Comparison of Retentive properties of two Attachment Systems in Mandibular Overdentures - An in vitro study

Asim Alsadig Satti

Student number: 3174859

Supervisors

Dr. N Patel *(BDS, MChD)*

Dr. MT Peck *(BchD, Msc (Dent), MChD, MRD (RCSE))*

November 2013

A Mini-thesis submitted for fulfillment of the requirements for the Degree of Magister Scientiae (MSc) in the Department of Restorative Dentistry, Faculty of Dentistry and World Health Organization (WHO) Oral Health Collaborating Centre, University of the Western Cape.

Comparison of Retentive properties of two Attachment Systems in Mandibular Overdentures - An in vitro study

Asim Alsadig Satti

Keywords

- Overdenture
- implant overdentures
- Implants
- Mandibular overdenture
- Retention
- Locator®
- OT equator
- Cyclic dislodgement
- Cyclic fatigue
- In-vitro

Abstract

AA. Satti. MSc Thesis, Department of Restorative Dentistry, University of the Western Cape.

Introduction: Implant supported overdentures show excellent clinical results for maladaptive denture patients. The mandibular 2-implant overdenture was considered as first choice standard of care for edentulous patients. In order to achieve retention and stability of overdenture, different attachments systems have been utilized. **Literature review**: In 2001, Locator® overdenture attachments were introduced and have become increasingly popular and widely used. The system is featured by self-aligning and dual retention properties, and can accommodate up to 40 degrees inter implant angulation. In 2013, the new attachment system OT equator had been launched with similar properties to the Locator® attachment system. Little information is available about this product, and there are no published articles on patients or in vitro studies to investigate the retention properties of this product. **Aim**: The aim of this study is to test and compare the retentive properties of two types of attachments i.e. Locator® and OT equator in a mandibular overdenture placed over 2 implants. **Methodology**: 8 blocks with dimensions 25 x 30 x 60 mm was fabricated using clear acrylic resin, 2 blocks used to house the implant laboratory analogs in a 0 degree angulation, one block received 2 Locator® abutments and the other received 2 OT equator abutments. The other 6 blocks were divided into two groups of three blocks each. One group was used to house the Locator® attachments pink nylon inserts and the other group was used to house the OT equator attachments clear nylon inserts. The cyclic fatigue was performed for 60 cycles of removal and placement, which was carried out as 57 cycles to be performed manually by one operator and 3 cycles by the universal material testing machine at crosshead speed of 50mm/min. The minimal required force for dislodgement was recorded in Newtons. Study samples were tested for 1440 cycles. The data was recorded and analyzed using SPSS software. **Results:** Mean initial retention of the Locator® with pink nylon inserts was 45.4±2.43N, in comparison to 37.3±6.27 N for the OT equator with the clear nylon inserts. In month 3 (360 cycles) the difference in retention was significant (P value = 0.003) with retentive values of 46.99±3.25 N and 34.09±1.34 N for Locator® and OT equator respectively. The retention values recorded in the period extending from month 10 (1200 cycle) till the end of study in month 12 (1440 cycles) showed statistical significant difference (P value < 0.05). At the end of study (1440 cycles) the Locator® showed a total loss of 33% of the initial retention, and it recorded 30.5 N, in comparison to 45% of the initial retention recorded in OT equator with a retention of 20.6 N. **Discussion:** All study samples showed reduction in retention after cyclic fatigue, the Locator® attachment system with pink nylon inserts shows superior retentive properties when compared to the OT equator clear nylon inserts in the initial retention and the total reduction of retention. **Conclusion:** The Locator® attachment system with pink nylon inserts shows better retention when compared to OT equator attachment system with clear nylon inserts.

November 2013

Declaration

I declare that "Comparison of Retentive properties of two Attachment Systems in Mandibular Overdentures - An in vitro study" is my own work, that has not been submitted before for any degree or examination in any other university, and that all the sources I have used or quoted have been indicated and acknowledged as complete references.

We declare that, there was no conflict of interest with products used in this study.

Asim Alsadig Satti November 2013

Signature

Acknowledgement

I would like express my sincere appreciation and gratitude to my supervisors, Dr. Patel for his guidance, help and support through all the stages of this project. Dr. Peck for initiating the idea of this research and for his support in the early days of this project.

It is a pleasure to express my gratitude to Prof. Grobler for his unlimited help in the data collection with the universal material testing machine.

My thanks also extend to Prof. Osman, staff of the Restorative Department specially Prof. Wilson, Dr. Khan for their help through my MSc course.

I am thankful to the staff of dental laboratory in Tygerberg Oral Health Center for their great assistance during samples preparation procedure.

I convey special acknowledgment to MIS Implants Technologies Ltd (MIS) and implant support services company (ISS) for their support with the implants components.

I would like to thank my colleague Dr. Petro, for his valuable assistance during data collection phase

Lastly, I am very grateful to all those who supported me in any respect during the completion of this project.

Dedication

To My Parents

Alsadig Satti and Fawzia Abdulrahman

for their

Constant support,

Encouragement

And love

Table of Contents

CHAPTER ONE

Introduction

The developed countries are experiencing a rapid decline in tooth loss. Hence tooth loss increases with age, these societies will continue to increase in the numbers of edentulous people because of the increase in mean age. Conventional complete dentures have been the standard option of care for more than a century (Feine *et al*., 2002). Complete denture wearers are usually satisfied with the upper denture but the majority of them often struggle to eat with the lower denture because of the lack of retention (Feine *et al*., 2002). Unlike the conventional complete denture, a study conducted by Zarb and Schmitt (1995) concluded that implant supported overdentures have excellent clinical results for maladaptive denture patients with promising long-term evidence supporting their effectiveness.

The prospect of using two implant supported overdenture in the treatment of mandibular denture related problems was highlighted by van Steenberghe *et al*., (1987). In his study, the success rate reported was 98% for an observation time of up to 52 months. Although previous studies had focused on the treatment of edentulous patients with fixed prostheses supported by six implants had been reported. van Steenberghe *et al* (1987) proposed the placement of fewer implants in advantageous sites rather than placing as many implants in limited space to achieve the original goal of six endosseous implants for the rehabilitation of a completely edentulous jaw. In 2002, a symposium held at McGill University in Canada, focused on the efficacy of available treatments for edentulous patients. The significance of the symposium was emphatic on the preference of treatment choice for edentulous patients. The mandibular 2-implant overdentures was considered as first choice standard of care for edentulous patients. (Feine, et al., 2002).The connection between endosseous implant and overdenture could be achieved by several types of attachments. These include bar, ball, magnet etc. These types of attachments will be discussed in detail in the literature review section.

The advancement in the manufacture of prosthetic components in relation to implants as well as the varieties of the attachment systems that are available for overdentures often confuse the clinicians in selecting the suitable or appropriate attachment system for their patients. However, despite the limitations of in-vitro studies, the in-vitro trials can provide scientific evidence on the material properties and serve as guidelines on the clinical appropriateness of this material in different clinical scenarios.

CHAPTER TWO

Literature review

2.1 The Concept of overdenture

An overdenture is defined as "a prosthesis that covers and is partially supported by natural teeth, tooth roots, and/or dental implants". (The Glossary of Prosthodontics Terms, 2005). Overdenture treatment has been available for decades, but its use was very limited and only applicable when the patient had remaining teeth to be used as overdenture abutments. However, since the introduction of implant treatment in dentistry, this concept changed and gained increasing popularity than before. The first reference in the English literature was reported in 1856 when Ledger encouraged the dental profession to leave "stumps" under a full set of artificial teeth (Ettinger, 1992). Crum and Rooney (1978) in a five year study, reported an average of 5.2 mm loss in the alveolar ridge height in denture patients when compared to overdenture patients who showed an average of 0.6 mm loss. This represents a ratio of 8:1 and the study concluded that retaining natural tooth roots and utilizing overdentures will lead to less vertical alveolar bone loss over time.

The effect of reducing bone loss will impact on preserving the alveolar ridge morphology thus enhancing retention, stability and support of the prosthesis. This is in addition to the support and retention provided by the overdenture abutments. Similarly, the retained roots plays an important role in proprioception because periodontal ligaments are supplied by nerve endings which aid in the determination of the position of the mandible and the bite force during mastication (Jacobs and van Steenberghe, 1994). Moreover, the psychological impact of retaining teeth in patients is important, Morrow *et al* (1969) mentioned that patients have an ever present fear of being rendered completely edentulous and the retention of even a single tooth can be of great psychological comfort.

2.2 Implant overdenture

Endosseous implants were introduced to dentistry in 1977 (Branemark et al., 1977). A few years later, van Steenberghe *et al* (1987) reported on the possibility of using overdentures supported by two Brånemark implants to treat mandibular denture problems.

According to the McGill Consensus statement, the conventional denture is no longer the best available treatment for an edentulous resorbed mandible. The evidence available today suggests that two implant supported overdenture should be considered the first choice of treatment for such patients (Feine, *et al*., 2002)

Randomized and non-randomized clinical trials show that mandibular 2-implant overdentures have been superior to conventional dentures regardless of the type of attachment system used (Feine *et al*., 2002). Patients who received 2-implant overdentures recorded higher score in Oral Impacts on Daily Performances (OIDP) when compared to patients who received conventional dentures. Patients find the implant overdentures significantly stable, and their ability to chew various foods is significantly improved. They can also speak comfortably and experience less impact on daily life than patients with conventional complete dentures (Melas *et al*., 2001)

There is also preliminary evidence that implant overdenture might help in improving the nutritional state, which will impact on the general health of the edentulous patients, particularly for senior adults who are vulnerable to malnutrition (Feine, *et al*., 2002)

2.3 Types of attachment systems for overdenture:

In order to achieve retention and stability of overdentures, different attachment systems can be utilized. An attachment system is defined according to the glossary of maxillofacial implants as "a design of a particular type of retentive mechanism employing compatible matrix and patrix corresponding components. Matrix refers to receptacle component of the attachment system, and patrix refers to the portion that has functional fit and engages the matrix". (Glossary of implant terms, 2007)

The prominent attachment systems are bar, ball, magnet types, and a number of individual mechanical attachments similar in size and function to the ball type. Generally, the selection of an attachment system depends on the experience and preference of practitioners (Kim *et al.*, 2012). The retentive force of the attachments is gained through either mechanical interlocking, frictional contact or magnetic forces of attraction between the patrices and matrices (Becerra & MacEntee, 1987).

The different types of attachments exhibit unique properties. The bar is especially useful when implants are nonparallel to one another making it difficult to develop a common path of placement between the implant abutments and the denture base. The bar attachments provide a separate, parallel path of placement of retentive bar clips allocated in the denture base. Simultaneously, it allows the bar to connect to a variety of nonparallel implant angulations. When more than two implants are used, parallel implant placement becomes progressively more difficult to achieve, making the bar attachment a popular choice. Unlike the bar attachment, the ball is considered the simplest. The simplicity of this attachment system on unsplinted implants this made them the preferred choice for clinicians especially with mandibular implant overdentures (Preiskel, 1996)

Ball attachment connectors are popular due its simple design, effectiveness and cost-effectiveness. The only disadvantage of this system is related to the high-profile of its abutment which may limit its use especially in patients with narrow jaw anatomy. Even though cost is an important factor to consider, ball attachments are less expensive when compared to other attachment types like Locator®. (Preiskel, 1996)

Magnetic connectors were introduced as a simple attachment modality for implant supported overdentures. Their advantages include ease of use, particularly when space is limited. The self-seating properties makes it suitable for those with minimal manual dexterity. The disadvantage of this type of attachment is the possibility of adverse effects of magnetic field in the head and neck region and not to mention their weak retentive capacity (Sadig, 2009).

2.3.1 Locator® attachment system:

The Locator® overdenture attachment were introduced in 2001 by (Zest Anchors, Escondido, CA, USA) and it has become increasingly popular and widely used. The system gains its retention through mechanical interlocking between the abutment and the nylon insert part of the matrix. The nylon inserts engages the implant abutment in a dual-retention, the outer and the inner parts of the nylon insert both incorporate and interlock over undercuts in the abutment body. The attachment apparatus consists of a Locator® abutment (patrix component) which is placed on the implant and a metal housing that is embedded within the intaglio surface of the denture that houses a nylon-insert (matrix component). The Locator® abutment is made of titanium alloy with a titanium nitride coating while the metal housing is made of titanium alloy. The height of attachment abutment is 1.78 mm without metal housing, and up to 2.5 mm with metal housing when used with internal connection implants, and 3.17 mm when used with external connection implants. The diameter of the abutment varies from 3.86 to 4.1 mm depending on the manufacturer mold.

The system comes with different color coded nylon inserts and varies depending on the retention required. The regular nylon inserts include: clear inserts have (5.0 pounds), the pink (3.0 pounds) and the blue (1.5 pounds). In the extended range of nylon-inserts, which provide angle correction up to 40°, these include: the green inserts which have (3.0 - 4.0 pounds), the orange have (2.0 pounds) and red have (0.5 - 1.5 pounds) and grey (0 pounds). (Zest Locator® brochure, 2011). The regular type of the Locator® nylon inserts can accommodate an implant angulation of 0°to 10° individually and up to 20° of divergence angle between two implants. The extended range Locator® nylon-inserts lack the inner retention feature and can individually accommodate for implant angulation of 10°to 20° with a maximum of 40 ° divergence angle between two implants. (Zest Locator® brochure, 2011)

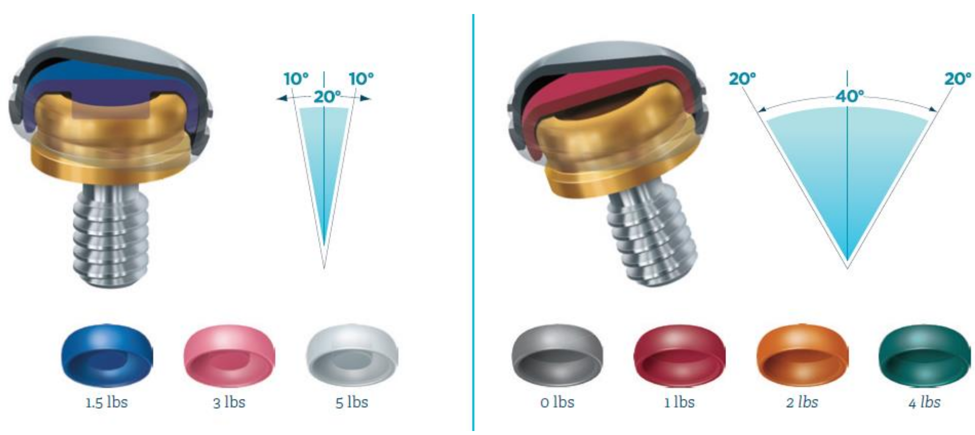


Figure 2.1: Locator® Nylon inserts

2.3.2 OT equator attachment system:

Recently, MIS Implants Technologies Ltd (MIS) launched a new attachment system called the OT equator. This form of attachment has the minimum vertical height and diameter for the overdenture abutment available in the market. The height of the OT equator abutment is 1.7 mm with a diameter of 2.5 mm. Similar to Locator®, the attachment abutment is made of titanium alloy with a titanium nitride coating, and the metal housing is made of titanium alloy. The OT equator comes with nylon components similar to the ones provided by the Locator® system i.e. clear inserts have "standard retention", the pink have "soft retention", the yellow have "extra-soft retention" and the violet have "high retention". (MIS product catalog, 2013)

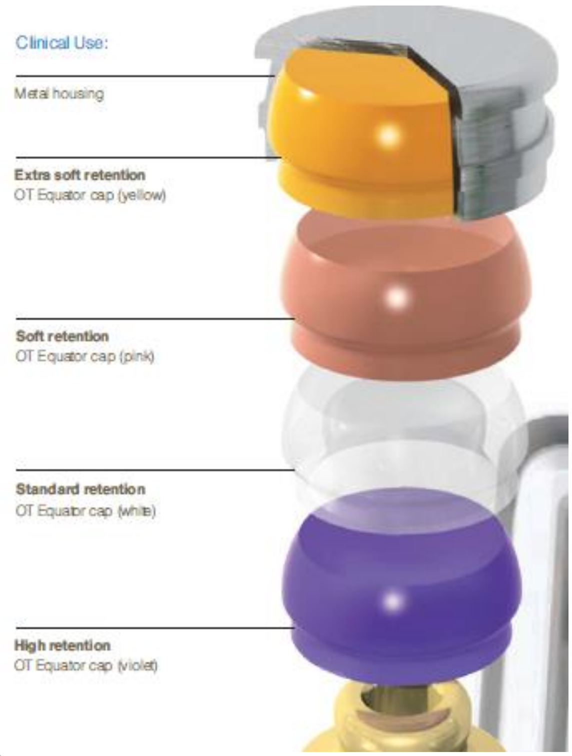


Figure 2.2: OT equator Nylon inserts

However, little information is available about this product and there are no published articles on patients or in vitro studies to investigate the retention properties of this product. In general, the choice of which attachment system to utilize is influenced by the retention required, jaw morphology, jaw anatomy, patient function and compliance for recall (Sadowsky and Caputo 2000). The selected attachments for an implant overdenture should have adequate retentive properties to enhance the retention of the prosthesis and simultaneously allow for easy placement and removal of the prosthesis by the patient (Trakas *et al*., 2006). In addition, angulation of the implants can also be an important factor when selecting attachments. Ideally, the free-standing stud-type attachments should be parallel to each other to provide ease of insertion and removal, and reduce wear potential (Walton *et al*., 2001)

2.4 The ideal retentive properties for the implant overdenture attachment system:

The retentive force provided by an attachment system should be high enough to retain the denture in place during function and prevent displacement by oblique forces. Clinicians often base their selection of attachment systems empirically on the presumed retentive qualities and the levels of patient satisfaction offered by the system (Burns *et al*., 1995; Cune *et al*., 2005). However, a definition for what an “acceptable” level of retention is for an attachment system remains elusive (Alsabeeha *et al*, 2009), and manufacturers provide limited data about the retentive strength and wear of attachments (Pigozzo *et al*., 2009). It has been suggested that the minimum retentive force expected for a single individual unsplinted attachment might be 4 N (Lehmann, 1978; Chung *et al*., 2004) although various retentive forces ranging from 1 to 85 N have been reported for different attachment systems in which the mandibular overdentures are retained by multiple implants (Chung *et al*., 2004; Petropoulos and Smith, 2002; Rutkunas *et al*., 2007; (Alsabeeha *et al*, 2009)). Other authors estimate that 20 N of retentive force is adequate for mandibular two-implant overdentures (Setz and Engel, 1998) while Pigozzo *et al* (2009) noted that 5–7 N would stabilize an overdenture.

2.5 Factors affecting the retention of attachment systems:

Many factors may influence the degree of retentive force of the attachment system. This may include the physical nature of the attachment system as well as its retention i.e. mechanical, frictional contacts or magnetic forces (Preiskel, 1996; Besimo, 2003; Laney *et al*., 2007). In vitro investigations revealed that attachment systems depend on mechanical interlocking and frictional contacts to have higher retention properties over those based on magnetic forces. (Sadig, 2009). Another factor that determines the retention properties of the attachment is the inter implant distance (Michelinakis *et al*, 2006; Doukas *et al*., 2008). Although the highest retentive force was reported at an interimplant distance of 29 mm for overdenture supported by two implants, a significant change was not achieved when the implants were placed at a shorter distance of 23 or 19 mm (Michelinakis *et al*, 2006; Doukas *et al*., 2008).

Other authors noted a reduction in the retentive force for attachments when the implant angulation was increased from 0° to 30° (Wiemeyer *et al*, 2001; Gulizio *et al*., 2005). Increased implant angulation has been reported to reduce the longevity of the attachment retention by causing premature wear of the components and required increased maintenance (Al-Ghafli *et al*., 2009; Jabbour, *et al*., 2013).

2.6 Fatigue of the rubber component of the Locator® attachment system

Wear is defined as "loss of material from a surface caused by mechanical action or through a combination of chemical and mechanical actions" (Anusavice, 1996). Different in vitro studies using Scanning Electron Microscopy (SEM) indicated that attachments systems inevitably undergo wear. These induced structural changes lead to a reduction or total loss of their retention. These events were reported to occur with attachments systems of varied materials and designs (Alsabeeha, *et al*., 2009).

2.7 Implant attachment systems In-vitro investigations:

Many studies have investigated the retentive properties of implant attachment systems in the past. A systematic review conducted to evaluate in-vitro studies done to investigate retention and wear of mandibular unsplinted different commercially available implant attachment systems. Their results concluded that there was a wide variability of the initial forces of retention as well as final retention forces. The result were contradictory even for similar attachment systems. They concluded that future investigations of attachment systems is needed to reach a consensus in better understanding of retentive properties of these attachment systems (Alsabeeha *et al*., 2009).

Therefore, we aim to investigate the retention properties of the widely used Locator® attachment system (Zest Anchors, Escondido, CA, USA) and newly launched OT equator attachment system (MIS implant technologies GmbH, Minden, Germany). The two attachment systems will be compared in terms of initial retentive forces, final retentive force after 1 year of simulated usage and wear features of the attachment components. The results will be compared to previously published literature of the Locator® attachment system.

CHAPTER THREE

Materials and Methods

3.1 Study design

Descriptive prospective Laboratory based study.

3.2 Sample size

The sample consisted of 2 groups of abutments one being the Locator® and the other the OT equator. 3 paired retention nylon inserts were used of each attachment system. The sample size had been determined and confirmed in consultation with a statistician.

3.3 Sample preparation

A rectangular plaster block with dimensions 25 x 30 x 60 mm was fabricated using orthodontic white plaster. This block was used as a template for constructing 8 acrylic blocks. After confirming the dimensions of the plaster block a mould was fabricated using heavy body polyvinyl siloxane impression material (President putty, Coltène Whaledent Inc, Switzerland). The mould was then used as a template to manufacture the final 8 acrylic blocks.

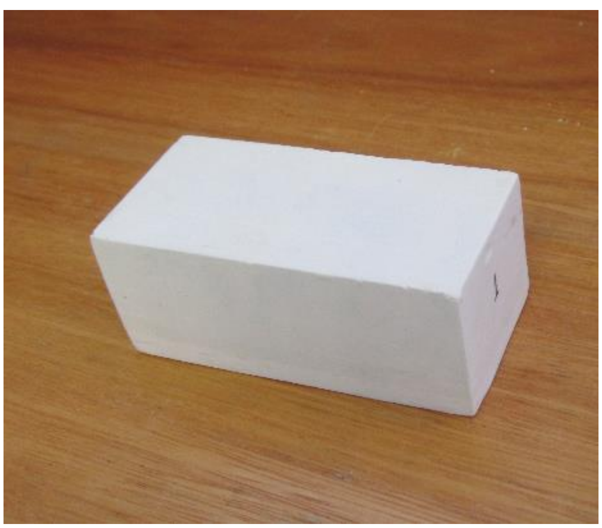


Figure 3.1: Plaster Block

Figure 3.2: Polyvinyl siloxane mould

Auto-polymerizing polymethyl methacrylate acrylic resin (Clear Ortho Jet acrylic resin; Lang, Wheeling, IL) was mixed according to the manufacturer's instructions and poured into the polyvinyl siloxane mould. The polymethyl methacrylate resin mixture was allowed to cure for 15 minutes under 3 bars of pressure.

The procedure was repeated to manufacture all 8 acrylic blocks with the dimensions of 25 x 30 x 60 mm. Two blocks out of these 8 blocks were selected (A Blocks). One block of these two blocks was used to house the 2 implant analogs and 2 Locator® abutments, while the other block was used to house the 2 implants analogs and 2 OT equator abutments. Of the remaining 6 blocks (Block B), 3 blocks were used to house overdenture male components of the Locator® system, while the other 3 were used to house the OT equator male components.

For the B blocks the manufacturing procedure included placing of M12 hex nut on one side of the acrylic block to aid attaching these blocks to the moving arm of the universal testing machine. Horizontal grooves were cut in the body of the screw nut to enhance attachment between the nut and acrylic material. The screw nut in acrylic blocks (Block B) was used to help attach these blocks in the moving arm of the testing machine.

In the A blocks, a mounted drill with a drill bur size 4mm was used to drill two vertical holes at a distance of 22 mm from each other with equal distance from the edges of the block, the two vertical holes were drilled to a depth of 12 mm. Two implant laboratory analogs with a diameter of 3.75 mm and length of 12 mm were then placed in the two holes and its fit in the drilled holes was checked. A surveyor was used to check the parallelism of the analogs after being connected with the Locator® abutments. After proper fit was confirmed, a fresh mix of the auto-polymerizing acrylic resin was injected in the two holes in the acrylic block and the lab analogs were placed and pushed in the full length of the 12 mm, the access material was removed and the auto-polymerizing acrylic resin allowed to polymerize for 15 minutes under 3 bars of pressure. The same procedure was repeated to secure the two OT equator abutments into block A.

After completion of the procedure of manufacturing (A) blocks, angulation was rechecked. All blocks were then trimmed and finished using coarse, medium and fine sand papers, pumice/water mix and a lathe polishing wheel.

The other 6 B blocks were randomly divided into two groups of three blocks each. One group was used to house the Locator® attachments and the other group used to house the OT equator attachments. The blocks were tagged according to the type of attachment, with each of the three blocks corresponding to one of the A blocks and numbered accordingly. Using mounted drill with a drill bur size 6 mm, two holes with a depth of 2 mm each were drilled at a distance of 22 mm from each other and with equal distance from the edges of the block.

Metal Locator® housings with the black processing inserts were placed on the Locator® abutments on the A block. Then the B block was placed over the housings and adequate relief for the housing was confirmed. The metal housings were picked-up in the B blocks using auto-polymerizing acrylic resin (Clear Ortho-Jet acrylic resin). A wooden spacer (2 mm thickness) was used to provide space between the A and B blocks while the clear acrylic cured. The same procedure was then repeated for the OT equator.

Following polymerization, the A and B blocks were separated, and the wood spacer removed. The surface of the B block was coated with a thin film of petroleum jelly. A layer of viscogel soft lining material was then flowed onto the surface of the A block, and the B block was reseated. The viscogel material was allowed to fully set prior to separation of the blocks. The viscogel layer was to acts as a soft tissue substitute which served to simulate the resilience of intraoral tissues during testing, and also served to accommodate any vertical resiliency of the attachment system. Finally, the black processing inserts were removed and replaced with the corresponding nylon inserts for each attachment system.

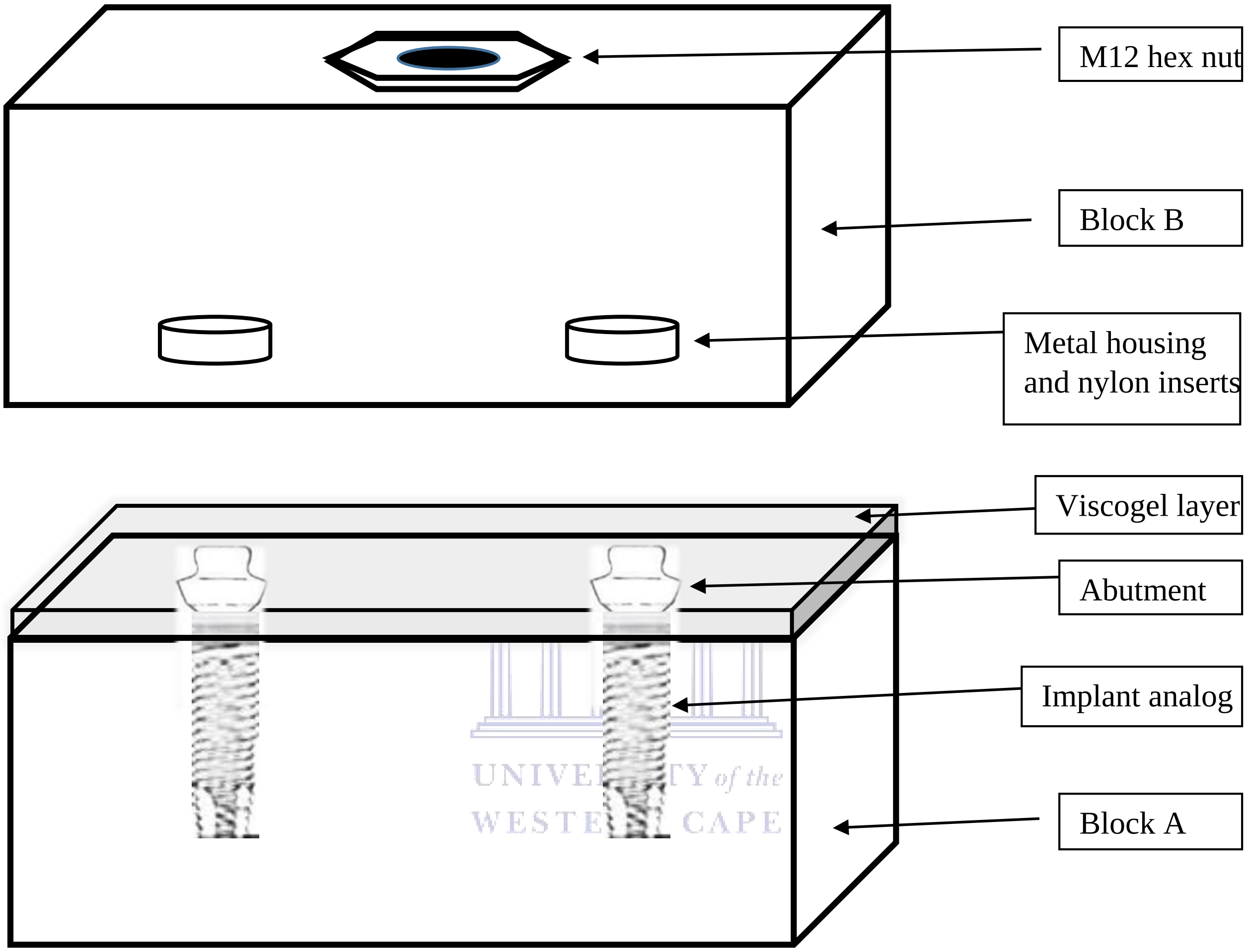


Figure 3.3: The final block A and B

The nylon inserts chosen for this study was pink nylon insert for Locator® attachment systems and clear nylon inserts for OT equator attachment systems. Both nylon inserts are considered as standard retention for both the attachment systems.

The first A block received 1.78 mm Locator® abutment (Zest Anchors, Escondido, CA, USA) with 2 mm cuff height, and the second A block received 1.7 mm standard OT equator abutment (MIS implant technologies GmbH, Minden, Germany) with 2 mm cuff height. All abutments were manually torqued at 20 N/cm, as per manufacturers' recommendations.

Figure 3.4: Locator® abutment

Figure3.5: OT equator abutment

A radiograph was taken of all study samples to check the parallelism of the attachment components after been secured in place.

The retention properties of different sample attachments were measured using the universal material testing machine (Zwick 1446, Zwick GmbH & Co, Germany) and software TestXpert V11.02 was used, the machine was set for crosshead speed 50mm/min. While the A block was placed in position parallel to the horizontal plane and securely tightened to the machine, and the B block was attached to the moving arm of the universal material testing machine. The minimal required force for dislodgement was recorded in Newtons. The initial dislodgement force was recorded for all study samples.

The cyclic fatigue was performed for 60 cycles of removal and placement, which was carried out as 57 cycles to be performed manually by one operator and 3 cycles by the testing machine.

According to Zarb *et al* (2003), patients tend to remove/place an overdenture prosthesis 4 times a day. Based on this assumption the number of removal and placement cycles can be calculated to simulate the time usage of the overdenture using the equation (Days = number of cycles/4).

Based on this equation, the study samples in this study were examined after every 60 cycles of dislodgement to simulate 15 days of usage. Each sample was tested 24 times to simulate 1 year of usage. Saline solution (0.9% NaCl) was used to lubricate the attachments' components during removal and placement cycles to simulate saliva.

3.4 Data collection methods

24 records for each study sample was recorded on a master sheet in MS Excel® software, matched with the number of the simulated time recorded in months. Each reading calculated as the mean of the 3 readings recorded by the universal material testing machine (Zwick). The 24 records accumulatively gave a result of 1 year of simulated usage.

3.5 Data analysis

Data was analyzed using SPSS software V22. Means and standard deviations were calculated. An independent T-test was used to compare the retention means of the two attachment systems at each of the 24 retention measures. A p value less than 0.05 was considered statistically significant.

CHAPTER FOUR

Results

The data was collected as 3 retention values for each sample measured after 57 manual removal and insertion cycles. The calculated mean of the 3 readings was considered as the final retention value after the 60 cycles. 24 retention values were measured for each sample in this study. The retention values of the 2 types of attachment was compared by SPSS V22 software using independent samples T test. P value less than 0.05 were considered significant.

The mean of the initial retention of Locator® with pink nylon inserts was 45.42±2.43N, in comparison to 37.29±6.27 N for OT equator with the clear nylon inserts. These results were statistically insignificant, p value = .104.

In month 3 (360 cycles) the difference in retention was significant, P value = 0.003 with retentive values of 46.99±3.25 N and 34.09±1.34 N for Locator® and OT equator respectively.

However, in month 6 (720 cycles) the retentive values for both attachment systems was reduced to measure 35.91±1.29 N for Locator® and 26.28±7.01 N for OT equator. Test for significance revealed a marginal p value of 0.08.

The retention values recorded in the period extending from month 10 (1200 cycle) untill the end of study in month 12 (1440 cycles) showed statistical significant difference (p value < 0.05). At the end of 12 months of the clinical simulation the Locator® retention values was 30.57±2.70 N and 20.60±2.84 N for Equator. The final results showed a significant difference, p value of 0.012. (Table 1)

The Locator® showed a loss of more than 25% of the initial retention at month 7 (840 cycles) which was recorded at earlier stage in OT equator in month 5.5 (660 cycles). (Table 2)

At the end of study (1440 cycles) Locator® shows a total loss of 33% of the initial retention hence it recorded 30.5 N, in comparison to 45% of the initial retention recorded in OT equator with a retention of 20.6 N. (Table 2)

Table (1): The retentive measures of Locator® and OT equator over 1440 insertion-removal cycles:

	Locator®		OT equator		
	Mean	**SD**	**Mean**	**SD**	*P value
Initial	45.42	2.43	37.29	6.27	0.104
0.5 Month	43.10	4.74	38.59	6.63	0.391
1 Month	41.34	5.01	37.54	5.57	0.43
1.5 Month	44.95	2.25	36.99	5.30	0.075
2 Months	43.74	1.63	39.50	4.52	0.201
2.5 Months	46.28	4.27	35.74	8.45	0.126
3 Months	46.99	3.25	34.09	1.34	0.003**
3.5 Months	47.62	3.10	35.28	2.19	0.005**
4 Months	42.33	0.51	33.15	5.48	0.045**
4.5 Months	38.51	3.85	29.02	4.93	0.058
5 Months	35.64	4.05	28.34	5.42	0.135
5.5 Months	36.37	0.34	25.48	4.90	0.018
6 Months	35.91	1.29	26.28	7.01	0.08
6.5 Months	36.99	0.37	26.79	8.03	0.159
7 Months	33.51	0.58	27.22	4.98	0.158
7.5 Months	35.44	3.09	26.54	5.85	0.08
8 Months	33.58	5.23	27.34	4.17	0.181
8.5 Months	32.56	4.14	27.19	5.32	0.24
9 Months	33.93	0.77	26.43	5.20	0.069
9.5 Months	31.86	0.94	25.62	5.20	0.169
10 Months	31.53	2.82	23.61	2.08	0.017**
10.5 Months	31.04	1.43	21.16	1.71	0.002**
11 Months	31.90	2.43	21.07	2.39	0.005**
11.5 Months	31.55	1.42	20.45	2.06	0.002**
1 Year	30.57	2.70	20.60	2.84	0.012**

Independent samples T test performed ****p value is significant***

Table (2): The percentage retention compared to the initial values over 1440 insertion-removal cycles:

	Locator®	%	OT equator	%
Initial	45.42	100	37.29	100
0.5 Month	43.10	95	38.59	103
1 Month	41.34	91	37.54	101
1.5 Month	44.95	99	36.99	99
2 Months	43.74	96	39.50	106
2.5 Months	46.28	102	35.74	96
3 Months	46.99	103	34.09	91
3.5 Months	47.62	105	35.28	95
4 Months	42.33	93	33.15	89
4.5 Months	38.51	85	29.02	78
5 Months	35.64	78	28.34	76
5.5 Months	36.37	80	25.48	68
6 Months	35.91	79	26.28	70
6.5 Months	36.99	81	26.79	72
7 Months	33.51	74	27.22	73
7.5 Months	35.44	78	26.54	71
8 Months	33.58	74	27.34	73
8.5 Months	32.56	72	27.19	73
9 Months	33.93	75	26.43	71
9.5 Months	31.86	70	25.62	69
10 Months	31.53	69	23.61	63
10.5 Months	31.04	68	21.16	57
11 Months	31.90	70	21.07	57
11.5 Months	31.55	69	20.45	55
1 Year	30.57	67	20.60	55

Throughout this study the mean retention recorded for Locator® during 12 month (1440 cycle) was 37.71 ± 5.77 N, with maximum mean retention recorded at 3.5 month (420 cycle) which was 47.62 N. The mean retention for OT equator was 29.25 ± 6.08 N, with the highest mean retention recorded at 39.5 N which recorded at month 2 (240 Cycles). (Table 3)

Table (3): The retention values throughout 1440 cycles:

	Locator®	OT equator
Initial reading	45.42	37.29
Final reading	30.57	20.6
Difference	14.85	16.69
Mean	37.71	29.25
Standard Deviation	5.77	6.08
Maximum	46.99	39.5
Minimum	30.57	20.45

The three Locator® system samples showed similar curve trends, characterized by a slight increase in retention after approximately 200 cycles. The curve reached its peak by cycle 350 and then started to drop rapidly until it reached a relatively more stable retention in cycle 650. After 650 cycles there is slight loss of retention which continues till the end of the experiment. Figure (4.1)

On the other hand, the OT equator samples was not homogenous. Although similar to the Locator® there was continuous loss of retention throughout the experiment. The OT equator samples didn't show the trend of increasing retention in the first cycles which was noticed in the Locator® samples. Figure (4.2)

Figure 4.1: Average Retention values of Locator® samples

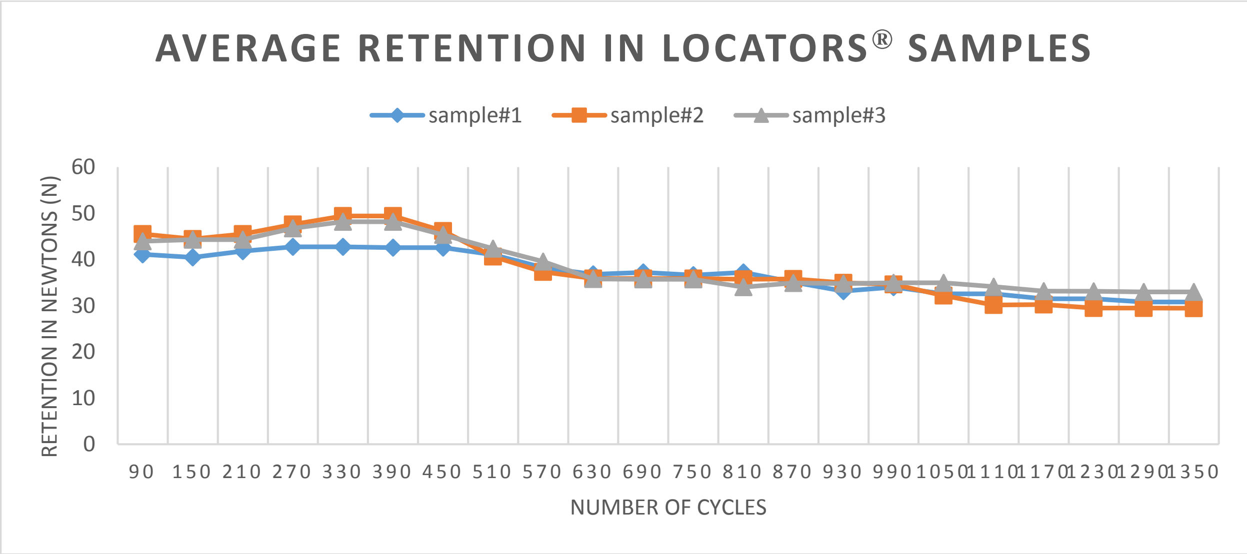
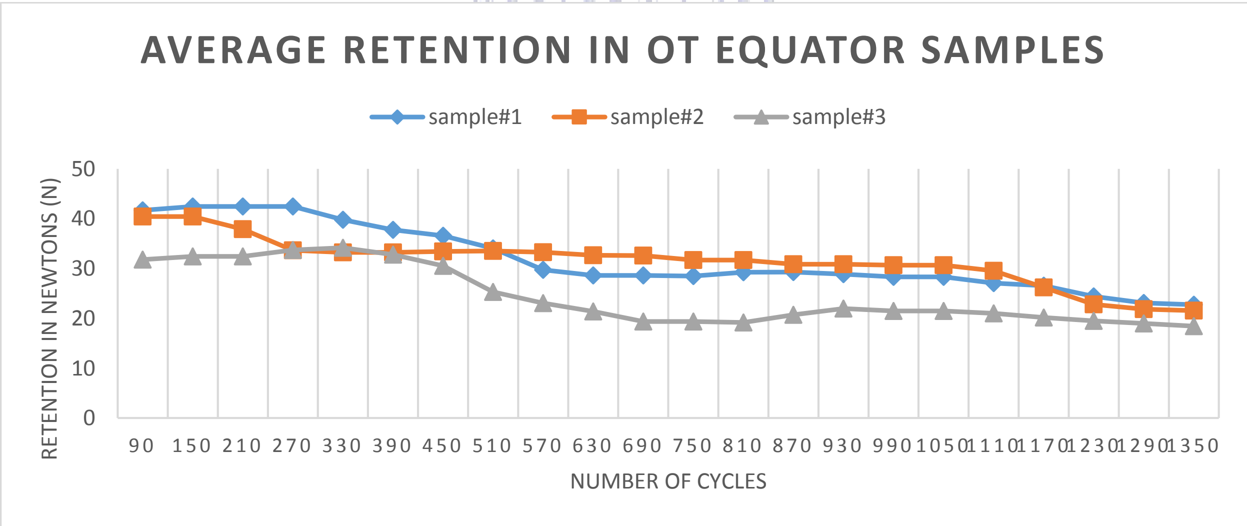


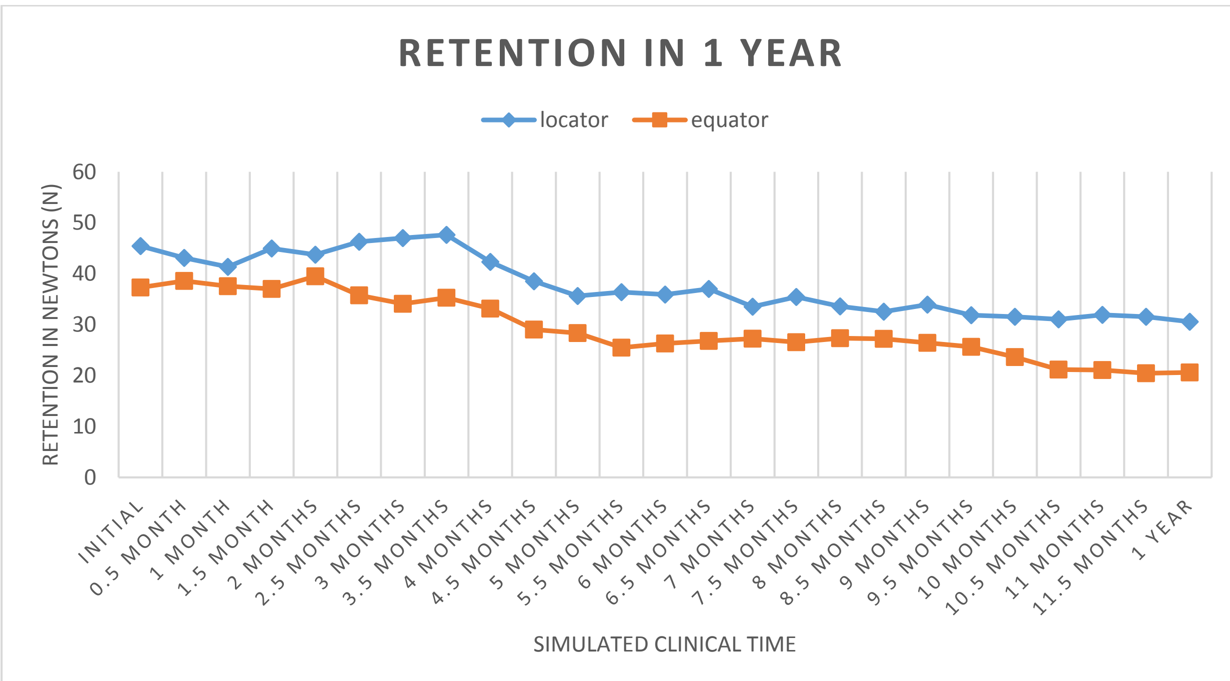
Figure 4.2: Average Retention values of OT equator samples



The curves generated after calculating the mean of the 3 samples is displayed in Figure 4.3. The two curves showed similarity in retention values during the first 2 months of clinical simulation.

After month 3 the retention curves of the two attachment systems showed some differences. The Locator® curve showed an increase in retention while the OT equator curve continued to show a loss in retention. However, in month 5 to the end of the experiment the two curves shows similar trends characterized by a continuous loss of retention. (Figure 4.3)

Figure 4.3: Comparison between mean retention values of Locator® and OT equator:



CHAPTER FIVE

Discussion

5.1 Introduction

The aim of the study was to compare the retentive properties of Locator® and OT equator overdenture attachment systems when placed over 2 implants. The pink nylon insert was used for Locator® and clear nylon insert used with OT equator.

5.2 Initial retention values

In this study, the mean initial retention values of Locator® attachment provided with pink nylon inserts was 45.4±2.43N even though was higher than the mean retention value recorded by OT equator (37.3±6.27 N). These initial results was statistically not significant (p value = 0.104). It showed a superior initial retention of the Locator® attachment which was approximately 8 N higher..

Greenbaum (2011), examined the retentive values of Locator® attachments with initially placed pink nylon-inserts compared to replacement pink nylon-inserts. In this in vitro study, five test samples of implant retained overdentures were prepared. Each attachment was tested with the initially placed pink nylon-insert and then with a replacement nylon-insert. Both the groups were tested for 2920 cycles. They recorded an initial retentive values of 47.72 ± 14.1N and 51.16±13.2N for the initially placed pink nylon inserts and the replacement pink nylon inserts respectively. This result is similar to the result recorded in our study (45.4±2.43N) where the initial pink nylon inserts were used in our experiment.

The mean initial retention recorded for Locator® pink nylon inserts in our study was slightly higher than the mean initial retention (33.5±9.77 N) recorded by Kobayashi (2013) for Locator® blue nylon inserts. Their investigation included subjecting three different types of attachments to 14,600 cycles of dislodgment. The reason for the mean difference in initial retention could be due to the use of blue nylon inserts which have less retentive properties than the pink nylon inserts.

A study conducted by Rutkunas *et al* (2005), assessed 3 samples of Locator® pink nylon inserts in a single implant setup. The samples were subjected to 2000 dislodgment cycles. Their results showed an initial retention of 10.6 N for the Locator® attachment with the pink nylon insert. However, it is difficult to compare this results to our results where 2 implants were used. In another study conducted by the same author, a value of 15.20 ± 6.9 N was the initial retention recorded for Locator® attachment pink nylon insert retained by single implant. (Rutkunas *et al*, 2011)

In 2004, Chung *et al* investigated the retention of the Locator® attachment system with clear nylon inserts over 540 cycles of repeated insertions and removals. In their experiment the Locator® attachment system were retained by two implants placed parallel to each other. They recorded initial retention of 42.19 ± 3.41 N. Although the clear nylon inserts had higher retentive properties than pink nylon insert, their result was lower than the result recorded in our study. In 2011, the same author then recorded a value of 86 N initial retention for Locator® system, but no mention of the type of the nylon inserts used in their study. (Chung, *et al*, 2011).

Alghafli *et al* 2009, investigated the effect of cyclic dislodgement on the retention of an overdenture attachment system when 2 implants were placed at different angulations. For the 2 implants at zero angulation, clear nylon inserts were used and an initial retentive value of 81.31N was recorded. These result were higher than the initial retention measured for the Locator® attachment pink nylon insert in our study and also higher than the initial retention measured in other studies (Chung *et al*, 2004).

5.3 The reduction in retention

All study samples showed reduction in retention after cyclic fatigue. These findings are consistent with the result of most in vitro studies investigating the retentive properties of attachment systems (Alsabeeha *et al*, 2009). The behavior of reduction on retention may differ between different attachment systems. In this study, the Locator® system with pink nylon inserts showed stability in the first few cycles with an initial retention force measure of 45.42±2.43 N, shortly thereafter there was an increase in the retention till reaching a peak at cycle 420 (month 3.5) with retention of

47.62±3.1 N. Shortly thereafter a rapid reduction in Locator® retention was recorded and continued till reaching a relatively more stable retention at cycle 600 (month 5) with a retention of 35.64±4.05 N. However, reduction in retention continues up to the cycle 1440 with a final retention recorded at 30.57±2.7 N. (Figure 4.3)

The occurrence of increasing retention in the Locator® system was previously reported by Kobayashi *et al* (2013). In this study, Locator® attachment system and the two implants set up showed an initial mean retention of 33.5±9.77 in the first 10 cycles, followed by a sharp increase in retention was reported up to cycle 100 (51.9±13.06 N). Between cycle 1000- 5000 the retention dropped below the initial retention values..

The increase in retentive properties of the attachment system was unexpected, and could be explained by the effect of the first cycles on the surfaces of the nylon inserts, which might cause irregularities in the body of the nylon insert, increasing the friction between the nylon insert and the abutment. The dual retention feature of Locator® system and the relatively wider surface area of the Locator® nylon insert must aid in magnifying the effect of friction between the two components,

The OT equator system shows relatively more constant behavior of retention reduction, where the reduction behavior recorded could be roughly divided into 3 stages; The first stage dominated by stability of retention up to cycle 240 (month 2) at that point the retention was 39.50±4.52 N. The second stage showed a continuous reduction in retention up to cycle 660 (month 5.5) where the mean retention measured 25.48±4.90 N. The third stage was similar to the first, where the retention values stabilized, with the final retention for OT equator at the end of the experiment being 20.60±2.84 (Figure 4.3).

The comparison between the two attachment systems, show that there was significant difference between 360 – 480 cycles (month 3 – month 4) This however, may be attributed to the increase in the retention of the Locator® system, accompanied by the reduction in retention in OT equator system at the same level. (Table 1) and (Figure 4.3)

Between cycle 1200 and 1440 (month 10 – month 12), a significant difference in the retention between the two attachment systems was seen. This could be related to the fact that Locator®

attachment showing more stable retention at this level when compared to OT equator system. (Table 1) and (figure 4.3)

5.4 The percentage of retention loss

At the end of this experiment, the Locator® system lost 33% of the initial retention compared to 45% in OT equator system. This could be due to the wider surface area for retention in the Locator® in comparison to the OT equator.

Similar results were recorded by Rutkunas *et al* (2005), who reported a loss of 30% of the initial retention of Locator® pink insert after 2000 cycles. Greenbaum (2011) found that after 2920 dislodgement cycles, a reduction of 25.8% for the initially placed pink nylon inserts and 50.4% for the replacement pink nylon was seen.

AlGafli *et al* (2009) calculated the number of dislodgement cycles required of the Locator® clear nylon insert to decrease from the initial values to certain percentages of retention loss. They reported that 217 dislodgment cycles were sufficient to cause a 25% reduction of the initial retention of Locator® clear inserts, 598 dislodgment cycles lead for a 50% reduction and 2313 lead for a 75% reduction.

Chung *et al* 2004, reported a 27.85 % loss of the initial retention of the Locator® clear nylon insert when they subjected it to 540 dislodgment cycles.

Jabbour *et al* (2013) investigated the loss of retention in Locator® attachments system with clear nylon insert in 24 patients. They reported that Locator® attachments system lost around 70% of their initial retention by the end of the study, with approximately 50% of retention loss occurring within the first 3 months of clinical function.

5.5 Wear of the nylon inserts

This study also assessed the visible physical changes to the body of the nylon inserts. All study samples were subjected to microscopic inspection after 360, 720, 1080 and 1440 cycle of dislodgment. Minor changes in the body of the nylon inserts were observed at the early stages. However, slight deformation was noticed after 1440 cycles.

The change in OT equator clear nylon inserts was minor and limited to the peripheral edges of the outer ring adjacent to the metal housing. Unexpectedly, two out of the six OT equator samples showed damage on the metal housing, the damage was superficial and limited in the size.

The body of the Locator® nylon insert showed changes in the inner retentive part of the nylon component, this phenomena was also reported by Jabbour *et al* (2013), where micro-computed tomography (mCT) of the Locator® clear nylon insert showed early deformation of the peripheral edges of the internal core after 1 week of clinical service.

On the other hand, limited deformation was seen in the peripheral edges of the outer ring of the Locator® attachment nylon insert and no changes were observed in the metal housing.

Rutkunas *et al* (2011) also investigated the dimensional change in the body of the pink Locator® attachment nylon insert and reported a decrease of 5.34% of the inner diameter of the plastic core, 2.1% in the inner diameter of the plastic ring and 0.88% in the inner diameter of the metal housing.

CHAPTER SIX

Conclusion and recommendation

Within the limitations of this in vitro study it can be concluded that both attachment system i.e Locator® and OT equator showed a reduction in retention after cyclic fatigue period.

Locator® attachment system used with pink nylon inserts showed superior retentive properties when compared to OT equator clear nylon inserts.

However, after 1 year of simulated clinical use both attachments showed retention values above 20 N, which is suggested by Setz and Engel (1998) to be the minimum retention required to retain implant supported overdentures.

The total loss of retention recorded after simulated 1 year of clinical usage necessitates the replacement of the nylon inserts components of these attachment systems to maintain constant and reliable retention for overdentures. On the other hand, this will help prevent damage to abutments or the metal housing that might follow the wear of the nylon inserts.

The cost of maintenance is also a factor to be considered when selecting the implant overdenture attachment system, OT equator attachments system is considered more cost-effective option in relation to the cost of replacing the Locator® nylon inserts.

Recommendation: Further research is needed to evaluate the retentive properties of these components for longer periods of cyclic fatigue. Also further research is recommended to test the retention properties of the other nylon inserts and retention with different implant angulations.

Future consensus in the methods of investigating the retentive properties of overdenture attachment systems is highly recommended for the applicability of comparison of results.

Annexure

Annexure 1: Data Collection sheet

		Locator®				OT equator		
		Sample 1	**Sample 2**	**Sample 3**		**Sample 1**	**Sample 2**	**Sample 3**
Initial	**Reading 1**							
	Reading 2							
	Reading 3							
	Mean							
0.5 Month	**60**							
1 Month	**120**							
1.5 Month	**180**							
2 Months	**240**							
2.5 Months	**300**							
3 Months	**360**							
3.5 Months	**420**							
4 Months	**480**							
4.5 Months	**540**							
5 Months	**600**							
5.5 Months	**660**							
6 Months	**720**							
6.5 Months	**780**							
7 Months	**840**							
7.5 Months	**900**							
8 Months	**960**							
8.5 Months	**1020**							
9 Months	**1080**							
9.5 Months	**1140**							
10 Months	**1200**							
10.5 Months	**1260**							
11 Months	**1320**							
11.5 Months	**1380**							
1 Year	**1440**							

Annexure 2:

Figure 1: *sample of final Block B*

Figure 2: *A measurement of 2 points 22 mm from each other and with equal distance from the edges of the block*

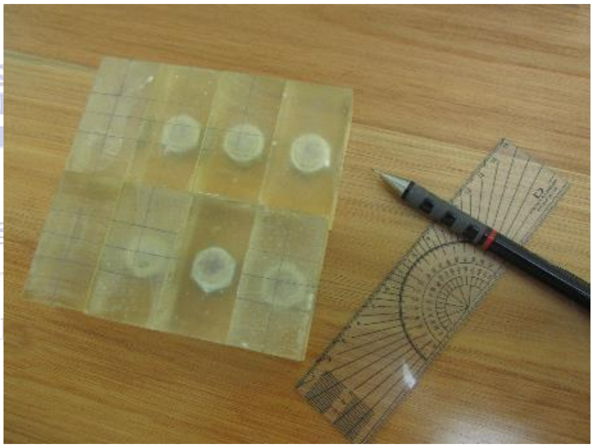


Figure 3: *Application of Viscogel layer to the samples*

Figure 4: A radiograph of Locator® attachment system sample

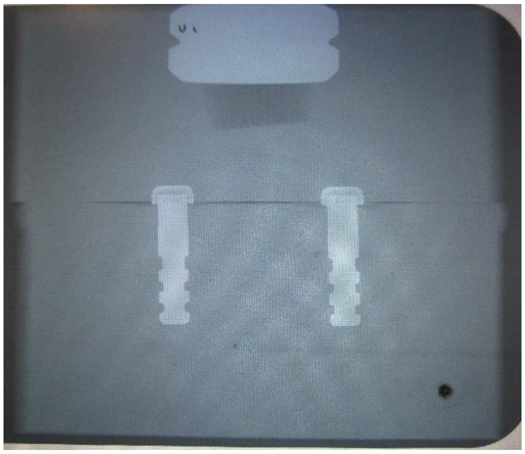


Figure 5: A radiograph of OT equator attachment system sample

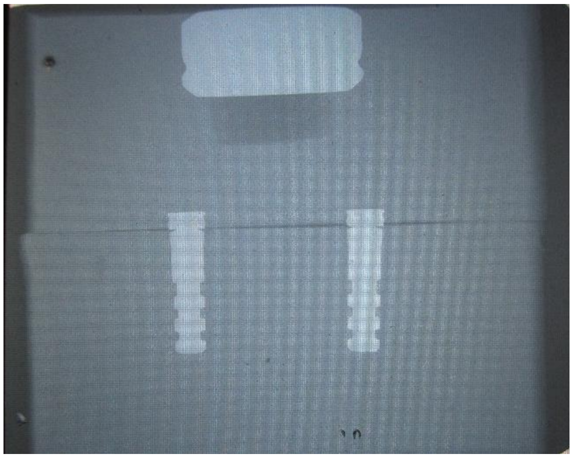


Figure 6: The abutment of the OT equator attachment system

Figure 7: The abutment of the Locator® attachment system

Figure 8: New clear nylon insert of the OT equator attachment system

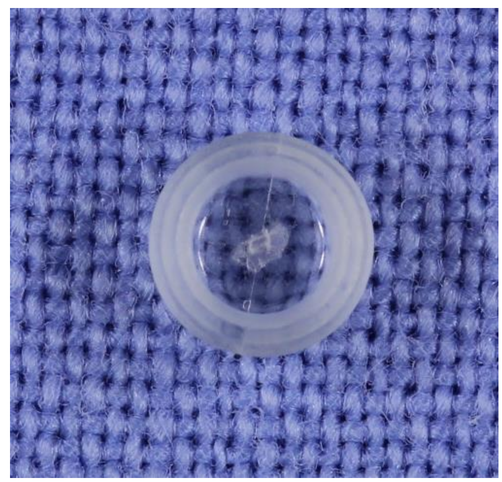


Figure 9: New pink nylon insert of the Locator® attachment system

Figure 10: Study sample attached to the universal material testing machine

Figure 11: OT equator male component after 1440 cycle, damage to the metal housing was noticed

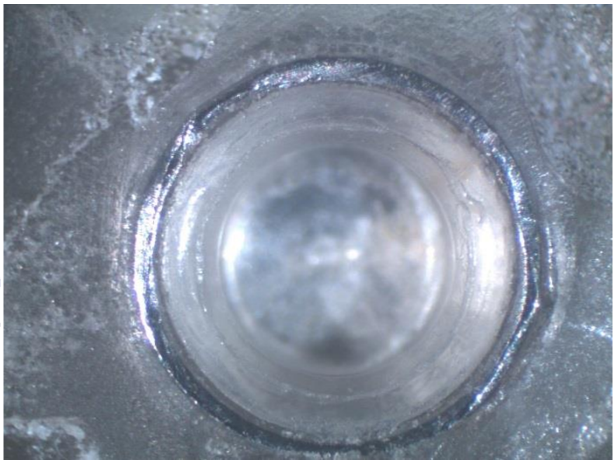


Figure 12: Locator® male component after 1440 cycle, damage noticed in the internal retention section

References

Al-Ghafli, S., Michalakis, K., Hirayama, H. & Kang, K., 2009. The in vitro effect of different implant angulations and cyclic dislodgement on the retentive properties of an overdenture attachment system. *J Prosthet Dent*, 102(3), pp. 140-7.

Alsabeeha, N., Atieh, M., Swain, M. & Payne, A., 2010. Attachment systems for mandibular single-implant overdentures: an in vitro retention force investigation on different designs. *Int J Prosthodont*, 23(2), pp. 160-6.

Alsabeeha, N., Payne, A. & Swain, M., 2009. Attachment systems for mandibular two-implant overdentures: a review of in vitro investigations on retention and wear features. *Int J Prosthodont,* 22(5), pp. 429-40.

Anusavice, K., 1996. *Phillips' science of dental materials. 10th ed.* Philadelphia: WB Saunders.

Becerra, G. & MacEntee, M., 1987. A classification of precision attachment. *J Prosthet Dent*, 58(3), pp. 322-7.

Besimo, C. & Guarneri, A., 2003. In vitro retention force changes of prefabricated attachments for overdentures. *J Oral Rehabil*, 30(7), pp. 671-8.

Brånemark, PI; Hansson, BO; Adell, R; Breine, U; Lindström, J; Hallén, O; Ohman,A, 1977. Osseointegrated implants in the treatment of the edentulous jaw. Experience from a 10-year period. *Scand J Plast Reconstr Surg Suppl,* Volume 16, pp. 1-132.

Burns, DR, 2004. The mandibular complete overdenture. *Dent Clin North Am,* 48(3), pp. 603-23.

Burns, D., Unger, J., Elswick, R. & Giglio, J., 1995. Prospective clinical evaluation of mandibular implant overdentures: Part II--Patient satisfaction and preference. *J Prosthet Dent*, 73(4), pp. 364-9.

Chung, KH; Whiting, D; Kronstrom, M; Chan, D; Wataha, J, 2011. Retentive characteristics of overdenture attachments during repeated dislodging and cyclic loading. *Int J Prosthodont*, 24(2), pp. 127-9.

Chung, K., Chung, C., Cagna, D. & Cronin, R., 2004. Retention characteristics of attachment systems for implant overdentures. *J Prosthodont*, 13(4), pp. 221-6.

Crum, R. & Rooney, G., 1978. Alveolar bone loss in overdentures: a 5-year study. *J Prosthet Dent*, 49(6), pp. 610-3.

Cune, M., van Kampen, F., van der Bilt, A. & Bosman, F., 2005. Patient satisfaction and preference with magnet, bar-clip, and ball-socket retained mandibular implant overdentures: a cross-over clinical trial. *Int J Prosthodont*, 18(2), pp. 99-105.

Doukas, D., Michelinakis, G., Smith, P. & Barclay, C., 2008. The influence of interimplant distance and attachment type on the retention characteristics of mandibular overdentures on 2 implants: 6-month fatigue retention values. *Int J Prosthodont*, 21(2), pp. 152-4.

Ettinger, R., 1992 . *overdentures: a longitudinal perspective.* Iowa: *University of Sydney press*

Feine, J.S; Carlsson, G. E.; Awad, M.A.; Chehade, A.; Head, T.; Lund, J.P.; MacEntee, M.; Mericske-Stern, R.; Mojon, P.; Morais, J.A.; Naert, I.; Payne, A.G.T.; Penrod, J.; Taylor, T.D.; Wismeijer, D., 2002. The McGill Consensus Statement on Overdentures. Mandibular 2-implant overdentures as first choice standard of care for edentulous patients. *Eur J Prosthodont Restor Dent*, 10(3), pp. 95-6.

Glossary of implant terms, 2007. Oral implantology. Glossary of implant terms. *J Oral Implantol*, Volume Suppl 1, pp. 2-14.

Greenbaum, D. S., 2011. Effect of simulated loading on the locator attachment system:a comparison between the retentive values of locator attachments with initially placed nylon-inserts and replacement nylon-inserts: an in-vitro study. MSc thesis. altimore College of Dental Surgery: University of Maryland

Gulizio, M., Agar, J., Kelly, J. & Taylor, T., 2005. Effect of implant angulation upon retention of overdenture attachments. *J Prosthodont*, 14(1), pp. 3-11.

Jabbour, Z; Fromentin, O; Lassauzay, C; Abi Nader, S; Correa, JA; Feine, J, 2013. Effect of Implant Angulation on Attachment Retention in Mandibular Two-Implant Overdentures: A Clinical Study. *Clin Implant Dent Relat Res.*

Jacobs, R. & van Steenberghe, D., 1994. Role of periodontal ligament receptors in the tactile function of teeth: a review. *J Periodontal Res,* 29(3), pp. 153-67.

Kim, H., Lee, J., Shin, S. & Bryant, S., 2012. Attachment systems for mandibular implant overdentures: a systematic review. *J Adv Prosthodont,* 4(4), pp. 197-203.

Kobayashi, M. et al., 2013. Effects of in vitro cyclic dislodging on retentive force and removal torque of three overdenture attachment systems. *Clin. Oral Impl. Res.* , Volume 00, p. 1–9.

Laney, WR; Broggini, N; Cochran, DL; Giannobile, WV; Hjørting-Hansen, E; Taylor, TD, 2007. *Glossary of Oral and Maxillofacial Implants.* Berlin

Lehmann, K. & Arnim, F., 1978. Studies on the retention forces ofsnap-on attachments. *Quintes Dent Technol,* Volume 7, p. 45–48.

Melas, F., Marcenes, W. & Wright, P., 2001. Oral health impact on daily performance in patients with implant-stabilized overdentures and patients with conventional complete dentures. *Int J Oral Maxillofac Implants,* 16(5), pp. 700-12.

Michelinakis, G., Barclay, C. & Smith, P., 2006. The influence of interimplant distance and attachment type on the retention characteristics of mandibular overdentures on 2 implants: initial retention values. *Int J Prosthodont,* 5(19), pp. 507-12.

MIS product catalog MIS technologies LTD:2013.

Morrow, R., Feldmann, E., Rudd, K. & Trovillion, H., 1969. Tooth-supported complete dentures: an approach to preventive prosthodontics.. *J Prosthet Dent,* Volume 21, pp. 513-22.

Petropoulos, V. & Smith, W., 2002. Maximum dislodging forces of implant overdenture stud attachments. *Int J Oral Maxillofac Implants,* 17(4), pp. 526-35.

Pigozzo, M., Mesquita, M., Henriques, G. & Vaz, L., 2009. The service life of implant-retained overdenture attachment systems. *J Prosthet Dent,* 102(2), pp. 74-80.

Preiskel, H. W., 1996. *Overdentures Made Easy: A Guide to Implant and Root Supported Prostheses.* 1 ed. London: Quintessence.

Rutkunas, V., Mizutani, H. & Takahashi, H., 2005. Evaluation of stable retentive properties of overdenture attachments. *Stomatologija,* 7(4), pp. 115-20.

Rutkunas, V, Mizutani, H. & Takahashi, H., 2007. Influence of attachment wear on retention of mandibular overdenture. *J Oral Rehabil*, 34(1), pp. 41-51.

Rutkunas V., Mizutani H., Takahashi, H., Iwasaki, N., 2011. Wear simulation effects on overdenture stud attachments. Dent Mater J. 30(6), pp. 845–853.

Sadig, W., 2009. A comparative in vitro study on the retention and stability of implant-supported overdentures. *Quintessence Int*, 40(4), pp. 313-9.

Sadowsky, S. & Caputo, A., 2000. Effect of anchorage systems and extension base contact on load transfer with mandibular implant-retained overdentures. *J Prosthet Dent*, 84(3), pp. 327-34.

Setz, I., Lee, S. & Engel, E., 1998. Retention of prefabricated attachments for implant stabilized overdentures in the edentulous mandible: an in vitro study. *J Prosthet Dent*, 80(3), pp. 323-9.

The glossary of prosthodontic terms, 2005. *J Prosthet Dent*, 94(1), pp. 10-92.

Trakas, T., Michalakis, K., Kang, K. & Hirayama, H., 2006. Attachment systems for implant retained overdentures: a literature review. *Implant Dent*, 15(1), pp. 24-34.

van Steenberghe, D., Quirynen, M., Calberson, L. & Demanet, M., 1987. A prospective evaluation of the fate of 697 consecutive intraoral fixures ad modum Brånemark in the rehabilitation of edentulism. *J Head Neck Pathol*, Volume 6, pp. 53-58.

Walton, J., Huizinga, S. & Peck, C., 2001. Implant angulation: a measurement technique, implant overdenture maintenance, and the influence of surgical experience. *Int J Prosthodont*, 14(6), pp. 523-30.

Wiemeyer, A., Agar, J. & Kazemi, R., 2001. Orientation of retentive matrices on spherical attachments independent of implant parallelism. *J Prosthet Dent*, 86(4), pp. 434-7.

Zarb, G., 2003. *Prosthodontic treatment for edentulous patients: complete dentures and implant-supported prosthes*. 12th ed ed. St. Louis: Mosby.

Zarb, G. & Schmitt, A., 1995. Implant prosthodontic treatment options for the edentulous patient. *J Oral Rehabil*, 22(8), pp. 661-71.

Zest Locator® brochure, Escondido, CA, USA: Zest Anchors, 2011.