those of Pandis et al. (2011), who measured arch dimension changes for MdIC and MdIM widths using conventional and self-ligating appliances in a single-center randomized controlled trial. The self-ligating appliance used by Pandis et al. (2011) was the DamonMX® (Ormco, Glendora, Calif) appliance (also a PSLS). They found an increase of 5,46% for the MdIC width (compared to 5,6% in this study), and 4,27% for the MdIM width (compared to 5,3% found in this study). Unfortunately they didn't measure the interpremolar or MdA/L dimensions so that comparison was not possible for those dimensions.

Fleming et al. (2009) reported an increase of 3,3% for MdIC, 3,17% for MdIM, 2,15% for Md1IPm and 3,6% for Md2IPm widths, however, they used a different self-ligating appliance system (SmartClip® (3M Unitek, Monrovia, Calif)) than what was used in this study.

For the CBS group, all measured dimensions, except for the maxillary arch length (MxA/L) and mandibular arch length (MdA/L) increased statistically significantly from T0 to T1. The MxA/L on average increased by only 0,05 ± 0,93 mm (0,2%), whereas the MdA/L increased by a mere 0,43 ± 0,97 mm (1,9%). Similar to the PSLS group, the greatest increase took place at both maxillary and mandibular first interpremolar dimensions. The Mx1IPm width increased statistically significantly by 3,74 ± 1,31 mm (10,6%), while the Md1IPm width increased statistically significantly by 3,15 ± 1,77 mm (9,4%). Studies by Tecco et al. (2009), Franchi et al. (2006), and Fleming et al. (2013) also found the greatest increase to be in the first interpremolar dimension for the maxillary arch treated with conventional bracket system appliances. Franchi et al. (2006) used traditional straight-wire appliance with low-friction ligatures.

Tecco et al. (2009) reported an increase of 14,1% for Mx1IPm width, while Franchi et al. (2006) found the first interpremolar width to increase by 11,23%. Fleming et al. (2013) reported an increase of 9,5% for the Mx1IPm width.

Maxillary arch length in the study by Franchi et al. (2006) increased minimally by 2,32% and that correlates with the almost negligible increase of 0,2% in this study.

The mandibular arch dimension changes correlated favourably to the study by Fleming et al. (2009), however more expansion in the premolar areas were noted in the present study. Fleming et al. (2009) reported increases of 4,4% for both Md1IPm and Md2IPm dimensions, compared to the 9,4% and 7,4% increase for Md1IPm and Md2IPm dimensions, respectively. In their study, Fleming et al. (2009) used a different conventional bracket system (Victory®, 3M Unitek) than what was used in this study, with a different prescription (MBT) and a different slot size (0,022"), making use of two operators to treat the participants in their study (compared to a single operator used in the present study). Their arch-wire sequence used for all subjects were: 0,016" NiTi, 0,017" x 0,025" NiTi, 0,019" x 0,025" NiTi, and 0,019" x 0,025" SS. All arch-wires in their study were of uniform arch form, however, the shape of the archwires that were used was not disclosed. Any difference in shape of the arch-wires used between the two studies could contribute or be responsible for the difference in amount of Md1IPm and Md2IPm expansion. MdIC- and MdIM widths correlated with those found by Pandis et al. (2010). Pandis et al. (2010) investigated the effect of treatment of mandibular crowding with self-ligating and conventional brackets on dental arch variables. They reported a 7,2% increase for MdIC width (compared to 5,6% in this study) and 2,26% increase for MdIM width (compared to 2% in this study).

We feel it important to comment on the type of expansion achieved (e.g. dental vs. skeletal), since the Damon System® makes claims of arch development with Fränkel-like effects and generation of bone due to extremely light forces. The Damon PSLS claims to produce uniquely stable arch dimensional changes through arch development, whereby arch length gain is achieved through bodily movement of the teeth or at least with "minimal" tipping combined with alveolar bone and surrounding tissues reshaping with a Fränkel-like effect (Ormco, 2013b, Cattaneo et al., 2011, Fleming et al., 2013). Although it was beyond the scope of this study to examine the type of expansion achieved, we would like to refer to the literature to address the issue. There is currently no evidence in the literature to support such claims. Studies by Cattaneo et al. (2011) and Paventy (2009) refute these claims. In a randomized clinical trial, Cattaneo et al. (2011) assessed transversal tooth movements and buccal bone modeling of maxillary lateral segments achieved with active or passive self-ligating bracket systems, using CBCT-scans and digital models. Expansion of the dental arches was achieved through buccal tipping, and the claim regarding expansion without tipping was rejected. No or limited modeling of the bone buccal to the premolars was detected, and no transverse augmentation of basal bone was observed (Cattaneo et al., 2011). Paventy (2009) evaluated facial bone changes using CBCT after arch development using the Damon System in nonextraction treatment of moderate to severe crowding. He reported that the Damon System effectively expanded both dental arches. However, facial bone did not correspondingly adapt after arch development was completed. In fact, facial bone decreased significantly in height and width for nearly all teeth measured (Paventy, 2009).

After baseline correction (ANCOVA test), it was noted in the present study that from T0 to T1, the PSLS group showed statistically significantly more expansion in the following four arch dimensions in comparison to the CBS group: maxillary second interpremolar (Mx2IPm) width, maxillary intermolar (MxIM) width, maxillary arch length (MxA/L) and mandibular intermolar (MdIM) width. On average, the PSLS group showed 1,49 mm more expansion for the Mx2IPm width between pre- and posttreatment change. MxIM width increased on average by 0,89 mm more in the PSLS group than the CBS group, MxA/L 0,61 mm more, and MdIM width 1,35 mm more compared to the CBS group. The second null hypothesis that stated no significant difference in arch dimension changes between the PSLS and CBS groups ($H_0 2$) was therefore rejected.

Interestingly, the maxillary intercanine (MxIC) width was the only dimension that showed more expansion in the CBS group compared to the PSLS group, but only by a mere 0,15 mm. In all other dimensions, the PSLS group produced more expansion than the CBS group.

Comparing maxillary arch width changes during orthodontic treatment with fixed self-ligating and traditional straight-wire appliances, Tecco et al. (2009) reported significant increase in both groups from T0 to T1 for all transverse measurements (MxIC, Mx1IPm, Mx2IPm and MxIM widths), but no significant difference between groups (Tecco et al., 2009). They treated 40 consecutive patients with an age range of 14 to 30 years with either 0,022" slot Victory® Series MBT brackets (3M Unitek), or Damon-3MX® self-ligating appliance (Ormco) during the leveling and aligning phase (treatment duration of 1 year). The arch-wire sequence used with the MBT appliance was: 0,016" and 0,019" x 0,025" NiTi form II (3M Unitek), while in the Damon-3MX®, it was: 0,014" and 0,016" followed by 0,016" x 0,025" CuNiTi (Ormco).

Pandis et al. (2010) investigated mandibular dental arch changes associated with treatment of crowding using self-ligating and conventional brackets. They measured and compared intercanine and intermolar widths in each group to each other. Pandis et al. (2010) reported increase in intercanine and intermolar widths for both bracket groups, however, the self-ligating group showed a statistically significant greater intermolar width increase than the conventional group of 1,5 mm on average. This compares favourably to the results of the present study (1,35 mm more expansion for the PSLS group over the CBS group), as well as with the study by Fleming et al. (2009) that was mentioned earlier. Fleming et al. (2009) reported a statistically significant greater increase in mandibular intermolar width in the group treated with the self-ligating appliance (SmartClip®), although the difference was only 0,91 mm.

Pandis et al. (2011) conducted a single-center randomized controlled trial to compare mandibular intermolar- and intercanine widths between patients treated nonextraction with conventional and self-ligating appliances. Fifty patients were randomly assigned between conventional and passive self-ligating appliances. Their study's findings contradicted the results of a previous study by Pandis et al. (2007), that found the self-ligating group had greater molar widths. However, arch wire forms and sequences differed between the two studies. Pandis et al. (2011) reported no difference in intermolar- and intercanine width between the two bracket systems, and they concluded that the use of conventional or self-ligating brackets did not seem to affect mandibular intermolar or intercanine width.

The differences for arch dimension changes between the PSLS and CBS groups in the present study could be attributed to the archwires that were used for each group. Using preformed nickel titanium (NiTi) archwires at the leveling and aligning stages of mechanotherpy precludes absolute control of the operator over the dimensions of the dental arch (Pandis et al., 2010). In the present study, the respective arch-wire shapes for each group (depicted in Figure 5.1 below) were maintained throughout the duration of treatment. The Damon® wires used in the PSLS group had a broader archform compared with the NiTi archwires used in the CBS group. Figure 5.1 compares the shapes of the following archwires that were used in the study: (a) 0,016" x 0,025" Damon® CuNiTi (Used as Both Upper and Lower Arch-Wire in PSL Group), (b) 0,016" x 0,025" NiTi (Upper Arch-Wire in CBS Group), and (c) 0,016" x 0,025" NiTi (Lower Arch-Wire in CBS Group).

The differences in posterior expansion may be attributed (solely or in part) to the differences in archwire form and cross-sectional thickness.

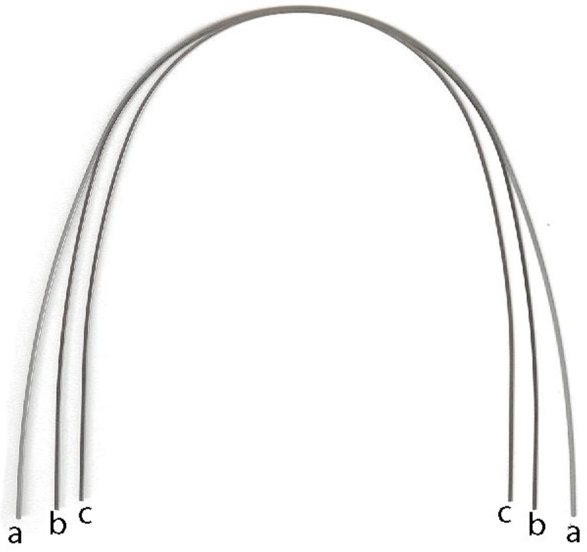


Figure 5.1: Comparison of Arch-Wire Shapes

In the multicenter, randomized controlled trial mentioned earlier by Fleming et al. (2013) who compared maxillary arch dimensional changes with passive and active self-ligation and conventional brackets in the permanent dentition, no differences in maxillary arch dimensional changes or molar and incisor inclination changes were found after alignment with passive self-ligating (DamonQ®), active self-ligating (In-OvationC®), or conventional brackets (Ovation®). These findings are in contrast with the findings of the present study that showed significantly more dental expansion in the PSLS group. The archwire sequence used in the Fleming et al. (2013) study, however, used a Damon wire sequence with all three of the bracket systems. The Damon arch-wire sequence comprised: 0,013" or 0,014" Damon®CuNiTi, 0,014" x 0,025" Damon®CuNiTi, 0,018" x 0,025" Damon®CuNiTi, and 0,019" x 0,025" Damon®SS arch-wires. All wires had Damon arch form and were uncoordinated to the original arch form or dimensions. The authors reported relatively large and similar dimensional increases for all three groups examined, which they believed to relate to the use of Damon arch-wires. Damon wires have a broad shape, particularly in the buccal segments, and could have contributed to the amount of expansion reported. To definitely prove this, however, would require further prospective research (Fleming et al., 2013).

With regard to the stability of treatment an important question is the implications of arch dimensional changes for long-term stability. The majority of evidence is supportive of the notion that indiscriminate transverse expansion, especially in the absence of any indication for using expansion (e.g. posterior crossbite), to accommodate dental width in a deficient arch length results in relapse, the extent of which depends on a number of factors potentially including the appliance and age of the patient (Pandis et al., 2010). Further, expansion of especially the intercanine width and excessive proclination of the mandibular incisors is known to be particularly unstable (Fleming et al., 2009, Little et al., 1988, Lundstrom, 1925, Strang, 1949, McCauley, 1944, Burke et al., 1998). In such cases relapse may occur from constriction of the expanded intercanine dimension and uprighting of the mandibular incisors posttreatment, and this will likely manifest as lower incisor irregularity (Little, 1990, Fleming et al., 2009). Therefore the implications for long-term stability of the arch dimension changes in the present study will depend on the nature and magnitude of those changes.

Pandis et al. (2010), states that the ideal scenario concerning arch dimensional changes in terms of relapse, would involve little incisor proclination and intercanine expansion, with most of the arch perimeter increase generated by expansion across the molars and premolars. Since most of the transverse expansion seen in the PSLS group occurred in the posterior areas in the present study, those teeth may therefore not be very prone to relapse. Even though the MxA/L in the PSLS group showed statistically significant increase over the CBS group, the increase was only 0,61 mm more in the PSLS group. This may not be clinically significant.

Without long-term follow-up studies of self-ligating systems, however, the implications of their use on long-term stability will remain largely unknown (Fleming et al., 2009).

CHAPTER 6

CONCLUSION

In a nonextraction approach to correct moderate/severe crowding, obtaining a correction is not the problem, but maintaining the corrected result is the challenge. Arch enlargement strategies are aimed at increasing the dental arch perimeter to allow resolution of crowding and achievement of optimum arch alignment and leveling. They include: active distalizing of posterior buccal segments, proclining of anterior teeth, and transversly widening of the dental arch (transverse expansion) (Little et al., 1990, Pandis et al., 2010, Franchi et al., 2006, Fleming et al., 2009). Without active distal movement, changes typically involve both transverse expansion and proclination of incisors (Fleming et al., 2009, Isik et al., 2005, Kim and Gianelly, 2003). This was confirmed in the present study with practically all measured dimensions increasing statistically significantly in both passive self-ligating and conventional appliance system groups. Null hypothesis ($H_0$1) stated that there are no significant arch dimension changes that occur after treatment with a 0,022" slot passive self-ligating system and a 0,018" slot conventional bracket system respectively. In light of the findings of this study, null hypothesis ($H_0$1) was rejected. Instead, an alternative hypothesis ($H_1$1), which states that there are significant arch dimension changes that occur after treatment with a 0,022" slot passive self-ligating system and a 0,018" slot conventional bracket system respectively, can be accepted.

There is enough evidence showing that increases in arch length and width during orthodontic treatment tend to return toward pretreatment values after retention (Shapiro, 1974, Johnson, 1977, Little et al., 1981, Steadman, 1961). Based on previous studies on relapse, it is generally agreed that postorthodontic occlusal stability is enhanced through maintenance of the original mandibular intercanine width and preservation of the original arch form (de la Cruz et al., 1995, Artun et al., 1996, Gardner and Chaconas, 1976, Shapiro, 1974).

The present study compared arch dimensional changes that occur during nonextraction fixed orthodontic therapy in both passive self-ligating and conventional appliance systems to each other. The results of this study showed that there is significantly more dental arch expansion with the passive self-ligating system than with the conventional bracket system.

The null hypothesis (H_02) stated that there is no significant difference in arch dimension changes between the PSLS and CBS groups. In the light of the findings of this study, null hypothesis (H_02) was rejected. Instead, an alternative hypothesis (H_12), which states that there is a significant difference in arch dimension changes between the PSLS and CBS groups, can be accepted.

Since overexpansion of dental arches are believed to be unstable and more prone to relapse, patients treated with a 0,022" slot passive self-ligating appliance system (particularly the appliance system used in the present study), may be more prone to relapse than patients treated with a 0,018" slot conventional appliance system.

Unfortunately, no long-term studies on stability of passive self-ligating appliance systems are available at the present time. Until then, their implications on long-term stability will remain largely unknown.

From the findings of this study and the study by Fleming et al. (2013) one can extrapolate that most of the arch dimensional changes that occurred was due to the shape of the arch-wires used, since the shape of the archwires generally corresponded to the pattern of expansion that was achieved. It seems that the brackets are merely handles of attachment for the arch-wires that makes all/most of the difference.

In light of the findings of the present study it may be recommended that the 0,022" slot passive self-ligating appliance system should not be used injudiciously in the treatment of all orthodontic cases, but rather be prudently applied in cases where dental arch expansion may be desired (e.g. case with pretreatment constricted arches). The prudent orthodontic practitioner will be careful to apply such an appliance in a crowded case with severe arch length/tooth size discrepancy where teeth are already proclined. Even though tooth extractions in orthodontics have decreased dramatically since the era of Tweed, extractions still have a rightful place in the treatment of some cases in orthodontics. However, it should be noted that the type of expansion achieved with the PSLS seems to be of a dental nature only.

Further studies comparing the same passive self-ligating appliance system that was used in the present study, to a 0,022" slot conventional appliance system may be worthwhile to investigate whether arch dimension changes during treatment follow a similar pattern to what was seen here. This could confirm the expansive nature of the passive self-ligating appliance system, and whether slot size has any effect on arch dimensional changes.

Furthermore, future studies to evaluate the degree of relapse are recommended.

LITERATURE REFERENCES

ADES, A. G., JOONDEPH, D. R., LITTLE, R. M. & CHAPKO, M. K. 1990. A long-term study of the relationship of third molars to changes in the mandibular dental arch. *Am J Orthod Dentofacial Orthop,* 97**,** 323-35.

AHN, J. S., PARK, M. S., CHA, H. S., SONG, H. C. & PARK, Y. S. 2012. Three-dimensional interpretation of intercanine width change in children: a 9-year longitudinal study. *Am J Orthod Dentofacial Orthop,* 142**,** 323-32.

AL YAMI, E. A., KUIJPERS-JAGTMAN, A. M. & VAN 'T HOF, M. A. 1999. Stability of orthodontic treatment outcome: follow-up until 10 years postretention. *Am J Orthod Dentofacial Orthop,* 115**,** 300-4.

ALPERN, M. C. 2008. Gaining Control with Self-Ligation. *Semin Orthod,* 14**,** 73-86.

ANDREWS, L. F. 1972. The six keys to normal occlusion. *Am J Orthod,* 62**,** 296-309.

ANDREWS, L. F. 1976. The straight-wire appliance, origin, controversy, commentary. *J Clin Orthod,* 10**,** 99-114.

ANDREWS, L. F. 1979. The straight-wire appliance. *Br J Orthod,* 6**,** 125-43.

ARTUN, J., GAROL, J. D. & LITTLE, R. M. 1996. Long-term stability of mandibular incisors following successful treatment of Class II, Division 1, malocclusions. *Angle Orthod,* 66**,** 229-38.

ATACK, N. & SANDY, J. 2009. *Postgraduate notes in orthodontics : DDS/MOrth programme,* Bristol, Division of Child Dental Health.

BEGG, P. R. 1956. Defferential Force in Orthodontic Treatment. *AJO,* 42**,** 481-510.

BEGOLE, E. A., FOX, D. L. & SADOWSKY, C. 1998. Analysis of change in arch form with premolar expansion. *Am J Orthod Dentofacial Orthop,* 113**,** 307-15.

BEGOLE, E. A. & SADOWSKY, C. 1999. Methodologies for evaluating long-term stability of dental relationships after orthodontic treatment. *Semin Orthod,* 5**,** 142-50.

BERGER, J. L. 2008. The SPEED System: An Overview of the Appliance and Clinical Performance. *Semin Orthod,* 14**,** 54-63.

BEUKES, S., DAWJEE, S. M. & HLONGWA, P. 2007. Facial profile perceptions in a group of South African blacks. *SADJ,* 62**,** 160, 162-7.

BHALAJHI, S. I. 2009. *Orthodontics: The Art and Science,* New Delhi, India, Arya MEDI Publishing House.

BIRNIE, D. 2008. The Damon Passive Self-Ligating Appliance System. *Semin Orthod,* 14**,** 19-35.

BISHARA, S. E. 2001. *Textbook of orthodontics,* Philadelphia ; London, Saunders.

BISHARA, S. E., CUMMINS, D. M. & ZAHER, A. R. 1997. Treatment and posttreatment changes in patients with Class II, Division 1 malocclusion after extraction and nonextraction treatment. *Am J Orthod Dentofacial Orthop,* 111**,** 18-27.

BLAKE, M. & BIBBY, K. 1998. Retention and stability: a review of the literature. *Am J Orthod Dentofacial Orthop,* 114**,** 299-306.

BOESE, L. R. 1980. Fiberotomy and reproximation without lower retention 9 years in retrospect: part II. *Angle Orthod,* 50**,** 169-78.

BONDEMARK, L., HOLM, A. K., HANSEN, K., AXELSSON, S., MOHLIN, B., BRATTSTROM, V., PAULIN, G. & PIETILA, T. 2007. Long-term stability of orthodontic treatment and patient satisfaction. A systematic review. *Angle Orthod,* 77**,** 181-91.

BURKE, S. P., SILVEIRA, A. M., GOLDSMITH, L. J., YANCEY, J. M., VAN STEWART, A. & SCARFE, W. C. 1998. A meta-analysis of mandibular intercanine width in treatment and postretention. *Angle Orthod,* 68**,** 53-60.

CATTANEO, P. M., TRECCANI, M., CARLSSON, K., THORGEIRSSON, T., MYRDA, A., CEVIDANES, L. H. & MELSEN, B. 2011. Transversal maxillary dento-alveolar changes in patients treated with active and passive self-ligating brackets: a randomized clinical trial using CBCT-scans and digital models. *Orthod Craniofac Res,* 14**,** 222-33.

CELAR, A., SCHEDLBERGER, M., DORFLER, P. & BERTL, M. 2013. Systematic review on self-ligating vs. conventional brackets: initial pain, number of visits, treatment time. *J Orofac Orthop,* 74**,** 40-51.

CHEN, S. S., GREENLEE, G. M., KIM, J. E., SMITH, C. L. & HUANG, G. J. 2010. Systematic review of self-ligating brackets. *Am J Orthod Dentofacial Orthop,* 137**,** 726 e1-726 e18; discussion 726-7.

COBOURNE, M. T. & DIBIASE, A. T. 2010. *Handbook of orthodontics,* Edinburgh, Mosby.

CROSS, J. J. 1996. The Tweed Philosophy: The Tweed Years. *Semin Orthod,* 2**,** 231-236.

DE LA CRUZ, A., SAMPSON, P., LITTLE, R. M., ARTUN, J. & SHAPIRO, P. A. 1995. Long-term changes in arch form after orthodontic treatment and retention. *Am J Orthod Dentofacial Orthop,* 107**,** 518-30.

FERGUSON, D. J., MAKKI, L., STAPELBERG, R., WILCKO, M. T. & WILCKO, W. M. 2014. Stability of the mandibular dental arch following periodontally accelerated osteogenic orthodontics therapy: preliminary studies. *Semin Orthod,* 20**,** 239-246.

FLEMING, P. S., DIBIASE, A. T., SARRI, G. & LEE, R. T. 2009. Comparison of mandibular arch changes during alignment and leveling with 2 preadjusted edgewise appliances. *Am J Orthod Dentofacial Orthop,* 136**,** 340-7.

FLEMING, P. S., LEE, R. T., MARINHO, V. & JOHAL, A. 2013. Comparison of maxillary arch dimensional changes with passive and active self-ligation and conventional brackets in the permanent dentition: a multicenter, randomized controlled trial. *Am J Orthod Dentofacial Orthop,* 144**,** 185-93.

FLEMING, P. S. & O'BRIEN, K. 2013. Self-ligating brackets do not increase treatment efficiency. *Am J Orthod Dentofacial Orthop,* 143**,** 11-9.

FRANCHI, L., BACCETTI, T., CAMPORESI, M. & LUPOLI, M. 2006. Maxillary arch changes during leveling and aligning with fixed appliances and low-friction ligatures. *Am J Orthod Dentofacial Orthop,* 130**,** 88-91.

GARDNER, S. D. & CHACONAS, S. J. 1976. Posttreatment and postretention changes following orthodontic therapy. *Angle Orthod,* 46**,** 151-61.

GERON, S. 2008. Self-Ligating Brackets in Lingual Orthodontics. *Semin Orthod,* 14**,** 64-72.

GRABER, T. M., VANARSDALL, R. L. & VIG, K. W. L. 2005. *Orthodontics : current principles and techniques,* St. Louis, Mo. ; [London], Elsevier Mosby.

GRABER, T. M., VANARSDALL, R. L. & VIG, K. W. L. 2012. *Orthodontics : current principles and techniques,* St. Louis, Mosby. ; [London], Elsevier Mosby.

HARRADINE, N. 2013. Self-ligating brackets increase treatment efficiency. *Am J Orthod Dentofacial Orthop,* 143**,** 10-8, 11-9.

HARRADINE, N. W. 2001. Self-ligating brackets and treatment efficiency. *Clin Orthod Res,* 4**,** 220-7.

HARRADINE, N. W. 2003. Self-ligating brackets: where are we now? *J Orthod,* 30**,** 262-73.

HARRADINE, N. W. 2008. The History and Development of Self-Ligating Brackets. *Semin Orthod,* 14**,** 5-18.

ISIK, F., SAYINSU, K., NALBANTGIL, D. & ARUN, T. 2005. A comparative study of dental arch widths: extraction and non-extraction treatment. *Eur J Orthod,* 27**,** 585-9.

JOHNSON, K. C. 1977. Cases six years postretention. *Angle Orthod,* 47**,** 210-21.

KHARBANDA, O. P. 2009. *Orthodontics: Diagnosis and Management of Malocclusion and Dentofacial Deformities,* India, Elsevier.

KIM, E. & GIANELLY, A. A. 2003. Extraction vs nonextraction: arch widths and smile esthetics. *Angle Orthod,* 73**,** 354-8.

KUFTINEC, M. M. & STOM, D. 1975. Effect of edgewise treatment and retention on manidbular incisors. *Am J Orthod,* 68**,** 316-22.

KUSY, R. P. 2002. Orthodontic biomaterials: from the past to the present. *Angle Orthod,* 72**,** 501-12.

KUSY, R. P. & WHITLEY, J. Q. 1997. Friction Between Different Wire-Bracket Configurations and Materials. *Semin Orthod,* 3**,** 166-177.

LEE, R. T. 1999. Arch width and form: a review. *Am J Orthod Dentofacial Orthop,* 115**,** 305-13.

LITTLE, R. M. 1975. The irregularity index: a quantitative score of mandibular anterior alignment. *Am J Orthod,* 68**,** 554-63.

LITTLE, R. M. 1990. Stability and relapse of dental arch alignment. *Br J Orthod,* 17**,** 235-41.

LITTLE, R. M., RIEDEL, R. A. & ARTUN, J. 1988. An evaluation of changes in mandibular anterior alignment from 10 to 20 years postretention. *Am J Orthod Dentofacial Orthop,* 93**,** 423-8.

LITTLE, R. M., RIEDEL, R. A. & STEIN, A. 1990. Mandibular arch length increase during the mixed dentition: postretention evaluation of stability and relapse. *Am J Orthod Dentofacial Orthop,* 97**,** 393-404.

LITTLE, R. M., WALLEN, T. R. & RIEDEL, R. A. 1981. Stability and relapse of mandibular anterior alignment-first premolar extraction cases treated by traditional edgewise orthodontics. *Am J Orthod,* 80**,** 349-65.

LITTLEWOOD, S. J., MILLETT, D. T., DOUBLEDAY, B., BEARN, D. R. & WORTHINGTON, H. V. 2006. Orthodontic retention: a systematic review. *J Orthod,* 33**,** 205-12.

LUNDSTROM, A. 1925. Malocclusion of the teeth regarded as a problem in connection with the apical base. *Int J Orthod Oral Surg Radiogr,* XI**,** 591-602.

MAVREAS, D. 2008. Self-Ligation and the Periodontally Compromised Patient: A Different Perspective. *Semin Orthod,* 14**,** 36-45.

MCCAULEY, D. R. 1944. The Cuspid and its Function in Retention. *Am J Orthod Oral Surg,* 30**,** 196-205.

MCLAUGHLIN, R. P. & BENNETT, J. C. 1989. The transition from standard edgewise to preadjusted appliance systems. *J Clin Orthod,* 23**,** 142-53.

MIHALIK, C. A., PROFFIT, W. R. & PHILLIPS, C. 2003. Long-term follow-up of Class II adults treated with orthodontic camouflage: a comparison with orthognathic surgery outcomes. *Am J Orthod Dentofacial Orthop,* 123**,** 266-78.

MOYERS, R. E., MOYERS, R. E. H. O. O. F. T. S. & GENERAL, P. 1988. *Handbook of orthodontics*, Year Book Medical Publishers.

MYSER, S. A., CAMPBELL, P. M., BOLEY, J. & BUSCHANG, P. H. 2013. Long-term stability: postretention changes of the mandibular anterior teeth. *Am J Orthod Dentofacial Orthop,* 144**,** 420-9.

NOJIMA, K., MCLAUGHLIN, R. P., ISSHIKI, Y. & SINCLAIR, P. M. 2001. A comparative study of Caucasian and Japanese mandibular clinical arch forms. *Angle Orthod,* 71**,** 195-200.

ONG, E., MCCALLUM, H., GRIFFIN, M. P. & HO, C. 2010. Efficiency of self-ligating vs conventionally ligated brackets during initial alignment. *Am J Orthod Dentofacial Orthop,* 138**,** 138 e1-7; discussion 138-9.

ORMCO. 2013a. *DAMON GLOSSARY* [Online]. California, USA: Ormco. Available: http://www.ormco.com/products/damon/education/damon-glossary.php [Accessed 2013].

ORMCO. 2013b. *Damon System* [Online]. Available: http://www.ormco.com/products/damon/index.php [Accessed March 2013].

PANDIS, N., POLYCHRONOPOULOU, A. & ELIADES, T. 2007. Self-ligating vs conventional brackets in the treatment of mandibular crowding: a prospective clinical trial of treatment duration and dental effects. *Am J Orthod Dentofacial Orthop,* 132**,** 208-15.

PANDIS, N., POLYCHRONOPOULOU, A., KATSAROS, C. & ELIADES, T. 2011. Comparative assessment of conventional and self-ligating appliances on the effect of mandibular intermolar distance in adolescent nonextraction patients: a single-center randomized controlled trial. *Am J Orthod Dentofacial Orthop,* 140**,** e99-e105.

PANDIS, N., POLYCHRONOPOULOU, A., MAKOU, M. & ELIADES, T. 2010. Mandibular dental arch changes associated with treatment of crowding using self-ligating and conventional brackets. *Eur J Orthod,* 32**,** 248-53.

PAQUETTE, D. E., BEATTIE, J. R. & JOHNSTON, L. E., JR. 1992. A long-term comparison of nonextraction and premolar extraction edgewise therapy in "borderline" Class II patients. *Am J Orthod Dentofacial Orthop,* 102**,** 1-14.

PAVENTY, A. 2009. Nonextraction treatment using the Damon System: a CBCT evaluation [master's thesis]. Norman, OK:. *University of Aklahoma*.

PECK, S. 2012. The Current Fashion of Nonextraction Dental Arch Expansion in Orhtodontics: A Critique. *Semin Orthod,* 18**,** 126-127.

PECK, S. & PECK, H. 1972. Crown dimensions and mandibular incisor alignment. *Angle Orthod,* 42**,** 148-53.

PROFFIT, W. R. 2013. *Contemporary orthodontics,* St. Louis, Mo., Elsevier/Mosby.

PROFFIT, W. R. & FIELDS, H. W. 2013. *Contemporary orthodontics,* St. Louis, Mo. ; London, Mosby.

PROFFIT, W. R., FIELDS, H. W. & SARVER, D. M. 2007. *Contemporary orthodontics,* St Louis, Mo. ; Edinburgh, Mosby/Elsevier.

RICHARDSON, M. E. 1999. A review of changes in lower arch alignment from seven to fifty years. *Semin Orthod,* 5**,** 151-9.

RINCHUSE, D. J., MILES, P. G. & SHERIDAN, J. J. 2007. Orthodontic retention and stability: a clinical perspective. *J Clin Orthod,* 41**,** 125-32.

RONAY, V., MINER, R. M., WILL, L. A. & ARAI, K. 2008. Mandibular arch form: the relationship between dental and basal anatomy. *Am J Orthod Dentofacial Orthop,* 134**,** 430-8.

ROSSOUW, P. E. 1999. Terminology: semantics of postorthodontic treatment changes in the dentition. *Semin Orthod,* 5**,** 138-41.

ROTH, R. H. 1976. Five year clinical evaluation of the Andrews straight-wire appliance. *J Clin Orthod,* 10**,** 836-50.

ROTH, R. H. 1987. The straight-wire appliance 17 years later. *J Clin Orthod,* 21**,** 632-42.

SCOTT, P., DIBIASE, A. T., SHERRIFF, M. & COBOURNE, M. T. 2008. Alignment efficiency of Damon3 self-ligating and conventional orthodontic bracket systems: a randomized clinical trial. *Am J Orthod Dentofacial Orthop,* 134**,** 470 e1-8.

SHAPIRO, P. A. 1974. Mandibular dental arch form and dimension. Treatment and postretention changes. *Am J Orthod,* 66**,** 58-70.

SHIVAPUJA, P. K. & BERGER, J. 1994. A comparative study of conventional ligation and self-ligation bracket systems. *Am J Orthod Dentofacial Orthop,* 106**,** 472-80.

STEADMAN, S. R. 1961. Changes of intermolar and intercuspid distances following orthodontic treatment. *Angle Orthod,* 31**,** 207-15.

STRANG, R. H. W. 1949. The Fallacy of Denture Expansion As a Treatment Procedure. *Angle Orthod,* 19**,** 12-22.

TAMIZHARASI & KUMAR, S. 2010. Evolution of Orthodontic Brackets. *JIADS,* 1**,** 25-30.

TECCO, S., TETE, S., PERILLO, L., CHIMENTI, C. & FESTA, F. 2009. Maxillary arch width changes during orthodontic treatment with fixed self-ligating and traditional straight-wire appliances. *World J Orthod,* 10**,** 290-4.

TREVISI, H. & BERGSTRAND, F. 2008. The SmartClip Self-Ligating Appliance System. *Semin Orthod,* 14**,** 87-100.

TWEED, C. 1941. The Application of the Principles of the Edgewise Arch in the treatment of Malocclusions: II. *Angle Orthodontist,* 11**,** 12-67.

VALANT, J. R. 2008. Time: A Self-Ligating Interactive Bracket System. *Semin Orthod,* 14**,** 46-53.

VANARSDALL, R. L., JR. 1999. Transverse dimension and long-term stability. *Semin Orthod,* 5**,** 171-80.

WAHL, N. 2005a. Orthodontics in 3 millennia. Chapter 5: the American Board of Orthodontics, Albert Ketcham, and early 20th-century appliances. *Am J Orthod Dentofacial Orthop,* 128**,** 535-40.

WAHL, N. 2005b. Orthodontics in 3 millennia. Chapter 6: More early 20th-century appliances and the extraction controversy. *Am J Orthod Dentofacial Orthop,* 128**,** 795-800.

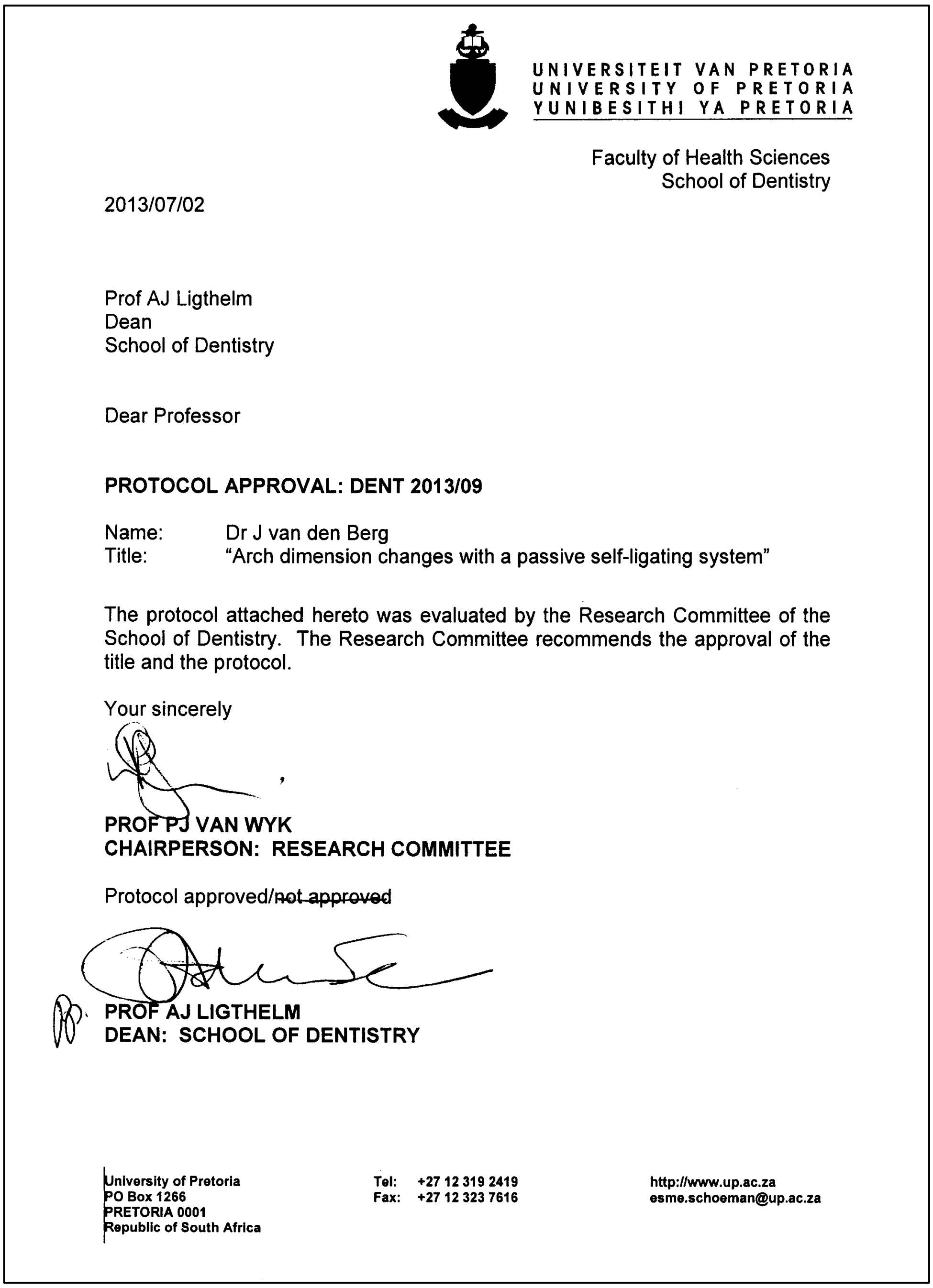
WAHL, N. 2008. Orthodontics in 3 millennia. Chapter 16: Late 20th-century fixed appliances. *Am J Orthod Dentofacial Orthop,* 134**,** 827-30.

WEINBERG, M. & SADOWSKY, C. 1996. Resolution of mandibular arch crowding in growing patients with Class I malocclusions treated nonextraction. *Am J Orthod Dentofacial Orthop,* 110**,** 359-64.

ZACHRISSON, B. U. 1997. Important aspects of long-term stability. *J Clin Orthod,* 31**,** 562-83.

ADDENDUM A

PROTOCOL APPROVAL LETTER FROM THE RESEARCH COMMITTEE OF THE FACULTY OF HEALTH SCIENCES, SCHOOL OF DENTISTRY, UNIVERSITY OF PRETORIA



UNIVERSITEIT VAN PRETORIA
UNIVERSITY OF PRETORIA
YUNIBESITHI YA PRETORIA

Faculty of Health Sciences
School of Dentistry

2013/07/02

Prof AJ Ligthelm
Dean
School of Dentistry

Dear Professor

PROTOCOL APPROVAL: DENT 2013/09

Name: Dr J van den Berg
Title: "Arch dimension changes with a passive self-ligating system"

The protocol attached hereto was evaluated by the Research Committee of the School of Dentistry. The Research Committee recommends the approval of the title and the protocol.

Your sincerely

PROF PJ VAN WYK
CHAIRPERSON: RESEARCH COMMITTEE

Protocol approved/~~not approved~~

PROF AJ LIGTHELM
DEAN: SCHOOL OF DENTISTRY

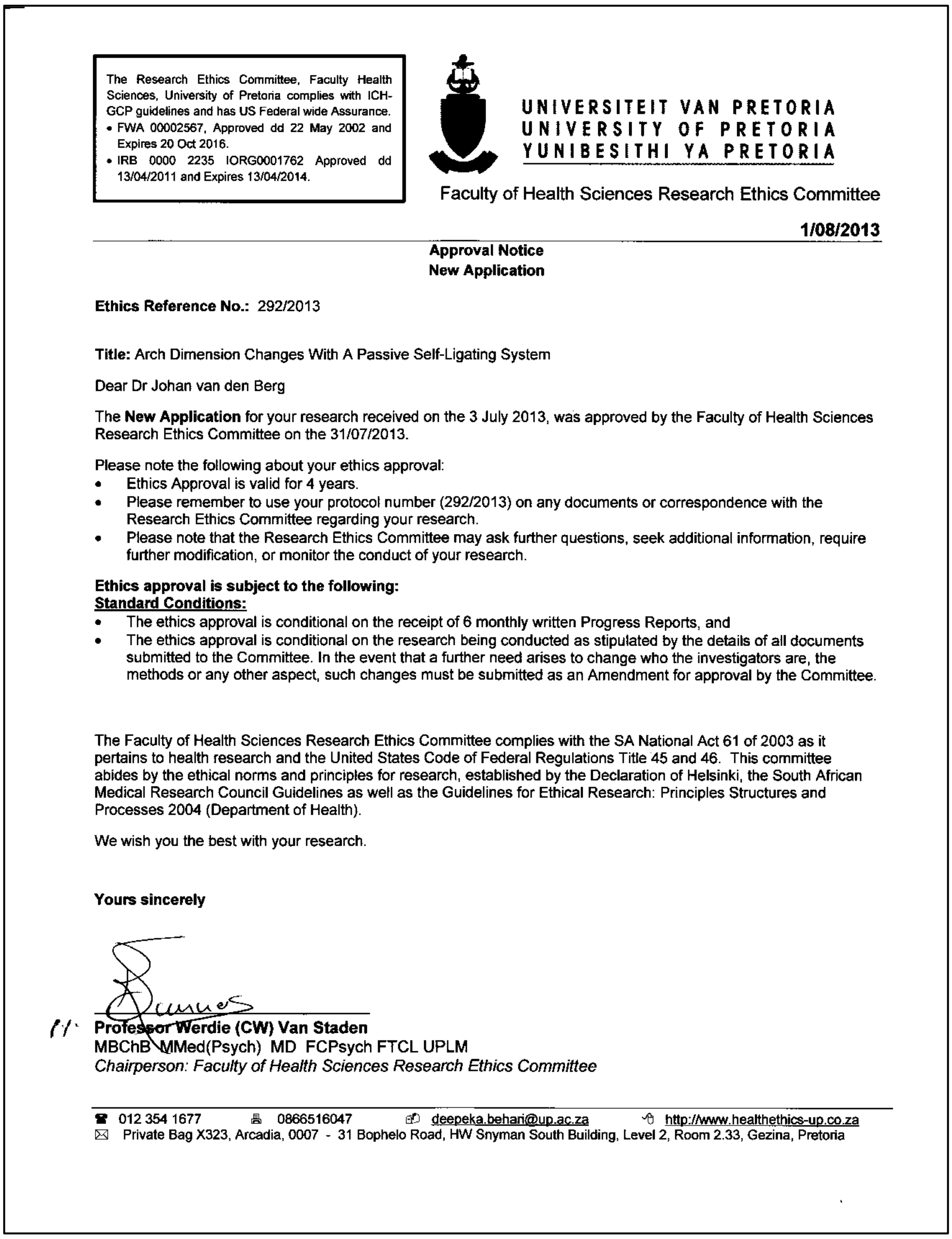
University of Pretoria
PO Box 1266
PRETORIA 0001
Republic of South Africa

Tel: +27 12 319 2419
Fax: +27 12 323 7616

http://www.up.ac.za
esme.schoeman@up.ac.za

ADDENDUM B

PROTOCOL APPROVAL LETTER FROM THE FACULTY OF HEALTH SCIENCES RESEARCH ETHICS COMMITTEE



The Research Ethics Committee, Faculty Health Sciences, University of Pretoria complies with ICH-GCP guidelines and has US Federal wide Assurance.
- FWA 00002567, Approved dd 22 May 2002 and Expires 20 Oct 2016.
- IRB 0000 2235 IORG0001762 Approved dd 13/04/2011 and Expires 13/04/2014.

UNIVERSITEIT VAN PRETORIA
UNIVERSITY OF PRETORIA
YUNIBESITHI YA PRETORIA

Faculty of Health Sciences Research Ethics Committee

1/08/2013

Approval Notice
New Application

Ethics Reference No.: 292/2013

Title: Arch Dimension Changes With A Passive Self-Ligating System

Dear Dr Johan van den Berg

The **New Application** for your research received on the 3 July 2013, was approved by the Faculty of Health Sciences Research Ethics Committee on the 31/07/2013.

Please note the following about your ethics approval:
- Ethics Approval is valid for 4 years.
- Please remember to use your protocol number (292/2013) on any documents or correspondence with the Research Ethics Committee regarding your research.
- Please note that the Research Ethics Committee may ask further questions, seek additional information, require further modification, or monitor the conduct of your research.

Ethics approval is subject to the following:
Standard Conditions:
- The ethics approval is conditional on the receipt of 6 monthly written Progress Reports, and
- The ethics approval is conditional on the research being conducted as stipulated by the details of all documents submitted to the Committee. In the event that a further need arises to change who the investigators are, the methods or any other aspect, such changes must be submitted as an Amendment for approval by the Committee.

The Faculty of Health Sciences Research Ethics Committee complies with the SA National Act 61 of 2003 as it pertains to health research and the United States Code of Federal Regulations Title 45 and 46. This committee abides by the ethical norms and principles for research, established by the Declaration of Helsinki, the South African Medical Research Council Guidelines as well as the Guidelines for Ethical Research: Principles Structures and Processes 2004 (Department of Health).

We wish you the best with your research.

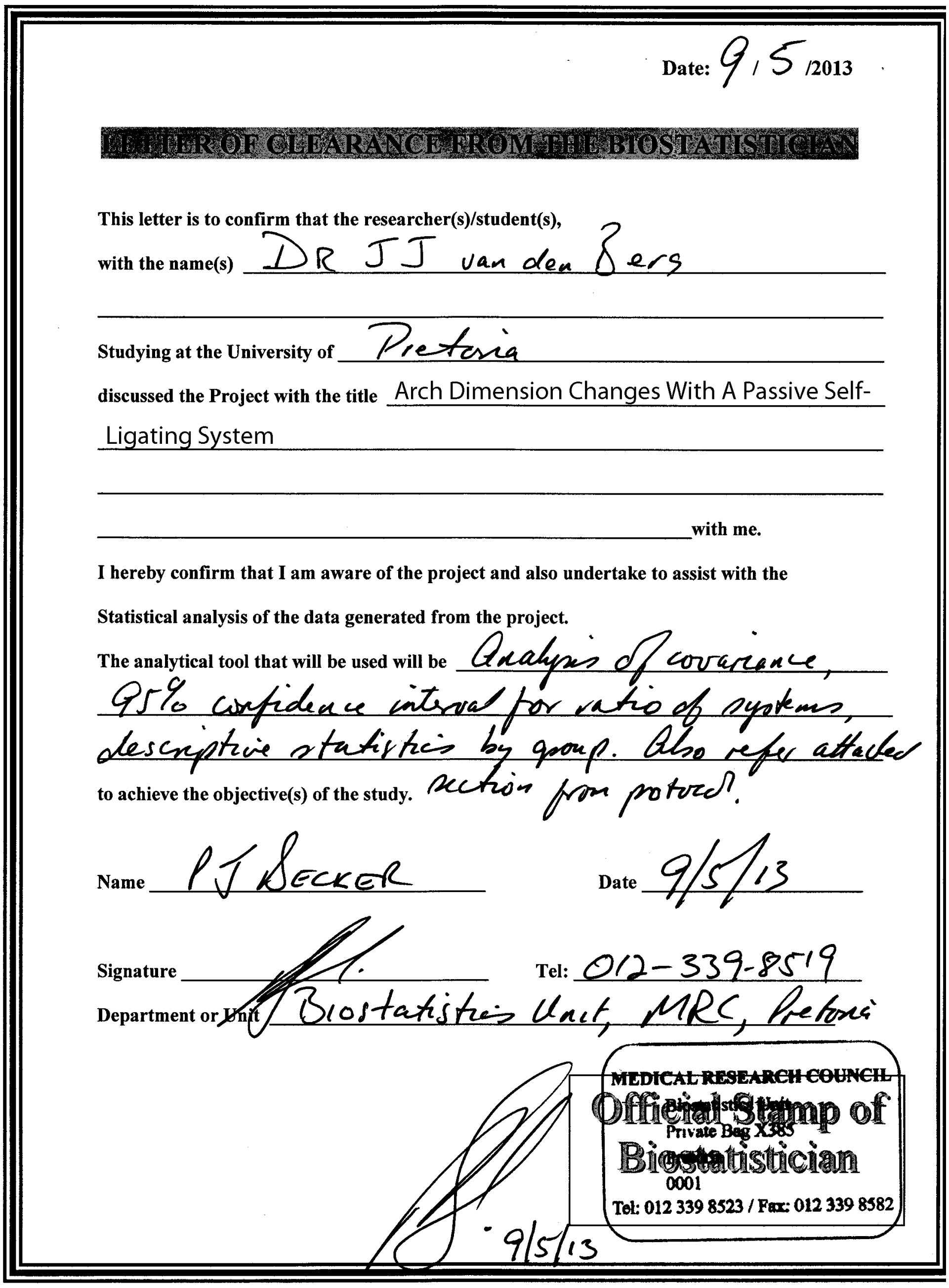
Yours sincerely

Professor Werdie (CW) Van Staden
MBChB MMed(Psych) MD FCPsych FTCL UPLM
Chairperson: Faculty of Health Sciences Research Ethics Committee

☎ 012 354 1677 🖷 0866516047 ✉ deepeka.behari@up.ac.za http://www.healthethics-up.co.za
✉ Private Bag X323, Arcadia, 0007 - 31 Bophelo Road, HW Snyman South Building, Level 2, Room 2.33, Gezina, Pretoria

ADDENDUM C

LETTER OF CLEARANCE FROM THE BIOSTATISTICIAN



Date: 9 / 5 /2013

LETTER OF CLEARANCE FROM THE BIOSTATISTICIAN

This letter is to confirm that the researcher(s)/student(s),

with the name(s) DR JJ van den Berg

Studying at the University of Pretoria

discussed the Project with the title Arch Dimension Changes With A Passive Self-Ligating System

with me.

I hereby confirm that I am aware of the project and also undertake to assist with the

Statistical analysis of the data generated from the project.

The analytical tool that will be used will be Analysis of covariance, 95% confidence interval for ratio of systems, descriptive statistics by group. Also refer attached section from protocol.

to achieve the objective(s) of the study.

Name PJ Becker

Date 9/5/13

Signature

Tel: 012-339-8519

Department or Unit Biostatistics Unit, MRC, Pretoria

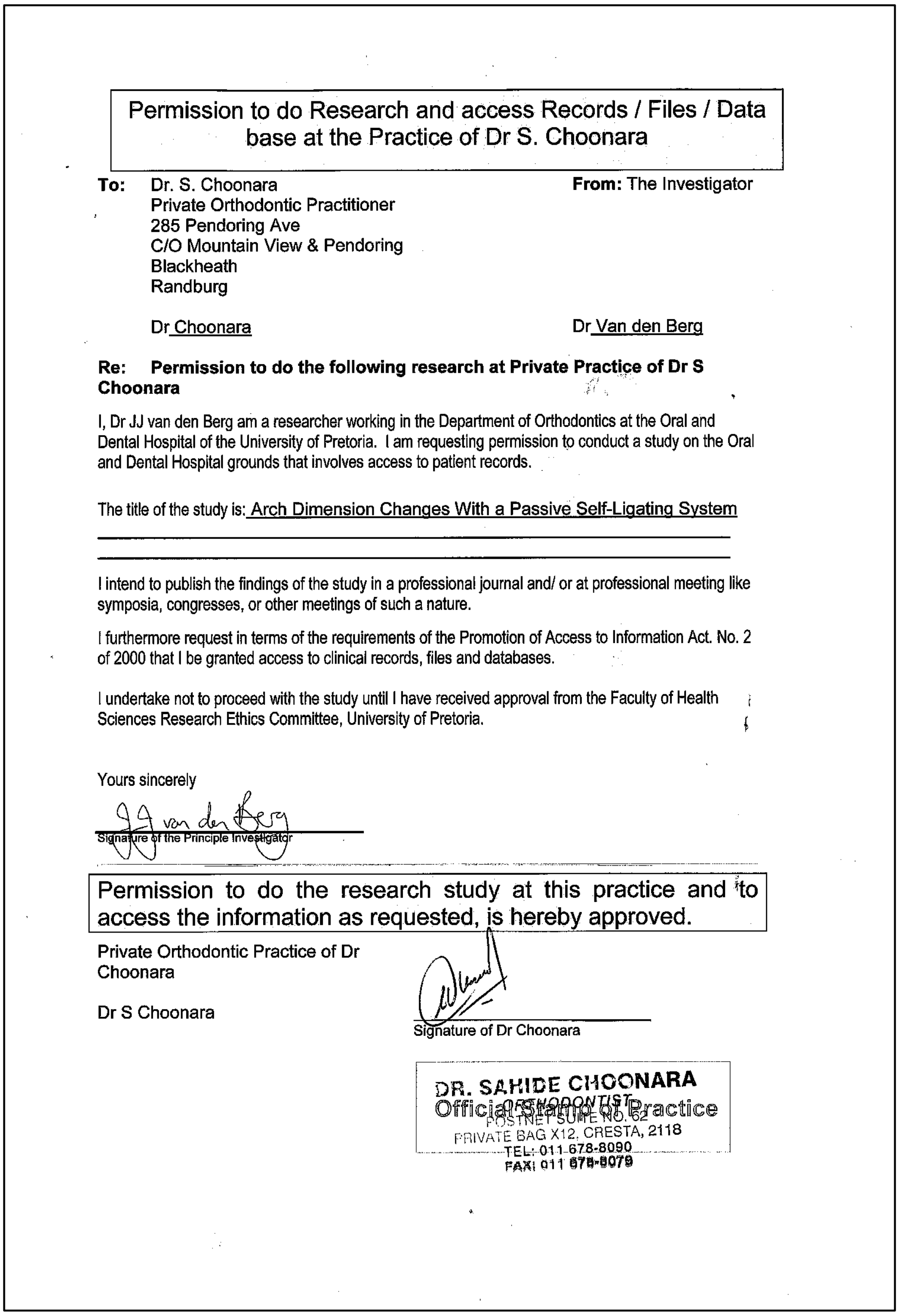
MEDICAL RESEARCH COUNCIL
Biostatistics Unit
Private Bag X385
Pretoria
0001
Tel: 012 339 8523 / Fax: 012 339 8582

Official Stamp of Biostatistician

9/5/13

ADDENDUM D

LETTER OF CONCENT FOR ACCESS OF RESEARCH RECORDS



Permission to do Research and access Records / Files / Data base at the Practice of Dr S. Choonara

To: Dr. S. Choonara
Private Orthodontic Practitioner
285 Pendoring Ave
C/O Mountain View & Pendoring
Blackheath
Randburg

From: The Investigator

Dr Choonara

Dr Van den Berg

Re: Permission to do the following research at Private Practice of Dr S Choonara

I, Dr JJ van den Berg am a researcher working in the Department of Orthodontics at the Oral and Dental Hospital of the University of Pretoria. I am requesting permission to conduct a study on the Oral and Dental Hospital grounds that involves access to patient records.

The title of the study is: Arch Dimension Changes With a Passive Self-Ligating System

I intend to publish the findings of the study in a professional journal and/ or at professional meeting like symposia, congresses, or other meetings of such a nature.

I furthermore request in terms of the requirements of the Promotion of Access to Information Act. No. 2 of 2000 that I be granted access to clinical records, files and databases.

I undertake not to proceed with the study until I have received approval from the Faculty of Health Sciences Research Ethics Committee, University of Pretoria.

Yours sincerely

JJ van den Berg
Signature of the Principle Investigator

Permission to do the research study at this practice and to access the information as requested, is hereby approved.

Private Orthodontic Practice of Dr Choonara

Dr S Choonara

Signature of Dr Choonara

Official Stamp of Practice

DR. SAHIDE CHOONARA
ORTHODONTIST
POSTNET SUITE NO. 62
PRIVATE BAG X12, CRESTA, 2118
TEL: 011 678-8090
FAX: 011 678-8079

ADDENDUM E

RAW DATA FOR ARCH DIMENSION MEASUREMENTS

line	subj_id	gr_cat	measure	t0	t1	diff
1	1	PSLBS	MxIC	34,4	34,15	-0,250
2	1	PSLBS	MxI1Pm	30,93	36,8	5,870
3	1	PSLBS	MxI2Pm	37,93	42,1	4,170
4	1	PSLBS	MxIM	43,81	45,64	1,830
5	1	PSLBS	MXA/L	25,58	26,53	0,950
6	1	PSLBS	MdIC	28,28	27,72	-0,560
7	1	PSLBS	MdI1Pm	30,96	34,74	3,780
8	1	PSLBS	MdI2Pm	40,06	41,95	1,890
9	1	PSLBS	MdIM	41,99	43,07	1,080
10	1	PSLBS	MdA/L	21,2	22,44	1,240
11	2	PSLBS	MxIC	34,92	35,29	0,370
12	2	PSLBS	MxI1Pm	36,55	39,25	2,700
13	2	PSLBS	MxI2Pm	43,63	44,43	0,800
14	2	PSLBS	MxIM	50,9	49,68	-1,220
15	2	PSLBS	MXA/L	29,32	28,54	-0,780
16	2	PSLBS	MdIC	29,99	27,82	-2,170
17	2	PSLBS	MdI1Pm	33,93	36,89	2,960
18	2	PSLBS	MdI2Pm	41,54	43,83	2,290
19	2	PSLBS	MdIM	43,86	47,49	3,630
20	2	PSLBS	MdA/L	21,3	24,46	3,160
21	3	PSLBS	MxIC	37,18	37,82	0,640
22	3	PSLBS	MxI1Pm	33,24	38,86	5,620
23	3	PSLBS	MxI2Pm	39,28	43,53	4,250
24	3	PSLBS	MxIM	43,26	46,88	3,620
25	3	PSLBS	MXA/L	26,07	29,57	3,500
26	3	PSLBS	MdIC	27,49	28,09	0,600
27	3	PSLBS	MdI1Pm	34,65	38,15	3,500
28	3	PSLBS	MdI2Pm	37,25	43,31	6,060
29	3	PSLBS	MdIM	39,47	43,05	3,580
30	3	PSLBS	MdA/L	23,48	24,09	0,610
31	4	PSLBS	MxIC	32,78	37,19	4,410
32	4	PSLBS	MxI1Pm	35,04	39,22	4,180
33	4	PSLBS	MxI2Pm	31,21	42,33	11,120
34	4	PSLBS	MxIM	42,54	43,49	0,950
35	4	PSLBS	MXA/L	27,35	28,6	1,250
36	4	PSLBS	MdIC	27,24	30,26	3,020
37	4	PSLBS	MdI1Pm	34	38,87	4,870
38	4	PSLBS	MdI2Pm	38,69	43,27	4,580
39	4	PSLBS	MdIM	39,72	43,36	3,640

40	4	PSLBS	MdA/L	23,79	23,66	-0,130
41	5	PSLBS	MxIC	33,06	36,31	3,250
42	5	PSLBS	MxI1Pm	35,09	39,35	4,260
43	5	PSLBS	MxI2Pm	41,48	44,55	3,070
44	5	PSLBS	MxIM	47,14	48,2	1,060
45	5	PSLBS	MXA/L	24,65	27,11	2,460
46	5	PSLBS	MdIC	26,03	27,92	1,890
47	5	PSLBS	MdI1Pm	34,35	36,77	2,420
48	5	PSLBS	MdI2Pm	39,88	42,23	2,350
49	5	PSLBS	MdIM	42,09	43,23	1,140
50	5	PSLBS	MdA/L	21,99	22,91	0,920
51	6	PSLBS	MxIC	33,81	39,15	5,340
52	6	PSLBS	MxI1Pm	33,7	40,8	7,100
53	6	PSLBS	MxI2Pm	42,39	46,13	3,740
54	6	PSLBS	MxIM	46,77	50,06	3,290
55	6	PSLBS	MXA/L	26,96	29,41	2,450
56	6	PSLBS	MdIC	27,44	29,34	1,900
57	6	PSLBS	MdI1Pm	34,93	39,49	4,560
58	6	PSLBS	MdI2Pm	45,06	47,32	2,260
59	6	PSLBS	MdIM	48,2	46,91	-1,290
60	6	PSLBS	MdA/L	23,21	24,15	0,940
61	7	PSLBS	MxIC	36,4	38,27	1,870
62	7	PSLBS	MxI1Pm	36,95	39,84	2,890
63	7	PSLBS	MxI2Pm	41,09	44,28	3,190
64	7	PSLBS	MxIM	47,76	48,81	1,050
65	7	PSLBS	MXA/L	30,48	29,12	-1,360
66	7	PSLBS	MdIC	27,26	28,89	1,630
67	7	PSLBS	MdI1Pm	34,57	36,49	1,920
68	7	PSLBS	MdI2Pm	40,65	41,7	1,050
69	7	PSLBS	MdIM	40,82	41,71	0,890
70	7	PSLBS	MdA/L	23,98	24,09	0,110
71	8	PSLBS	MxIC	35,73	35,39	-0,340
72	8	PSLBS	MxI1Pm	34,32	38,96	4,640
73	8	PSLBS	MxI2Pm	42,02	43,99	1,970
74	8	PSLBS	MxIM	46,77	49,03	2,260
75	8	PSLBS	MXA/L	25,53	27,11	1,580
76	8	PSLBS	MdIC	26,38	26,42	0,040
77	8	PSLBS	MdI1Pm	35,85	35,32	-0,530
78	8	PSLBS	MdI2Pm	41,14	41,67	0,530
79	8	PSLBS	MdIM	42,36	44,18	1,820
80	8	PSLBS	MdA/L	22,23	22,87	0,640
81	9	PSLBS	MxIC	36,13	34,59	-1,540
82	9	PSLBS	MxI1Pm	30,06	38,51	8,450
83	9	PSLBS	MxI2Pm	36	42,31	6,310
84	9	PSLBS	MxIM	41,58	43,97	2,390
85	9	PSLBS	MXA/L	24,41	25,7	1,290
86	9	PSLBS	MdIC	21,57	27,04	5,470

87	9	PSLBS	MdI1Pm	32,52	35,76	3,240
88	9	PSLBS	MdI2Pm	32,31	40,61	8,300
89	9	PSLBS	MdIM	37	40,49	3,490
90	9	PSLBS	MdA/L	20,64	21,46	0,820
91	10	PSLBS	MxIC	38,77	40,88	2,110
92	10	PSLBS	MxI1Pm	39,94	41,64	1,700
93	10	PSLBS	MxI2Pm	44,45	46,48	2,030
94	10	PSLBS	MxIM	48,22	49,96	1,740
95	10	PSLBS	MXA/L	32,07	31,9	-0,170
96	10	PSLBS	MdIC	26,49	30,01	3,520
97	10	PSLBS	MdI1Pm	37,18	39,67	2,490
98	10	PSLBS	MdI2Pm	45,29	44,5	-0,790
99	10	PSLBS	MdIM	42,63	44,17	1,540
100	10	PSLBS	MdA/L	26,75	27,74	0,990
101	11	PSLBS	MxIC	34,41	34,88	0,470
102	11	PSLBS	MxI1Pm	32,35	36,96	4,610
103	11	PSLBS	MxI2Pm	37,94	41,1	3,160
104	11	PSLBS	MxIM	40,88	43,41	2,530
105	11	PSLBS	MXA/L	28,44	27,14	-1,300
106	11	PSLBS	MdIC	24,03	25,53	1,500
107	11	PSLBS	MdI1Pm	28,14	34,66	6,520
108	11	PSLBS	MdI2Pm	27,51	39,67	12,160
109	11	PSLBS	MdIM	34,27	38,77	4,500
110	11	PSLBS	MdA/L	24,97	22,94	-2,030
111	12	PSLBS	MxIC	31,23	37,79	6,560
112	12	PSLBS	MxI1Pm	35,12	40,33	5,210
113	12	PSLBS	MxI2Pm	42,66	45,67	3,010
114	12	PSLBS	MxIM	47,37	49,75	2,380
115	12	PSLBS	MXA/L	30,09	28,35	-1,740
116	12	PSLBS	MdIC	26,25	28,43	2,180
117	12	PSLBS	MdI1Pm	33,06	37,95	4,890
118	12	PSLBS	MdI2Pm	39,91	45,18	5,270
119	12	PSLBS	MdIM	43,09	46,46	3,370
120	12	PSLBS	MdA/L	24,34	23,49	-0,850
121	13	PSLBS	MxIC	37,94	36,59	-1,350
122	13	PSLBS	MxI1Pm	33,28	37,52	4,240
123	13	PSLBS	MxI2Pm	37,71	41,29	3,580
124	13	PSLBS	MxIM	44,43	44,7	0,270
125	13	PSLBS	MXA/L	27,07	28	0,930
126	13	PSLBS	MdIC	25,23	27,71	2,480
127	13	PSLBS	MdI1Pm	33,32	35,75	2,430
128	13	PSLBS	MdI2Pm	34,83	39,32	4,490
129	13	PSLBS	MdIM	39,51	41,24	1,730
130	13	PSLBS	MdA/L	22,34	22,89	0,550
131	14	PSLBS	MxIC	31,35	37,03	5,680
132	14	PSLBS	MxI1Pm	33,15	38,08	4,930
133	14	PSLBS	MxI2Pm	40,33	42,65	2,320

134	14	PSLBS	MxIM	45,07	46,05	0,980
135	14	PSLBS	MXA/L	31,77	30,5	-1,270
136	14	PSLBS	MdIC	22,73	28,14	5,410
137	14	PSLBS	MdI1Pm	29,11	36,93	7,820
138	14	PSLBS	MdI2Pm	34,63	41,52	6,890
139	14	PSLBS	MdIM	40,04	42,13	2,090
140	14	PSLBS	MdA/L	24,76	26,43	1,670
141	15	PSLBS	MxIC	36,3	35,38	-0,920
142	15	PSLBS	MxI1Pm	34,17	39,63	5,460
143	15	PSLBS	MxI2Pm	41,23	43,85	2,620
144	15	PSLBS	MxIM	45,75	47,44	1,690
145	15	PSLBS	MXA/L	24,61	26,78	2,170
146	15	PSLBS	MdIC	27,78	28,11	0,330
147	15	PSLBS	MdI1Pm	32,34	37,76	5,420
148	15	PSLBS	MdI2Pm	39,05	43,19	4,140
149	15	PSLBS	MdIM	41	42,48	1,480
150	15	PSLBS	MdA/L	20,69	23,39	2,700
151	16	CBS	MxIC	32,5	33,5	1,000
152	16	CBS	MxI1Pm	36,75	38,28	1,530
153	16	CBS	MxI2Pm	43,96	44,02	0,060
154	16	CBS	MxIM	49,38	48,6	-0,780
155	16	CBS	MXA/L	23,99	24,08	0,090
156	16	CBS	MdIC	25,4	25,09	-0,310
157	16	CBS	MdI1Pm	35,53	35,89	0,360
158	16	CBS	MdI2Pm	43,07	42,19	-0,880
159	16	CBS	MdIM	44,41	42,86	-1,550
160	16	CBS	MdA/L	19,65	20,75	1,100
161	17	CBS	MxIC	36,3	36,02	-0,280
162	17	CBS	MxI1Pm	37,08	40,67	3,590
163	17	CBS	MxI2Pm	42,13	43,71	1,580
164	17	CBS	MxIM	45,07	46,12	1,050
165	17	CBS	MXA/L	27,86	27,33	-0,530
166	17	CBS	MdIC	27,16	27,12	-0,040
167	17	CBS	MdI1Pm	35,99	38,38	2,390
168	17	CBS	MdI2Pm	42,36	44,85	2,490
169	17	CBS	MdIM	42	43,72	1,720
170	17	CBS	MdA/L	22,99	22,88	-0,110
171	18	CBS	MxIC	32,74	35,69	2,950
172	18	CBS	MxI1Pm	33,73	38,18	4,450
173	18	CBS	MxI2Pm	39,21	41,12	1,910
174	18	CBS	MxIM	44,29	43,76	-0,530
175	18	CBS	MXA/L	25,92	27,2	1,280
176	18	CBS	MdIC	26,41	27,17	0,760
177	18	CBS	MdI1Pm	31,1	36,27	5,170
178	18	CBS	MdI2Pm	38,88	40,69	1,810
179	18	CBS	MdIM	39,48	39,71	0,230
180	18	CBS	MdA/L	21,55	21,92	0,370

181	19	CBS	MxIC	31,35	34,96	3,610
182	19	CBS	MxI1Pm	36,06	39,1	3,040
183	19	CBS	MxI2Pm	42,48	42,58	0,100
184	19	CBS	MxIM	46,43	44,63	-1,800
185	19	CBS	MXA/L	26	26,49	0,490
186	19	CBS	MdIC	21,99	25,59	3,600
187	19	CBS	MdI1Pm	32,43	34,45	2,020
188	19	CBS	MdI2Pm	39,08	40,19	1,110
189	19	CBS	MdIM	41,1	39,82	-1,280
190	19	CBS	MdA/L	20,75	21,59	0,840
191	20	CBS	MxIC	35,56	37,75	2,190
192	20	CBS	MxI1Pm	34,25	38,5	4,250
193	20	CBS	MxI2Pm	38,91	41,37	2,460
194	20	CBS	MxIM	42,92	43,94	1,020
195	20	CBS	MXA/L	30,96	29,2	-1,760
196	20	CBS	MdIC	24,55	27,45	2,900
197	20	CBS	MdI1Pm	30,73	36,8	6,070
198	20	CBS	MdI2Pm	35,09	39,66	4,570
199	20	CBS	MdIM	36,63	37,83	1,200
200	20	CBS	MdA/L	25,05	24,82	-0,230
201	21	CBS	MxIC	33,36	36,73	3,370
202	21	CBS	MxI1Pm	34,7	40,27	5,570
203	21	CBS	MxI2Pm	39,31	44,64	5,330
204	21	CBS	MxIM	45,65	47,39	1,740
205	21	CBS	MXA/L	27,25	26,54	-0,710
206	21	CBS	MdIC	25,72	27,76	2,040
207	21	CBS	MdI1Pm	32,03	37,33	5,300
208	21	CBS	MdI2Pm	36,31	44,32	8,010
209	21	CBS	MdIM	41,72	45,57	3,850
210	21	CBS	MdA/L	21,24	21,91	0,670
211	22	CBS	MxIC	31,72	33,82	2,100
212	22	CBS	MxI1Pm	35,55	37,57	2,020
213	22	CBS	MxI2Pm	42,27	42,54	0,270
214	22	CBS	MxIM	47,15	47,11	-0,040
215	22	CBS	MXA/L	27,69	26,48	-1,210
216	22	CBS	MdIC	28,67	26,92	-1,750
217	22	CBS	MdI1Pm	34,38	36,34	1,960
218	22	CBS	MdI2Pm	40,16	41,84	1,680
219	22	CBS	MdIM	42,83	44,95	2,120
220	22	CBS	MdA/L	21,45	21,61	0,160
221	23	CBS	MxIC	35,26	38,05	2,790
222	23	CBS	MxI1Pm	36,02	40,61	4,590
223	23	CBS	MxI2Pm	42,32	44,35	2,030
224	23	CBS	MxIM	47,59	47,15	-0,440
225	23	CBS	MXA/L	27,39	27,59	0,200
226	23	CBS	MdIC	28,63	29,94	1,310
227	23	CBS	MdI1Pm	36,18	37,72	1,540

228	23	CBS	MdI2Pm	41,61	42,45	0,840
229	23	CBS	MdIM	43,03	43,05	0,020
230	23	CBS	MdA/L	21,16	22,39	1,230
231	24	CBS	MxIC	35,03	36,25	1,220
232	24	CBS	MxI1Pm	34,36	38,89	4,530
233	24	CBS	MxI2Pm	39,95	43,79	3,840
234	24	CBS	MxIM	46,34	47,73	1,390
235	24	CBS	MXA/L	26,15	26,6	0,450
236	24	CBS	MdIC	24,92	27,82	2,900
237	24	CBS	MdI1Pm	32,41	36,26	3,850
238	24	CBS	MdI2Pm	38,53	42,76	4,230
239	24	CBS	MdIM	42,05	42,68	0,630
240	24	CBS	MdA/L	21,37	21,75	0,380
241	25	CBS	MxIC	32,46	34,72	2,260
242	25	CBS	MxI1Pm	34,25	36,66	2,410
243	25	CBS	MxI2Pm	39,25	41,26	2,010
244	25	CBS	MxIM	43,64	43,65	0,010
245	25	CBS	MXA/L	25,96	26,12	0,160
246	25	CBS	MdIC	22,89	27,41	4,520
247	25	CBS	MdI1Pm	30,55	35,02	4,470
248	25	CBS	MdI2Pm	35,77	39,83	4,060
249	25	CBS	MdIM	38,4	39,11	0,710
250	25	CBS	MdA/L	21,76	23,85	2,090
251	26	CBS	MxIC	33,83	35,91	2,080
252	26	CBS	MxI1Pm	33,79	37,93	4,140
253	26	CBS	MxI2Pm	39,15	41,43	2,280
254	26	CBS	MxIM	41,89	43,79	1,900
255	26	CBS	MXA/L	26,51	27,15	0,640
256	26	CBS	MdIC	24,35	28,26	3,910
257	26	CBS	MdI1Pm	32,71	36,49	3,780
258	26	CBS	MdI2Pm	37,99	41,41	3,420
259	26	CBS	MdIM	37,89	37,81	-0,080
260	26	CBS	MdA/L	22,69	23,83	1,140
261	27	CBS	MxIC	37,57	38,73	1,160
262	27	CBS	MxI1Pm	34,74	41,45	6,710
263	27	CBS	MxI2Pm	39,91	45,18	5,270
264	27	CBS	MxIM	46,92	47,95	1,030
265	27	CBS	MXA/L	26,21	28,26	2,050
266	27	CBS	MdIC	30,34	30,28	-0,060
267	27	CBS	MdI1Pm	33,08	38,75	5,670
268	27	CBS	MdI2Pm	37,58	44,54	6,960
269	27	CBS	MdIM	41,97	42,65	0,680
270	27	CBS	MdA/L	22,32	23,71	1,390
271	28	CBS	MxIC	35,25	37,82	2,570
272	28	CBS	MxI1Pm	36,47	39,39	2,920
273	28	CBS	MxI2Pm	41,41	43,76	2,350
274	28	CBS	MxIM	45,88	48,4	2,520

275	28	CBS	MXA/L	29,72	29,42	-0,300
276	28	CBS	MdIC	28,64	29,67	1,030
277	28	CBS	MdI1Pm	35,46	37,77	2,310
278	28	CBS	MdI2Pm	39,32	42,92	3,600
279	28	CBS	MdIM	43,1	44,41	1,310
280	28	CBS	MdA/L	24,93	23,62	-1,310
281	29	CBS	MxIC	31,58	34,68	3,100
282	29	CBS	MxI1Pm	34,06	37,19	3,130
283	29	CBS	MxI2Pm	38,71	40,38	1,670
284	29	CBS	MxIM	43,15	43,92	0,770
285	29	CBS	MXA/L	26,35	26,24	-0,110
286	29	CBS	MdIC	24,13	25,58	1,450
287	29	CBS	MdI1Pm	32,27	35,04	2,770
288	29	CBS	MdI2Pm	37,8	39,97	2,170
289	29	CBS	MdIM	38,54	40,16	1,620
290	29	CBS	MdA/L	21,88	21,28	-0,600
291	30	CBS	MxIC	35,88	35,96	0,080
292	30	CBS	MxI1Pm	33,6	37,11	3,510
293	30	CBS	MxI2Pm	38,84	40,77	1,930
294	30	CBS	MxIM	42,72	45,15	2,430
295	30	CBS	MXA/L	28,38	27,8	-0,580
296	30	CBS	MdIC	26,93	27,88	0,950
297	30	CBS	MdI1Pm	34,14	35,66	1,520
298	30	CBS	MdI2Pm	39,22	40,16	0,940
299	30	CBS	MdIM	39,08	40,85	1,770
300	30	CBS	MdA/L	24,57	23,23	-1,340
301	31	CBS	MxIC	36,84	37,06	0,220
302	31	CBS	MxI1Pm	37,1	40,62	3,520
303	31	CBS	MxI2Pm	43,1	45,2	2,100
304	31	CBS	MxIM	47,79	49,74	1,950
305	31	CBS	MXA/L	27,25	27,89	0,640
306	31	CBS	MdIC	27,45	27,81	0,360
307	31	CBS	MdI1Pm	36,37	37,66	1,290
308	31	CBS	MdI2Pm	43,19	44,63	1,440
309	31	CBS	MdIM	43,36	43,62	0,260
310	31	CBS	MdA/L	22,48	23,65	1,170

ADDENDUM F

RAW DATA FOR DETERMINATION OF INTRA- AND INTER-EXAMINER RELIABILITY

id	reader	MxIC	MxI1Pm	MxI2Pm	MxIM	MxA_L	MdIC	MdI1Pm	MdI2Pm	MdIM	MdA_L
1	0	36,3	37,08	42,13	45,07	27,86	27,16	35,99	42,36	42	22,99
1	1	36,43	37,33	42,31	45,29	27,57	27,25	35,98	42,47	41,98	22,9
1	2	36,45	37,34	42,21	45,26	27,62	27,45	36,47	42,46	42	23,55
2	0	35,39	38,96	43,99	49,03	27,11	26,42	35,32	41,67	44,18	22,87
2	1	35,39	39,17	44,16	48,82	27,54	26,19	35,46	41,43	44,24	22,74
2	2	35,52	39,17	44,34	49,06	27,06	26,54	35,72	41,68	44,2	23,04
3	0	31,23	35,12	42,66	47,37	30,09	26,25	33,06	39,91	43,09	24,34
3	1	31,29	35,34	42,92	47,61	30,21	26,35	33,22	40,24	43,06	23,81
3	2	31,36	35,53	42,96	47,65	29,72	26,02	32,64	39,98	43,42	23,58
4	0	33,06	35,09	41,48	47,14	24,65	26,03	34,35	39,88	42,09	21,99
4	1	33,22	34,97	41,46	46,77	25,15	25,86	34,13	39,89	42,28	21,19
4	2	32,87	35,17	41,61	47,06	24,77	25,52	34,18	39,3	42,33	21,37
5	0	38,77	39,94	44,45	48,22	32,07	26,49	37,18	45,29	42,63	26,75
5	1	38,79	39,91	44,13	48,23	31,87	26,6	37,23	44,78	42,46	26,43
5	2	38,8	40,07	44,57	47,56	32,09	26,42	37,04	44,49	42,92	26,34