THE RETENTIVE FORCE REDUCTION OF DIFFERENT OT-EQUATOR CAPS AND REMOVAL TORQUE OF RETENTIVE COMPONENTS OF A MINI DENTAL IMPLANT SYSTEM UNDER CYCLIC DISLODGEMENT

THEERAYUT RATTANADECH

MASTER OF SCIENCE IN DENTISTRY

GRADUATE SCHOOL
CHIANG MAI UNIVERSITY
MARCH 2019

THE RETENTIVE FORCE REDUCTION OF DIFFERENT OT-EQUATOR CAPS AND REMOVAL TORQUE OF RETENTIVE COMPONENTS OF A MINI DENTAL IMPLANT SYSTEM UNDER CYCLIC DISLODGEMENT

THEERAYUT RATTANADECH

A THESIS SUBMITTED TO CHIANG MAI UNIVERSITY IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE DEGREE OF MASTER OF SCIENCE IN DENTISTRY

GRADUATE SCHOOL, CHIANG MAI UNIVERSITY
MARCH 2019

THE RETENTIVE FORCE REDUCTION OF DIFFERENT OT-EQUATOR CAPS AND REMOVAL TORQUE OF RETENTIVE COMPONENTS OF A MINI DENTAL IMPLANT SYSTEM UNDER CYCLIC DISLODGEMENT

THEERAYUT RATTANADECH

THIS THESIS HAS BEEN APPROVED TO BE A PARTIAL FULFILLMENT OF
THE REQUIREMENTS FOR THE DEGREE OF
MASTER OF SCIENCE
IN DENTISTRY

Examination Committee:

.... Chairman
(Prof.Dr. Peter A. Reichart)

.... Member
(Assoc.Prof.Dr. Pathawee Khongkhunthian)

.... Member
(Asst.Prof.Dr. Weerapan Aunmeungtong)

.... Member
(Lect.Dr. Pisaisit Chaijareenont)

Advisory Committee:

.... Advisor
(Assoc.Prof.Dr. Pathawee Khongkhunthian)

.... Co-advisor
(Asst.Prof.Dr. Weerapan Aunmeungtong)

1 March 2019

ACKNOWLEDGEMENTS

I would like to express my sincere thanks and appreciation to my advisor, Assoc. Prof. Dr. Pathawee Khongkhunthian for his precious suggestions and for supporting me to complete this thesis.

I wish to express gratitude to my co-advisor Assist. Prof. Dr. Weerapan Aunmeungtong for his professional guidance and help in improvement of this thesis.

My sincere appreciation is expressed to Faculty of Dentistry, Chiang Mai University for materials, equipment and financial support. I would like to acknowledge the Graduate School, Chiang Mai University, for research grants.

I would also like to express thankfulness to Lect. Dr. Kittisak Buddhachat, Department of Biology, Naresuan University and Dr. Thanapat Sastraruji, Dental Research Center, Faculty of Dentistry, Chiang Mai University, for their kind statistics advice and the use of testing machine in this research project and instructor.

I would like to thank Dr. M. Kevin O Carroll, Professor Emeritus of the University of Mississippi School of Dentistry, USA, and Faculty Consultant at Chiang Mai University Faculty of Dentistry, Thailand, for his assistance in the preparation of the manuscript.

My special thanks are also extended to all my friends and the staff of the Department of Implantology, Faculty of Dentistry, Chiang Mai University, for their support and helpful suggestions.

Last but not least, I would like to thank my family for their endless support.

Theerayut Rattanadech

หัวข้อวิทยานิพนธ์ การศึกษาการลดลงของแรงดึงและแรงบิดออกของส่วนหัวตัวยึดติดโอที อีเควเตอร์ที่แตกต่างกันในรากเทียมขนาดเล็กภายใต้กระบวนการให้แรงดึงเข้า-ออกทางเชิงกล

ผู้เขียน นายธีระยุทธ รัตนเดช

ปริญญา วิทยาศาสตรมหาบัณฑิต (ทันตแพทยศาสตร์)

คณะกรรมการที่ปรึกษา รศ.ทพ.ดร. ปฐวี คงขุนเทียน อาจารย์ที่ปรึกษาหลัก

ผศ.ทพ.ดร. วีระพันธุ์ อุ่นเมืองทอง อาจารย์ที่ปรึกษาร่วม

บทคัดย่อ

เพื่อศึกษาผลของการลดลงของแรงดึงและแรงบิดออกของส่วนหัวตัวยึดติดโอที อีเควเตอร์ที่แตกต่างกันในรากเทียมขนาดเล็กภายใต้กระบวนการให้แรงดึงเข้า-ออกทางเชิงกล ชิ้นงานรากเทียมพีดับบลิวพลัสและส่วนหัวตัวยึดติดโอที อีเควเตอร์ จำนวน 50 ชิ้นงาน แบ่งชิ้นงานเป็น 2 กลุ่ม ตามการเอียงตัวของรากเทียม (กลุ่มที่ 1 = 0 องศา และกลุ่มที่ 2 = 15 องศา) แบ่ง 5 กลุ่มย่อย ตามสีของยางส่วนหัวตัวยึดติดโอที อีเควเตอร์ ได้แก่ ยางสีดำ ยางสีเหลือง ยางสีชมพู ยางสีขาว และยางสีม่วง จำนวนกลุ่มละ 5 ชิ้นงาน ขันสกรูส่วนหัวตัวยึดติดโอที อีเควเตอร์ ด้วยแรงบิดเข้าขนาด 25 นิวตันเซนติเมตร ทดสอบชิ้นงานด้วยกระบวนการดึงเข้า-ออกทางเชิงกลจำนวน 2,880 รอบ ในน้ำปราศจากไอออน ทำการวัดแรงดึง ณ จุดเริ่มต้น รอบดึงเข้า-ออกที่ 360, 720, 1,440 และ 2,880 หลังจากสิ้นสุดการทดสอบ ทำการขันวัดแรงบิดออกของสกรูส่วนหัวตัวยึดติดโอที อีเควเตอร์ นำผลมาวิเคราะห์ทางสถิติชนิดความแปรปรวนแบบทางเดียวและสถิติการทดสอบค่าทีที่ระดับนัยสำคัญ 0.05

ผลการศึกษาวิจัยพบว่า ณ จุดเริ่มต้น พบยางสีม่วงที่ 0 องศา ให้ค่าแรงดึงมากที่สุด (33.24 ± 1.52 ถึง 21.95 ± 0.86 นิวตัน) ตามด้วยยางสีขาว ยางสีชมพู ยางสีเหลือง และยางสีดำอย่างมีนัยสำคัญทางสถิติ เมื่อรอบการทดสอบเพิ่มขึ้นพบแรงดึงออกของส่วนหัวตัวยึดติดโอที อีเควเตอร์ลดลงอย่างมีนัยสำคัญในยางกลุ่ม 15 องศามากกว่ายางกลุ่ม 0 องศา ยกเว้นยางสีดำ พบการลดลงของแรงบิดออกของสกรูส่วนหัวตัวยึดติดโอที อีเควเตอร์ เมื่อสิ้นสุดการทดสอบ อย่างไรก็ตามไม่พบความแตกต่างอย่างมีนัยสำคัญของแรงบิดออกระหว่างยางกลุ่ม 0 องศาและ 15 องศา

การเพิ่มขึ้นของรอบดึงเข้า-ออกทางเชิงกลและการเอียงตัวของรากของรากเทียมส่งผลต่อแรงดึงเข้า-ออกของส่วนหัวตัวยึดติดโอที อีเควเตอร์ พบการลดลงของแรงบิดออกหลังสิ้นสุดการทดสอบเปรียบเทียบกับแรงบิดเริ่มต้น อย่างไรก็ตามการเอียงตัวของรากเทียมไม่ส่งผลต่อแรงบิดออกอย่างมี

นัยสำคัญทางสถิติ ตัวยึดติดโอที อีเควเตอร์ในรากเทียมที่มีการเอียงมากขึ้นควรทำการติดตามผลการรักษา และอาจจะพิจารณาขันสกรูซ้ำเป็นประจำทุกปี

Thesis Title The Retentive Force Reduction of Different OT-Equator Caps and Removal Torque of Retentive Components of a Mini Dental Implant System Under Cyclic Dislodgement

Author Mr. Theerayut Rattanadech

Degree Master of Science (Dentistry)

Advisory Committee Assoc. Prof. Dr. Pathawee Khongkhunthien Advisor
Asst. Prof. Dr. Weerapan Aunmeungthong Co-advisor

ABSTRACT

The aim of this study was to evaluate the retentive force reduction of different OT-Equator caps and removal torque on retentive components in different angulation on mini dental implant under cyclic dislodgement. Fifty specimens of PW Plus mini implant and OT-Equator attachment models (n = 50) were divided into 2 groups based on implant angulations (Group I = 0°angle, Group II = 15°angle). Each group was divided into 5 subgroups (N = 5) based on weight-color coded of retentive caps (black, yellow, pink, white, violet). All screws were tightened to 25 Ncm. The cyclic dislodgement for a total of 2,880 cycles were carried out over the models immersed in deionized water. The retentive force at the initial and after 360, 720, 1,440 and 2,880 cycles were recorded. Then, after the final cycle, all screw abutments were un-tightened and measured for the removal torque. The data were analysed using One-way ANOVA and T-test with significant difference at $p<0.05$.

At initial cycle, the violet nylon inserts in 0° angle exhibited the highest retentive force over time (33.24 ± 1.52 N to 21.95 ± 0.86 N), with statistically significant differences followed by the white, pink, yellow and black nylon ($p<0.05$).The increase in cyclic dislodgement significantly reduced the retentive force of OT-Equator retentive caps in 15° than 0° angle excepted for the black cap. The removal torque also decreased at the final dislodging cycle. However, there were no significantly differences between removal torques of attachment components in different angulations ($p>0.05$). Increasing of cyclic dislodgement and implant angulation significantly affected on retentive force of OT-Equator attachment. The reduction of removal torque after 2,880 cycles compared to insertion

torque was found, however the implant angulation did not have significant influence on removal torque. OT-Equator with increased implant angulation required regular follow-up each year and screw re-tightening might be considered.

.

CONTENTS

CONTENTS (cont.)

LIST OF TABLES

LIST OF FIGURES

Page

CHAPTER 1

Introduction

1.1 Principles/ Theories and Rationales

Severe maxillary and mandibular atrophy is considered a poor health condition affecting quality of life due to compromising stability, support and retention of a removable denture, especially at mandible. Therefore, prosthetic management of mandibular edentulous arch has been challenging (1, 2). Implant-retained overdenture is an alternative treatment for patients who had undergone moderate to severe ridge resorption, which offers better esthetics, speaking ability, comfort, retention, and stability of the prosthesis. It also has some advantages over full arch fixed implant prostheses, such as fewer implants required and lower cost (3-5). A consensus statement from McGill University and the British Society for the Study of Prosthetic Dentistry stated that mandibular two-implant-retained overdenture was the first choice standard care of treatment (6, 7). Placement of the standard sized implants to retain the full denture provides patient satisfaction. However, in case of patients with severe alveolar bone resorption, bone augmentation may be required for implant placement, with the consequence of an increase in costs and treatment time (8).

The use of mini dental implant (MDI) is frequently offered as an alternative treatment procedure in many cases of limited ridge anatomy. The glossary of oral and maxillofacial implants defined MDIs as “implant fabricated of the same biocompatible materials as other implants but of smaller dimensions. Implant can be made as one piece to include an abutment designed for support and/or retention of a provisional or definitive prosthesis” (9). MDIs have diameters ranging from 1.8 to 3.3 millimeter and lengths ranging from 10 to 15 millimeter compare to standard-diameter implants which range from about 3.4 to 5.8 millimeter (10). They can be used in narrow atrophic edentulous ridge without bone augmentation. The advantages compared to standard size implants are that the technique is simple and involves minimally invasive surgery which preserves blood supply and bone height around the implants (11, 12). Therefore, it presents less complicated surgical morbidity, shorter healing duration and cost effectiveness of prostheses (12). The survival rate of MDI retained mandibular overdenture has been reported in the range of 81-97.4% after 3 years (12-14). Moreover, two and four MDIs have been reported to be immediately used successfully after a 1-year follow up for retaining lower complete dentures (15, 16). The clinical and radiographic peri-implant tissue responses of immediately loaded mini dental implants retained a mandibular overdenture were also found satisfactory after 3 years (14).

Various attachment systems have been utilized in order to achieve retention and stability of implant-overdentures. The selection of attachment systems should be considered regarding to jaw anatomy, mucosal ridge, oral function, long term outcomes of retention and prosthetic maintenance (17-20). Previous studies reported MDIs clinically used with bar and ball attachments (21, 22). Bar MDI-attachment systems for mandibular overdenture had better two-year survival rate (97.8%) when compared to ball attachment (90.0%) (22). Bar attachment provides more retention than ball attachment. However, bar design appeared to be technically sensitive in clinical and laboratory process. The prosthodontics maintenance requires higher cost with screw retightening and retainer adjustment (19). Ball attachment was considered the simplest design with favorable clinical outcomes. Nevertheless, gradual loss of retention was found to be the most common complication due to wear and damage of O-ring leading to replacement after 5 years of service (21). Stud attachments such as Locator (Zest Dental Solutions, Carlsbad, CA, USA) and OT-Equator (OT-Equator, Rhein83, Bologna, Italy) have been widely used due to attachment height reduction, favorable magnitude and stress distribution (18, 23, 24). Locator attachments are available in different vertical heights. They are resilient, retentive, and durable, and have some built-in angulation compensation. The repair and replacement are fast and easy. In addition, Locator attachments provide an adequate retention and better maintenance compared to ball and bar (19). Recently, OT-Equator attachment has been introduced for another low profile, small diameter (vertical height of 2.1 mm and diameter 4.4 mm) implant attachment supported removable denture which allowed implants divergence up to 30°. Implant assisted overdenture with OT-Equator can be used successfully without negatively affecting peri-implant tissues health (24). This form of attachment is affordable, simple use with various retention levels and easy for maintenance.

The success of implant-retained overdentures dominantly depends on the retentive capacity of its attachment component to maintain its long-term function. The movement between the retentive surfaces of an attachment during insertion and removal of the overdenture lead to wear and diminish retentive forces over time (25-29). In addition, the incidence of attachment loosening was reported in 30% regarding prosthetic implant complications which seem to be a common problem after insertion. Abutment screw loosening lead to implant prosthesis movement and unfortunately screw fracture (29). This evidence might be due to functional load on attachment component. Besides, implant malalignment has been reported to influence both loss of retention and removal torque on attachment component after the function (26).

The retention and removal torque behavior of OT-Equator on divergence implant angulation of MDI after simulated function are lack of available information. Therefore, the aim of the present study was to evaluate the retentive force reduction and removal torque of OT-Equator attachment on mini dental implant in different angulation under cyclic dislodgement. The null hypothesis of this study was that there were no significance differences of retentive forces and removal torque among different retentive components of OT-Equator after insertion-removal cycles.

1.2 Purposes of the study

To evaluate the reduction of retentive force of different OT-Equator and removal torque of retentive component of a mini dental implant retained overdenture system.

1.3 Hypothesis of the study

Null hypothesis: There is no difference in removal torque value and rate of removal force when OT-equator attachment received cyclic dislodgement on mini dental implant retained overdenture.

1.4 Anticipated benefits

To estimate time to replace retentive cap when used stud attachment on mini dental implant including time to retightened or changed the screw of attachment.

CHAPTER 2

Literature Review

The literature review is divided into four parts as follow:

2.1 Implant retained overdenture

2.2 Mini dental implants

2.3 Attachment system

2.4 Complication associated implant retained overdenture

2.1 Implant retained overdenture

Complete dentures have been the standard treatment for edentulous patients. However the lower denture poor retention affect to poor quality of life (30). Nowadays, implant-retained overdentures provide a good opportunity for dentists to improve the oral health of patients. Patients found the implant overdentures significantly more stable, and they rate their ability to chewing various foods as significantly easier. In addition, they are more comfortable and speak more easily with implant overdentures (31). There are many reasons for selecting an implant retained overdenture such as financial, patient prefers, oral hygiene, poor bone quality, extreme ridge defects and health status (5). The cost and performance information for implant mandibular overdenture may also permit practitioners and their patients to make more valid informed decisions.

A systematic review, Sadowsky et al. (32) represented the conclusion protocol for maxillary implant overdentures.

2.1.1 A maxillary implant overdentures gives a stabilized removable solution for the edentulous maxilla that enhanced patient satisfaction and oral health quality of life.

2.1.2 4 to 6 implants are generally applied in successful cohort studies.

2.1.3 When 4 or less implants are used for maxillary implant overdentures, an unsplinted attachment designs have a higher implant failure rate than splinted implants.

2.1.4 Implant-supported in maxillary overdenture that have more than 4 splinted-implant were found higher survival rates (>95%) when compares with less than 4 non-splint implants.

2.1.5 In general, both splinted and solitary anchorage systems are encouraged. Maintenance may be higher for solitary attachments. Increased soft tissue inflammation has been reported under bars.

For mandible, a consensus statement from McGill University suggests that a 2-implant overdenture should become the first choice of treatment for the edentulous mandible (6). Mandibular two-implant overdentures have been shown to be superior to conventional dentures in many clinical trials. Van Steenberghe et al. (33) proposed the placement of only 2 implants in the edentulous mandible. Their 98% success rate, with up to 52 months of observation, was encouraging. Mericske-Stern et al. (34) reported 97% implant survival with 2 implants (splinted or solitary), irrespective of keratinized tissue or duration of edentulism. Jemt et al. (35) reported 100% cumulative success rate for overdentures supported by 2 implants; the mean marginal bone loss was 0.5 mm during a 5-year period. Naert et al. (36) compared the clinical outcome of different overdenture anchorage systems and found 100% implant success after 5 years for all groups. Moreover, implant retained mandibular overdentures can immediately loaded to retained overdenture. Many study have been published regarding immediate loading of implants supporting an overdenture edentulous mandibles, reporting 97.6% survival rates of immediately loaded implants comparable with delayed loading (37-39).

2.2 Mini dental implants

Hjørting-Hansen et al. (40) wrote in glossary of oral and maxillofacial implants to defined mini dental implants as "implant fabricated of the same biocompatible materials as other implants but of smaller dimensions. Implant can be made as one piece to include an abutment designed for support and/or retention of a provisional or definitive prosthesis" and they reported from their literature reviews that mini dental implant have diameters from 1.8 mm. to 2.9 mm.

Flanagan and Mascolo (10) described mini dental implants have diameters ranging from 1.8 to 3.3 millimeter and lengths ranging from 10 to 15 millimeter. Standard-diameter implants range from about 3.4 to 5.8 millimeter. One advantage of mini dental implants is that it can be placed without raising a surgical flap, therefore making the procedure minimally invasive. The surgical procedure is simple and does not rely on any unpredictable grafting techniques. The technique involves minimal surgery and less complicated prostheses. Therefore it presents less surgical morbidity and cost when compared to standard implants.

Mini dental implants may be appropriate with narrow and atrophic edentulous ridges and also may be immediately loaded in the appropriate osseous situations (41).

Shatkin et al. (42) studied in mini dental Implants for long-term fixed and removable prosthetics concluded they are frequently used mini dental implants in many cases of limited ridge anatomy. Mini dental implants (MDIs) have diameters ranging from 1.8 mm to 2.4 mm. Small diameter implants are generally 2.75 mm to 3.3 mm in diameter.

Mini dental implants can retain maxillary or mandibular removable dentures. When placing in dense bone, mini dental implants can be immediately loaded to retain removable complete and partial dentures with more than 90% survival rate (43, 44). Edentulous people who treated with mini dental implants in nine dental practices revealed that the advantages of mini dental implants (minimally invasive, cost-effective and short treatment duration) could inspire elderly patients who suffering from various diseases to choose implants for the stabilization of their complete dentures (45).

A systematic reviews represented definitive prosthodontic treatment with mini dental implant.

2.2.1 The evidence for short-term survival of mini dental implants when used for definitive prosthodontic treatment in a one year interval survival rate of 94.7%. However, the follow-up period of many implants was reported to be less than 12 months.

2.2.2 Limited evidence for the medium term survival and no evidence for the long-term survival of mini implants when used for definitive prosthodontic treatment.

2.2.3 Current terminology in the literature does not differentiate between mini implants and narrow diameter dental implants.

The survival rate of mini dental implant has been reported. Aunmeungtong et al. (15) concluded that two and four mini dental implants can be immediately used successfully for retaining lower complete dentures, as shown after a 1-year follow up. Elsyad at el. (14) found clinical and radiographic peri-implants tissue responses of immediately loaded mini dental implants retained a mandibular overdenture were satisfactory after 3 years (survival rate and success rates were 96.4% and 92.9%)

A 5-year prospective study evaluated patient satisfaction and prosthetic aspects of mini dental implants retained overdenture in 112 fixtures concluded that patients have satisfied with MDI-retained mandibular overdentures in terms of daily life such as eating, comfort, healing process, socialization, stability/retention of mandibular dentures, oral hygiene, and ease of handling the dentures increased significantly with time (21). Tomasi at el. (28) reported the same result from a study of patient satisfaction with mini-implant stabilized full dentures. The placement of mini-implants as retentive component for full dentures with poor functional stability has a positive impact on the patients oral function and comfort as well in social life.

2.3 Attachment system

There are many commercially available attachment system for implant overdentures. These include Nobel Biocare ball attachments, OT-Equator, Zest Locator® and "O-ring" attachments, Sterngold ERA® attachments and various magnetic and bar attachments (46). Implant companies provide technical guideline for their own systems. The choice of attachment is a matter of personal preference. When multiple implants and bars are used and the denture is fully or almost fully implant-borne, it is necessary to consider a metal reinforcement, such as a cast metal framework within the overdenture base (46). Attachment retention forces from 5 to 7 N have been indicated to be sufficient for implant-retained overdentures during function (5).

The different types of attachments exhibit unique properties. The bar is useful when implants are nonparallel to place 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 and it allows the bar to connect to a nonparallel implant angulations. When more than two implants are used, parallel implant placement becomes 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 (19, 21, 22, 46).

Ball attachment connectors are popular due its simple design, and cost-effectiveness. The disadvantage of this system is the high-profile of its abutment which may limit its use especially in patients with narrow jaw anatomy (21). Although cost is an important factor to consider, ball attachments are less expensive when compared to other attachment types like Locator®.

The Locator attachment which was introduced in 2001 has become widely applied has several advantages over other systems. It has a low profile design that advantage for cases with limited inter-ridge space. This geometry has a role in spreading occlusal loads through the abutment to the implant in a more favorable magnitude and distribution because of the reduced lever arm length thus optimizing loads around dental implants. Another characteristic of the locator attachment is the dual retention through both external and internal mating surfaces that offers high durability and long lasting performance. However, this leads to limited lateral and hinge movement, which may be responsible for transferring more moment loads to the implant, thus increases the stress in the bone around the implant that may be contributed to increased vertical bone loss while decreasing the stress in the posterior residual ridge with less need for relining (18, 23).

The OT-Equator is a new line of low profile attachment. It is considered the smallest attachment system available with the least overall dimension (vertical height of 1.7 mm and 2.5 mm diameter). It combines the simplicity of ball attachments, with the variety of retention levels and easy replacement options of Locators (24). 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.

2.4 Complication associated implant retained overdenture

The success of implant-retained overdentures depends on the retentive capacity of its attachment component to sustain its long-term function. The movement between the retentive surfaces of an attachment during mastication and removal of the overdenture will lead to wear and diminish retentive forces over time (26, 47). Dunnen at el. (48) studies a three-year retrospective complications of mandibular implant-retained overdentures. The study found that the loosing of screws and abutments were the most common mechanical problems.

In clinical complications, Goodacre at el. (29) reported overdenture loss of retention/ adjustment has highest rate of mechanical complications (30%). Many studies evaluated the ball, bar and Locator attachments regarding the retention force and prosthetic complications. Ball attachments were documented that O-rings normally loose retention, and must be replaced at time (19-22). The most frequent complications of bar attachment was retightening of the bar screw and adjustments of the bar retainers (29, 46). A metal– metal or metal–plastic/nylon stud attachment show differences wear of retentive component regarding its surface after removal–insertion usage. Another frequently observed prosthetic complication is the loosening of overdenture abutments or the fixation screws of bar attachments. Overloading of the implants usually causes loosening of the implant component (26, 29).

Adjustments	Number of patients (patients with recurring adjustments in parentheses)		
	1st year $n = 104$	2nd year $n = 103$	3rd year $n = 103$
Loose screws/abutments	33	12 (10)	7
Decubital ulceration treatments	22	11 (3)	8 (2)
Minor occlusal adjustments	6	5	6
Activation of retentive clips	8	9	4 (3)
Replacement resilient components	6	9 (1)	1
Abutment replacements	6	10	18
Corrections denture borders	10	10 (1)	2 (1)
Replacement of fractured artificial teeth	3	6	3

Figure 2.1 Distribution of patients with regard to adjustments during the 3 subsequent years of follow-up (48).

	Number placed/affected	Mean incidence
Overdenture loss of retention/adjustment	376/113 prostheses	30%
Esthetic veneer fracture (resin)	663/144 prostheses	22%
Overdenture relines	595/114 prostheses	19%
Overdenture clip/attachment fracture	468/80 prostheses	17%
Esthetic veneer fracture (porcelain)	258/36 prostheses	14%
Overdenture fracture	570/69 prostheses	12%
Opposing prosthesis fracture	168/20 prostheses	12%
Acrylic resin base fracture	649/47 prostheses	7%
Prosthesis screw loosening	4501/312 screws	7%
Abutment screw loosening	6256/365 screws	6%
Prosthesis screw fractures	7094/282 screws	4%
Metal framework fractures	2358/70 prostheses	3%
Abutment screw fractures	13,160/244 screws	2%
Implant fractures	12,157/142 implants	1%

Figure 2.2 Most common implant complications (29).

CHAPTER 3

Materials and Methods

The materials and methods are divided into two parts as followed:

3.1 The materials, instruments and experimental process

3.2 Statistical analyses

3.1 The materials, instruments and experimental process

Fifty PW Plus mini implants (PW Plus Co., Ltd., Nakorn Pathom, Thailand) diameter 3.0 mm and height 12 mm with conical implant-abutment connection were placed into the resin blocks (Block A) (Chockfast orange resin, Shannon Industrial Estate, Co. Clare, Ireland) with 0° angulation (Figure 3.1). The platform of the implant was at the same level of the resin block. Each OT-Equators abutment (Rhein83, Bologna, Italy) was screwed and tightened to each implant with a digital torque gauge (Tohnichi torque gauge, model BTGE50CN, Tohnichi Mfg. Co. Ltd., Tokyo Japan) to 25 Ncm following the instruction from the manufacturer. After ten minutes, all abutments were retightened with the same torque to reduce the settling effect.

OT-Equators metal housing with nylon inserts were attached into the abutments. The customized metal blocks were placed over the metal housings and space relief were prepared. The metal housings were picked up in the customized metal blocks (Block B) (Figure 3.2) using auto-polymerizing acrylic resin (TOKUYAMA Rebase II, TOKUYAMA dental, Tokyo, Japan) mixed according to the manufacturer's instructions. The alignment of nylon insert-metal housing to the abutment-implant axis was set up at 0° with Universal Testing Machine (Instron 8872, Canton, MA, USA).

The model specimens were divided into 2 groups according to different implant angulation. There were group I: 0° angle (N=25) and group II: 15°angle (N=25). Each group consisted of 5 subgroups with different weight-color coded of nylon retentive inserts (black; control, yellow; 0.6kg, pink; 1.2kg, white; 1.8kg, violet; 2.5kg) (Fig.3). Block A was attached into the fixed lower part of the testing machine which allowed to angulate the implant axis while Block B was positioned to the upper part. Each specimens group was tested under cyclic dislodgement with the Universal Testing Machine (Instron 8872, Canton, MA, USA) with a frequency of 1 Hz and crosshead speed of 2 mm per milliseconds. The assembly was immersed in a plastic container filled with demineralized water at room temperature during the cyclic test (Figure 3.4).

The retentive force after insertion-removal cycles were recorded at simulated 3 months (360 cycles), 6 months (720 cycles), 1 year (1,440 cycles) and 2 years (2,880 cycles) of function with a number of four cycles per days. The retentive force and removal torque after cyclic dislodgement of each time intervals were investigated. The removal torque of attachment screw of all specimens after testing were measured with the digital torque gauge. After 2,880 cyclic dislodgement, all male attachment abutment were undergone for scanning electron microscopy (SEM) (JSM-5410LV, JEOL Ltd, Tokyo, Japan) inspection at magnification of ×35 for any damage or shape alteration.

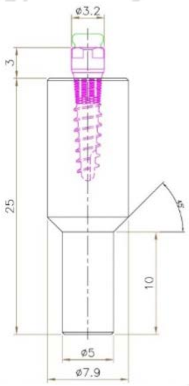


Figure 3.1 Schematic sketch of PW Plus mini implant in resin block (Block A)

Figure 3.2 The customized metal blocks with OT-Equators metal housing and nylon inserts (Block B)

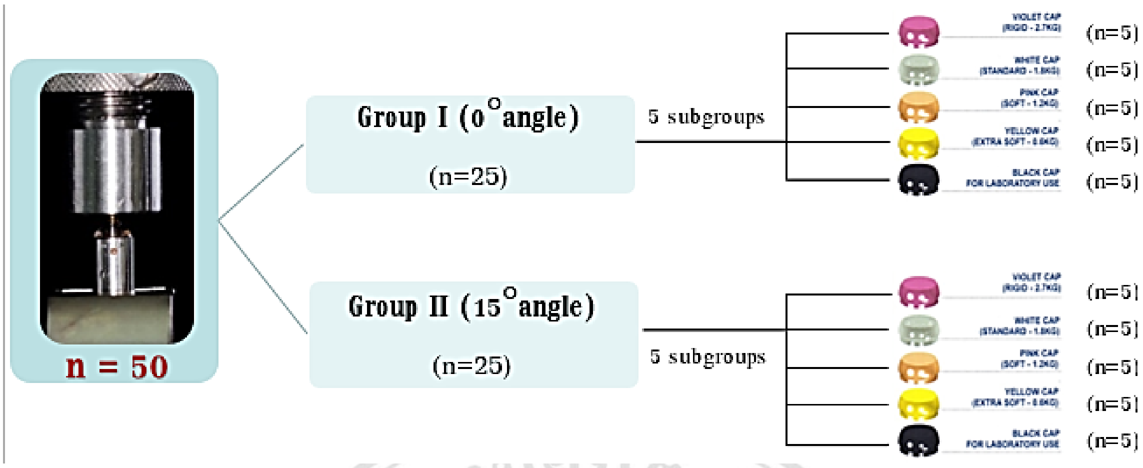


Figure 3.3 Schematic diagram for experimental procedure

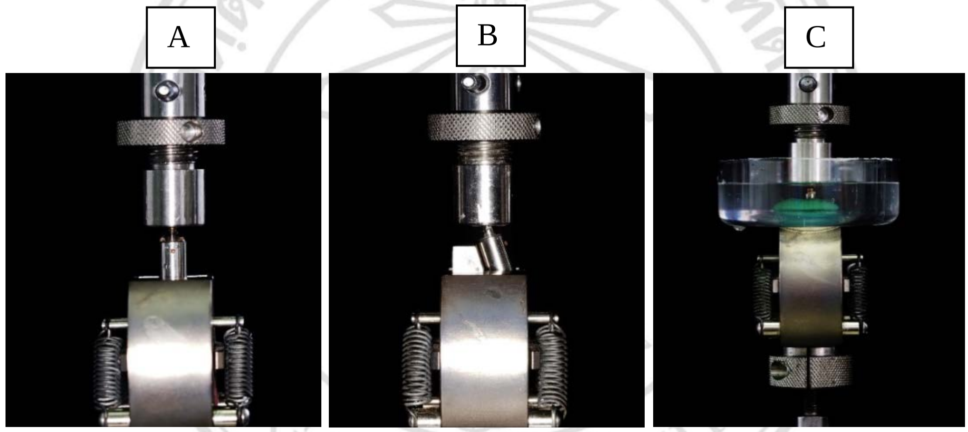


Figure 3.4 xperimental models simulation of cyclic dislodgement using universal testing machine: A, 0° angle. B, 15° angle. C, model immersed in deionized water.

3.2 Statistical analyses

All data were evaluated for normality test using Kolmogorov-Smirnov test. The retentive force of the different OT-Equator retentive cap over the different cycles was performed by One-way ANOVA. The retentive force and removal torque reduction of different five OT-Equator retentive caps in two groups (0° and 15° angle) were compared using t-test. The study also compared the torque change between initial torque and removal torque of each OT-Equator retentive cap using t-test. A significant difference was considered at $p<0.05$. The data were analyzed by using SPSS 17.0 software (SPSS Inc., Chicago, IL, USA).

CHAPTER 4

Results

The results of this study are presented in two parts as follows:

4.1 Retentive force

4.2 Removal torque

4.1 Retentive force

According to Kolmogorov-Smirnov test, the data are showing normal distribution. The mean retentive force (N) and standard deviation (SD) of different OT- Equator retention caps in different angulation under cyclic dislodgement are shown in Table 4.1. At the beginning of cyclic dislodgement (0 cycle), the different retentive forces of each color-coded retentive caps in both angulation at 0° and 15° were observed. For each subgroup, the black nylon exhibited the lowest initial retentive force, followed by the yellow, pink, white and violet nylon. Furthermore, the retentive force at the baseline of all groups were found higher than those of the force giving by manufacturer.

After cyclic dislodgment from the beginning to 2880 cycles, both attachment angulation presented similar pattern of decreasing retentive force overtime (Figure 4.1). In each group of angulationangulations, there were statistically significant differences of retentive force reduction overtime among each color-coded retentive capscap (Figure 4.2).When compared between two angulations in each retentive group, there was no significant difference in black nylon group. However, there is significant difference in other groups ($p<0.001$) (Table 4.2). The percentage of attachment retention loss in each groupsgroup were calculated and compared to initial retention (0 cycle) (Table 4.3). The negative values indicated decrease in removal force.

Table 4.1 Mean retentive force (N) and standard deviation (SD) of different attachment groups under cyclic dislodgement

Attachment group	**Mean retentive force (N) ± SD**				
	cycle				
	n = 0	**n = 360**	**n = 720**	**n = 1440**	**n = 2880**
Angulation 0°					
black	6.16 ± 0.44	5.11 ± 0.35	4.53 ± 0.34	3.84 ± 0.62	3.49 ± 0.67
yellow	9.61 ± 0.21	8.74 ± 0.19	8.10 ± 0.27	6.58 ± 0.28	5.60 ± 0.44
pink	17.71 ± 0.38	15.51 ± 0.64	13.32 ± 0.49	11.88 ± 0.71	10.68 ± 0.68
white	21.30 ± 1.08	17.88 ± 0.79	15.84 ± 1.04	12.05 ± 0.96	11.02 ± 0.82
violet	33.24 ± 1.52	29.54 ± 0.66	26.93 ± 0.44	24.80 ± 0.71	21.95 ± 0.86
Angulation 15°					
black	4.73 ± 0.30	4.37 ± 0.21	4.21 ± 0.24	4.21 ± 0.22	4.07 ± 0.19
yellow	7.3 ± 0.23	6.47 ± 0.78	5.44 ± 0.36	4.77 ± 0.38	4.20 ± 0.21
pink	14.18 ± 0.23	12.56 ± 0.38	9.87 ± 0.49	9.03 ± 0.52	6.97 ± 0.22
white	16.48 ± 0.59	14.02 ± 0.52	11.07 ± 0.42	8.58 ± 0.46	7.06 ± 0.36
violet	20.89 ± 0.68	17.12 ± 0.44	14.25 ± 0.26	10.24 ± 0.49	8.68 ± 0.27

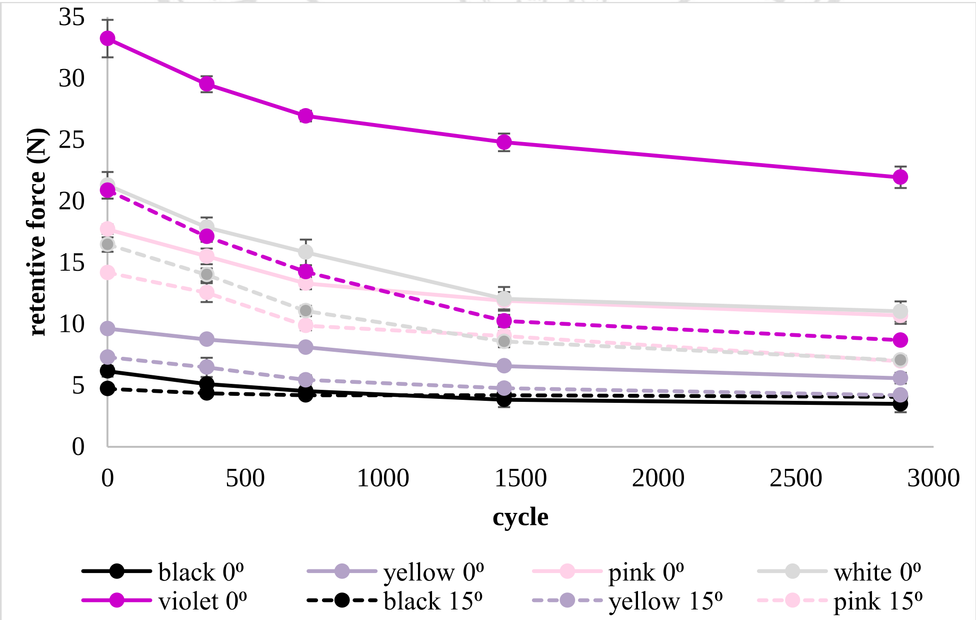


Figure 4.1 Mean retentive forces of different attachment groups in different angulations under cyclic dislodgement

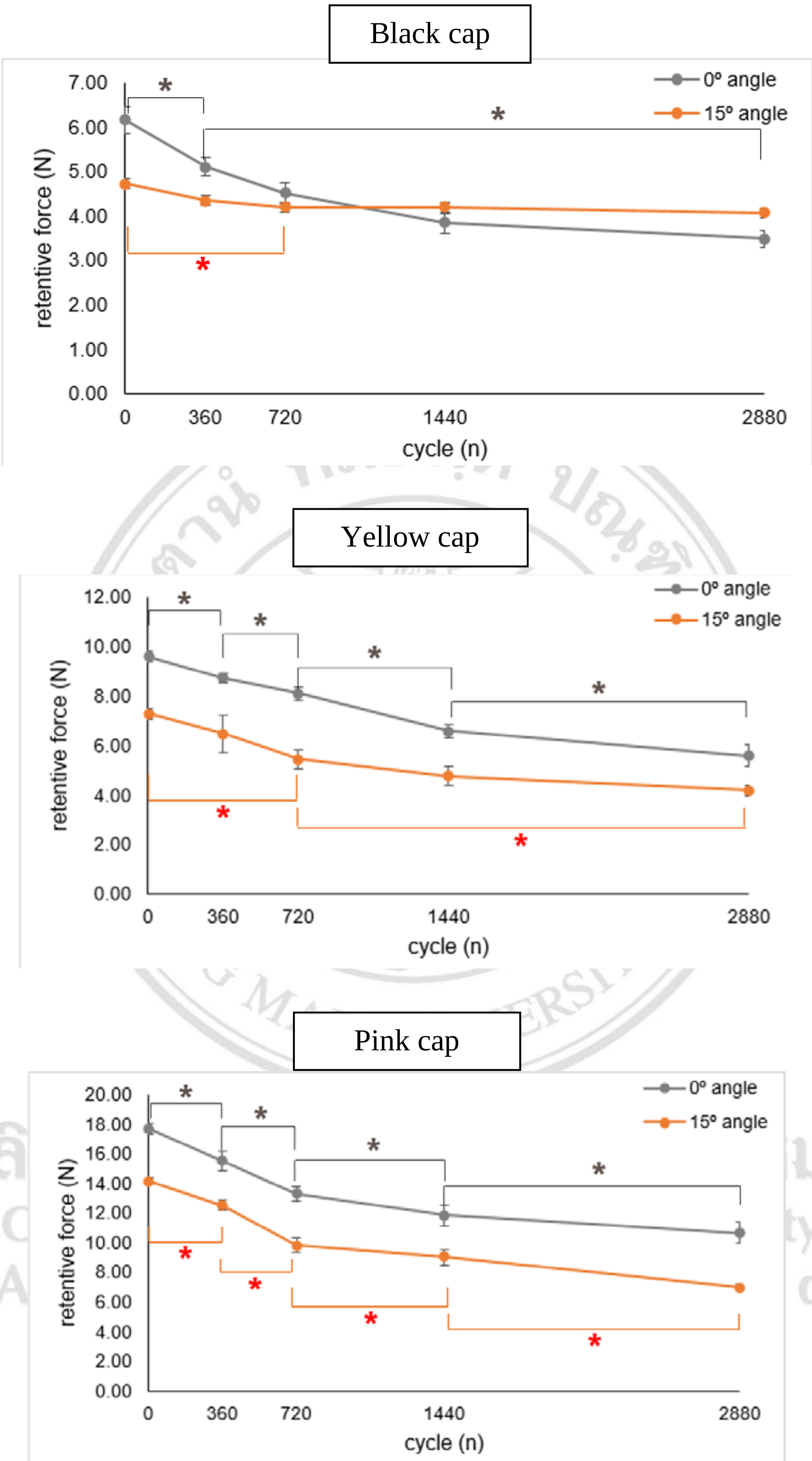
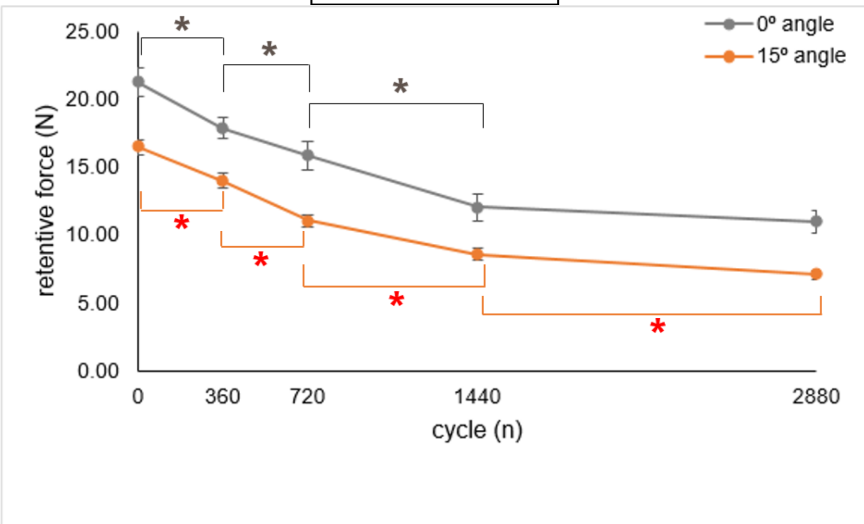


Figure 4.2 Significant differences of mean retentive force of each color coded retentive caps under cyclic dislodgement. (*p-values were calculated at significant < 0.05).

White cap



Violet cap

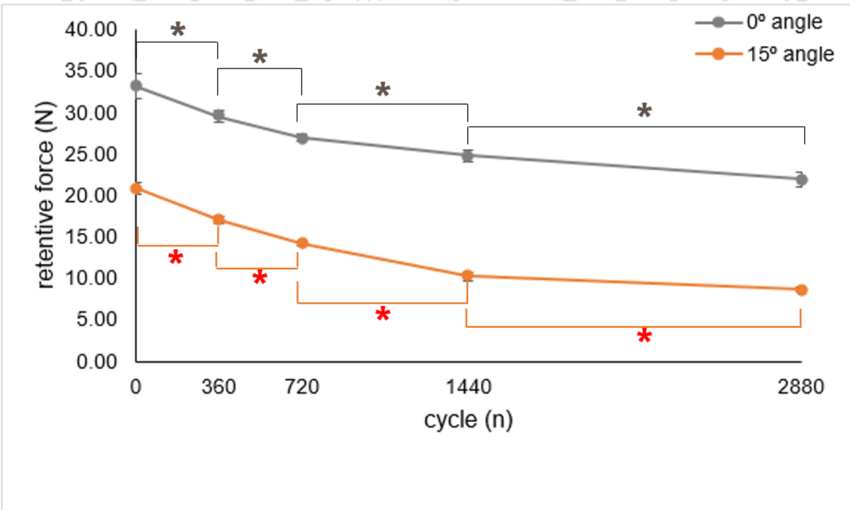


Figure 4.2 Significant differences of mean retentive force of each color coded retentive caps under cyclic dislodgement. (*p-values were calculated at significant < 0.05) (cont.)

Table 4.2 The angle effect of removal forces between 0^0 and 15^0 angulation of the OT-Equator color-coded retentive caps

OT-Equator retentive cap	T-test angle effect
Black cap	$p = 0.086$
Yellow cap	$p < 0.001$*
Pink cap	$p < 0.001$*
White cap	$p < 0.001$*
Violet cap	$p < 0.001$*

*Statistically significant differences ($p<0.05$).

Table 4.3 Percentage loss of retention of attachment retention loss compared to initial retention

Angulation	Cycle (n)	Black (%)	Yellow (%)	Pink (%)	White (%)	Violet (%)
0^0	360	-17.01	-9.05	-12.44	-16.07	-11.14
	720	-26.48	-15.73	-24.83	-25.65	-18.97
	1440	-37.58	-31.56	-32.91	-43.43	-25.40
	2880	-43.32	-41.79	-39.69	-48.26	-33.97
15°	360	-7.76	-11.27	-11.47	-14.94	-18.04
	720	-11.13	-25.37	-30.41	-32.84	-31.79
	1440	-11.14	-34.66	-36.30	-47.97	-50.97
	2880	-13.92	-42.37	-50.82	-57.18	-58.47

4.2 Removal torque

All removal torque values in this study were normaly distributed. The comparison of removal torque of each groups at the final and the initial cycle are shown in Table 4.4. From initial insertion torque of attachment (25 NCm.), the removal torques after 2,880 cycles were reduced significantly when compared to the initial insertion torque ($p < 0.05$). The removal torque of different OT-Equator color-coded retentive caps in 0^0 and 15^0 angle at the end of 2,880 dislodging cycles are shown in Table 4.5. There were no statistically significant differences between 0^0 and 15^0 angle groups ($p>0.05$). The removal torques within each color-coded retentive caps in 15 ^{0} angle groups were lower than those of the 0^0 angle groups except for the pink cap (Figure 4.3). There was no complete screw loosening found after 2,880 cycles. From SEM inspection, there were neither damage nor shape alteration found compared to the new attachment screw (Figure 4.4)

Table 4.4 Removal torque of different OT- Equator color-coded retentive caps in 0^0 and 15^0 angle at 2,880 dislodging cycles compared to initial insertion torque

OT-Equator retentive cap	**Removal torque (Ncm)**	***p*-value comparing with initial insertion torque**	**Removal torque (Ncm)**	***p*-value comparing with initial insertion torque**
	Mean ± SD		**Mean ± SD**	
	0^0 angle		**15^0 angle**	
Black	21.63±2.72	0.0123*	20.71±2.00	0.0007*
Yellow	21.7±2.25	0.0056*	20.54±1.79	0.0003*
Pink	19.83±1.46	0.0000*	20.57±1.08	0.0000*
White	20.37±1.53	0.0001*	20.06±1.77	0.0001*
Violet	20.97±1.25	0.0000*	20.02±2.18	0.0005*

*Statistically significant differences (p<0.05).

Table 4.5 The removal torque of different OT-Equator color-coded retentive caps in 0^0 and 15^0 angle at 2,880 dislodging cycles

OT-Equator retentive cap	**Removal torque (Ncm)**		**T-test**
	Mean ± SD		
	0^0 angle	**15^0 angle**	***p*-value**
Black	21.63±2.72	20.71±2.00	0.559
Yellow	21.7±2.25	20.54±1.79	0.393
Pink	19.83±1.46	20.57±1.08	0.390
White	20.37±1.53	20.06±1.77	0.775
Violet	20.97±1.25	20.02±2.18	0.423

*Statistically significant differences (p<0.05).

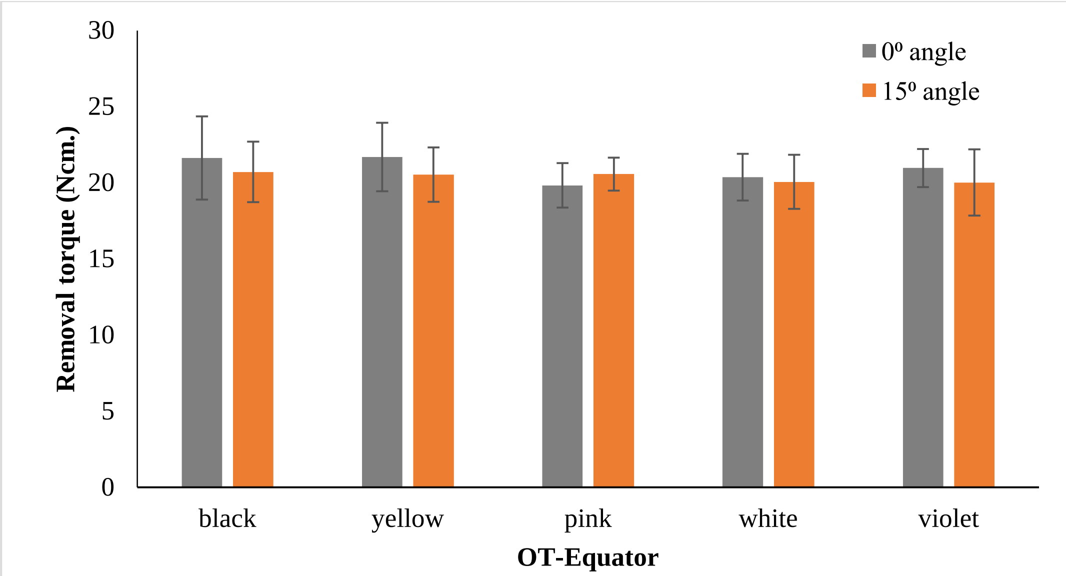


Figure 4.3 The bar chart demonstrated Tthe removal torque of different OT-Equator color-coded retentive caps in different angulation after 2,880 cyclic dislodgement

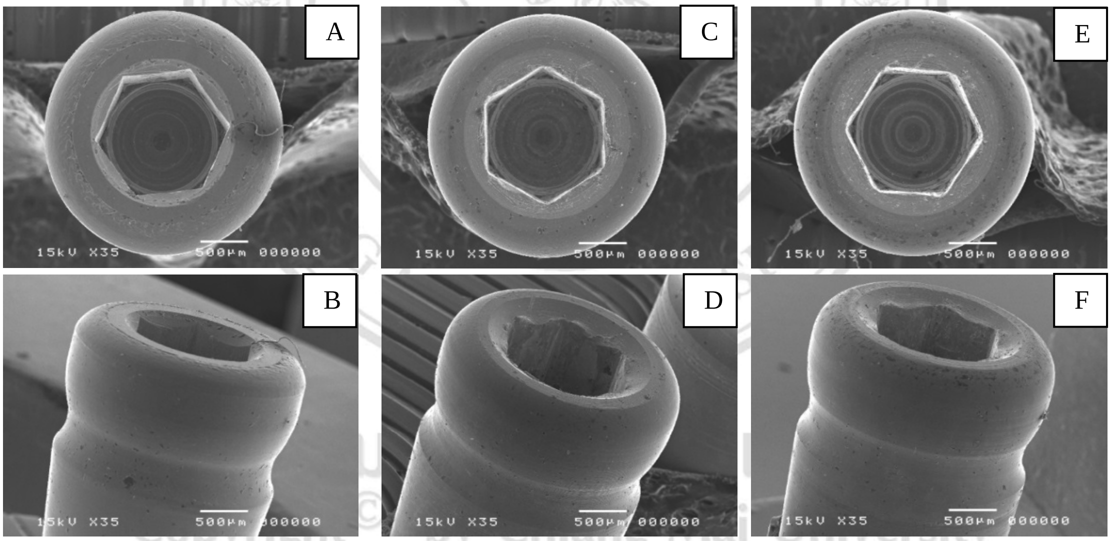


Figure 4.4 SEM images of the patrix surface (attachment abutment); abutment before test (A, B), 0^0 angle group after test (C, D), 15^0 angle group after test (E, F)

CHAPTER 5

Discussion

This in-vitro study evaluated the change of retentive force and removal torque of OT-Equator attachment in different angulations under cyclic dislodgement. The results of this study revealed that increase in cyclic dislodgement significantly reduced the retentive force of OT- Equator retentive caps in 15° than 0° angle except for the black cap. The removal force also decreased at final dislodging cycle. However, there were no significantly differences between removal torques of attachment components on mini implant in different angulations.

The implant retained/supported overdenture should have adequate retentive capacity to enhance the retention of the prosthesis (17). Previous studies revealed that implant angulation and attachment component wear influenced the change in retentive force during long term wearing period (25-27, 49-53). In vitro studies investigated the change of retentive capacity after simulated insertion-removal usage with cyclic dislodgement (25-28, 49-53). In this study, the cycles of 360, 720, 1,440 and 2,880 were used to simulate in-vivo function of OT-Equator in 3 months, 6 months, 1 year and 2 years respectively which was based on 4 removal-insertions per day. The results of this study demonstrated significant differences in baseline retention between nylon retentive components of which the violet cap was the most retentive, followed by the white, the pink, the yellow and finally the black cap. These weight color-code retentive caps indicated different levels of retention which varied from 6.16 ± 0.44 N to 33.24 ± 1.52 N. The relation of different color coded inserts in the present study were in accordance with the investigations of other different attachment systems such as Locator (51, 52, 54). However, the retentive force at the baseline of all groups were found higher than those of the manufacturer. Other previous studies have evaluated the retention capacity of OT-Equator attachment systems at the baseline. As for the pink cap at an angulation of 0°, Tomás et al. (28) obtained the initial retention value of 16.36 ± 2.94 N, which is similar to our study at 17.71 ± 0.38 N. However, Marin et al. (25) demonstrated greater baseline retention of pink female component at

51.81 ± 2.64 N which was in discordance with our study due to different designs of experimental models consisting of a pair attachment. In addition, some studies found that the relation between the initial retention force and color-coded retentive inserts were independent (27, 53). These discrepancies might be caused by manufacturing process, different design and position of attachment systems (51).

After cyclic dislodgement, gradually progressive loss of retention was exhibited with similar pattern in all retentive caps of both 0° and 15 °of angulation. After 2,880 insertion-removal cycles, all groups exhibited loss of retention corresponding with retentive level of different color coded retentive caps. Within each color-coded retentive cap of each angulation, there were statistically significant differences of mean retentive force values overtime ($p<0.05$). The black cap group exhibited the lowest retention with no significance differences of retentive force overtime between 0° and 15 ° angle groups ($p>0.05$). This finding can be explained by the fact that the black processing insert is recommended to be removed and replaced by other color-codes retentive caps before function due to its inadequate retention. Previous studies reported that the increase of insertion/removal cycle had significant effects on retentive force reduction of various attachments which the experiments were on parallel implants or at right angle to occlusal plane. Marin et al. (25) found that pair implants OT-Equator with pink retentive caps exhibited 14.08% loss retentive force after 3,000 insertion/removal cycle at 0° of angulation. The present study showed 39% loss of retention at 2,880 final cycles on single attachment whereas Tomás et al. (28) presented 8.07% loss of retention at 3,000 cycles. The authors also compared the retentive force of pink retentive cap between Locator and OT-Equator. They found that both systems showed similar characteristic at the baseline, however, OT-Equator (30.26%) obtained significant lower retention than those of Locator (49.76%) after 14,600 cycle. Another study, however, revealed that retentive force reduction of Locator was considerably up to 78.6% of baseline retention after 15,000 cycles. The different color coded retentive components of Locator were also reported that they might not necessarily provide significantly different retention (27). Regardless of different attachment systems and design of experimental studies, the retentive force reduction has been reported discrepancies range of retentive values. These results cannot be directly compared. However, all studies showed similar tendency of decrease in retention after insertion-removal cycles.

In clinical situation, it can be complicated to place implants parallel to each other according to insufficient bone quality or anatomical limitations as well as patient affordability of prostheses. According to the manufacture, OT-Equator is designed with an abutment to be placed at angulation of between 0° and 15°. The present study investigated differences in retentive force values between different angulations. The results revealed that the 15° angle group had a significant greater loss of retentive force than the 0° angle group except for the black cap. Many studies have stated that increasing implant angulation under cyclic dislodgement had negative effect on retention of implant overdentures which support the finding in the present study (49, 50, 53). Al-Ghafli et al. (49) reported significant decrease in retention of Locator among 0°, 5°, 10°, 15° and 20° angles which 20° angle exhibited the lowest values after 15,000 cycles. Another study showed correspondingly significant decrease of retention at 0°, 10°, 20° angulation at 1,440 cycles, while vigorously loss of retention was found at 30°, 40° angulation after 720 cycles (50). The 20° angulation of Clix®, Dalbo-Plus® and Locator also revealed higher loss of retention when compared to 0° angle (53).

The main cause of decrease in retention after frequent loading could be wear induced-structural changes of attachment (17, 27). The higher angulation of inner part of attachment, the higher force needs of insertion-removal force. The consequent increase in friction force caused abrasion and deformity of nylon inserts of patrix attachment which was significant detected in higher implant angulation (25, 27, 53). OT-Equator nylon components are made of polyamide which offers light weight, smooth surface, chemical resistance, dimensional stability and flexibility (25). However, the nylon components have a high sensitivity to wear during long term function due to several factors which consequently lead to decrease in retentive force (50). As a result, the change of morphology and wear of attachment component due to nonparallel implant and recurrent loading overtime could lead to loss of retention. Different studies revealed retention to stabilize mandibular overdenture ranging from 5-7 N from Pigozzo (5) and Besimo (55). In contrast, Setz (56) required 20 N of minimal retention for two-implant mandibular overdenture. As for loss of retention after long term usage, the proper period of time to replace the attachments of implant retained/supported overdenture is not well defined (49). According to the results of this study, it can be assumed that OT-Equator retentive with 0° angle until 2-year simulating insertion-removal function can still provide adequate retention with a retentive force ranging from 5.60 ± 0.44 N to 33.24 ± 1.52 N. However, the yellow cap with angulation of 15° after 1,440 cycles obtained too low retention to retain overdenture with a retentive value of 4.77 ± 0.38 N. This was lower than that referenced by different authors (5, 55). Therefore, the nonparallel attachment may require 1 year of maintenance and be replaced by a new retentive insert.

The removal torque is the amount of rotational force used to loosen the screw which is used to analyze the remaining torque after mechanical loading compared to preload (57, 58). Many studies revealed various factors affecting on removal torque reduction of single implant abutment after mechanical loading (59, 60). Nevertheless, the removal torque investigations of overdenture attachment are currently lacking in dental research. There was a study of Kobayashi et al. (26) who evaluated the effect of cyclic dislodgement on retention and removal torque of Locator on normal implant diameter (Straumann RN 4.1mm) after 14,600 insertion/removal cycles. The study found significant decrease of both removal torque of Locator with 0° angle (29.5 ± 3.30 Ncm) and those with 12°angle (29.5 ± 4.17 Ncm) in comparison to initial insertion torque (35 Ncm). The results of both angulations exhibited similar values after final cyclic dislodgement. These finding is in accordance with the present study on mini implants (PW Plus 3.0mm) of which the removal torque of all attachment abutments were statistically significant lower at the final cyclic dislodgement than those at the initial (25 Ncm). Winkler et al. (61) explained that 2% to 10% of initial preload was lost as a result of settling effect. Accordingly, the removal torque exhibited less than the torque initially used to place the screw. Moreover, the external joint separating force such as non-axial load and insertion-removal force might allow separation of the joint and lead in screw loosening (61). However, from the results of the present study, no statistically significant differences were found in removal torques between 0° (ranged from 19.83 ± 1.53 to 21.70 ± 2.25 Ncm) and 15° of angulation (ranged from 20.02 ± 2.18 to 20.71 ± 2.00 Ncm) after 2,880 cycles. Therefore, there was no significant influence of the implant-angulation on removal torque after 2,880 cycles, even if the attachment was inserted on mini implant. This finding could be explained by damage of the attachment due to mechanical loading was limited on retentive components which is in accordance to previous studies (26, 53, 62). Aroso et al. (53) did not detect any visible deformation in the surface of Locator metal abutment even in different angulation but confirmed the wear in the internal part of white, pink and blue retentive components after 5,400 cycles. In addition, another *in vivo* study demonstrated significant wear of the nylon insert of Locator attachment under micro-computed tomography after 1 year of clinical wearing. There was no significant wear pattern on the abutments, despite the minimal scratch on its external surface under SEM evaluation (62). However, three-dimensional movement around the implant axis during mastication, cleaning agents, parafunctional habit and water absorption could be other important factors influencing the wear discrepancies of attachment systems (49, 53).

Within the limit of the study, it was concluded that greater cyclic dislodgement and increasing of implant angulation significantly affected retentive force of OT-Equator attachments. The value of retentive force of OT-Equator in simulating 2 year of denture insertion/removal is acceptable to retain mini implant overdenture. The reduction of removal torque after 2,880 cycles compared to insertion torque was found, however the implant angulation did not seem to have significant influence on removal torque. The low-profile OT-Equator can be used on mini implant to retain overdenture. Nevertheless, it should be noted that Nylon inserts with increased implant angulation required regularly follow up to replace them each year and screw re-tightening might be considered. Further *in vivo* studies are necessary to investigate the retentive behavior and its long term clinical relevance.

CHAPTER 6

Conclusions

Within the limitations of this in vitro study, it can be concluded that:

1. Greater cyclic dislodgement and increasing of implant angulation significantly affected on retentive force of OT-Equator attachment.

2. The reduction of removal torque after 2,880 cycles was found, however the implant angulation did not seem to have significant influence on removal torque.

3. The value of retentive force of OT-Equator in simulating 2 year of denture insertion/removal is acceptable to retain mini implant overdenture.

4. Nylon inserts with increase implant angulation required regularly follow up to replace them each year and screw re-tightening on attachment might be consider.

REFERENCES

[1] Fitzpatrick, B. Standard of care for the edentulous mandible: A systematic review. J Prosthet Dent. 2006; 95(1): 71-8.

[2] Critchlow, S.B.and Eliss, J.S. Prognostic indicators for conventional complete denture therapy: a review of the literature. J Dent. 2010; 38(1): 2-9.

[3] Fueki, K., Kimoto, K, Ogawa, T, and Garrett, N.R. Effect of implant-supported or retained dentures on masticatory performance: a systematic review. J Prosthet Dent. 2007; 98(6): 470-7.

[4] Siadat, H., Alikhasi, M., Mirfazaelian, A., Geramipanah, F., and Zaery, F. Patient satisfaction with implant-retained mandibular overdentures: a retrospective study. Clin Implant Dent Relat Res. 2008; 10(2): 93-8.

[5] Pigozzo, M.N., Mesquita, M.F., Henriques, G.E., and Vaz, L.G. The service life of implant-retained overdenture attachment systems. J Prosthet Dent. 2009; 102(2): 74-80.

[6] Feine, J.S., Carlsson, G.E., Awad, M.A., Chehade, A., Duncan, W.J., Gizani S, et al. The McGill consensus statement on overdentures. Mandibular two-implant overdentures as first choice standard of care for edentulous patients. Int J Oral Maxillofac Implants. 2002; 17(4): 601-2.

[7] Thomason, J.M., Kelly, S.A., Bendkowski, A., and Ellis, J.S. Two implant retained overdentures-A review of the literature supporting the McGill and York consensus statements. J Dent. 2012; 40(1): 22-34.

[8] Sivaramakrishnan, G. and Sridharan, K. Comparison of patient satisfaction withmini-implant versus standard diameter implant overdentures: a systematic review and meta-analysis of randomized controlled trials. Int J Implant Dent. 2017; 3(1): 29.

[9] Laney, W.R. Glossary of Oral and Maxillofacial Implants. Int J Oral Maxillofac Implants. Chicago:Quintessence Publishing Co;2007, p.40, 102, 113, 133.

[10] Flanagan, D. and Mascolo, A. The mini dental implant in fixed and removable prosthetics: a review. J Oral Implantol. 2011; 37 Spec No: 123-32.

[11] Jeong, S-M, Choi, B-H, Li, J., Kim, H-S, Ko, C-Y, Jung, J-H, et al. Flapless implant surgery: an experimental study. Oral Surg Oral Med Oral Pathol Oral Radiol Endod. 2007; 104(1): 24-8.

[12] Ahn, M-R, An, K-M, Choi, J-H, and Sohn D-S. Immediate loading with mini dental implants in the fully edentulous mandible. Implant Dent. 2004; 13(4): 367-72.

[13] Bidra, A.S. and Almas, K. Mini implants for definitive prosthodontic treatment: a systematic review. J Prosthet Dent. 2013; 109(3): 156-64.

[14] Elsyad, M., Gebreel, A., Fouad, M., and Elshoukouki, A. The clinical and radiographic outcome of immediately loaded mini implants supporting a mandibular overdenture. A 3-year prospective study. J Oral Rehabil. 2011; 38(11): 827-34.

[15] Aunmeungtong, W., Kumchai, T., Strietzel, F.P., Reichart, P.A.,and Khongkhunthian, P. Comparative Clinical Study of Conventional Dental Implants and Mini Dental Implants for Mandibular Overdentures: A Randomized Clinical Trial. Clin Oral Implants Res. 2016; 19(2): 328-340.

[16] Tomasi, C., Idmyr, B.O., and Wennström, J.L. Patient satisfaction with mini-implant stabilised full dentures. A 1-year prospective study. J Oral Rehabil. 2013; 40(7): 526-34.

[17] Alsabeeha, N.H., Payne, A.G., and Swain, M.V. Attachment systems for mandibular two-implant overdentures: a review of in vitro investigations on retention and wear features. Int J Prosthodont. 2009; 22(5): 429-40.

[18] Daou, E.E. Stud attachments for the mandibular implant-retained overdentures: Prosthetic complications. A literature review. Saudi Dent J. 2013; 25(2): 53-60.

[19] Cakarer, S., Can, T., Yaltirik, M., and Keskin, C. Complications associated with the ball, bar and Locator attachments for implant-supported overdentures. Med Oral Patol Oral Cir Bucal. 2011; 16(7): e953-e9.

[20] Kleis, W.K., Kämmerer, P.W., Hartmann, S, Al-Nawas, B., and Wagner, W. A comparison of three different attachment systems for mandibular two-implant overdentures: one-year report. Clin Implant Dent Relat Res. 2010; 12(3): 209-18.

[21] Elsyad, M.A. Patient satisfaction and prosthetic aspects with mini-implants retained mandibular overdentures. A 5-year prospective study. Clin Oral Implants Res. 2016; 27(7): 926-33.

[22] Schwindling, F.S.and Schwindling F.P. Mini dental implants retaining mandibular overdentures: A dental practice-based retrospective analysis. J Prosthodont Res. 2016; 60(3): 193-8.

[23] El-Anwar, M.I., and Mohammed, M.S. Comparison between two low profile attachments for implant mandibular overdentures. J Gen Eng Biotech. 2014; 12(1): 45-53.

[24] Ammar, N.A., El-Khodary, N.M., and Abdelhamid, A.M. Clinical Evaluation of the Implant Retained Overdenture with OT-Equator Attachments. Int J Sci Res. 2016; 5(9): 643-647.

[25] Marin, D., Leite, A., Junior, N., Paleari, A., Pero, A., and Compagnoni, M. Retention Force and Wear Characteristics of three Attachment Systems after Dislodging Cycles. Br Dent J. 2018. 576-82.

[26] Kobayashi, M., Srinivasan, M., Ammann, P., Perriard, J., Ohkubo, C., Müller, F., et al. Effects of in vitro cyclic dislodging on retentive force and removal torque of three overdenture attachment systems. Clin Oral Implants Res. 2014; 25(4): 426-34.

[27] Rutkunas, V., Mizutani, H., Takahashi, H., and Iwasaki, N. Wear simulation effects on overdenture stud attachments. Dent Mater J. 2011; 30(6): 845-53.

[28] Tomás, M.N., Barquero, J., Estevan, L., Escuder, A., Otaolaurruchi, E.J. In vitro retention capacity of two overdenture attachment systems: Locator® and Equator®. J Clin Exp Dent. 2018; 10(7): e681-e686.

[29] Goodacre, C.J., Bernal, G, Rungcharassaeng, K., and Kan, J.Y. Clinical complications with implants and implant prostheses. J Prosthet Dent. 2003; 90(2): 121-32.

[30] Thomason, J.M., Feine, J., Exley, C., Moynihan, P., Muller, F., Naert, I., et al. Mandibular two implant-supported overdentures as the first choice standard of care for edentulous patients - the York Consensus Statement. Br Dent J. 2009; 207(4): 185-6.

[31] Melas, F. and Marcenes, W., Wright PS. Oral health impact on daily performance in patients with implant-stabilized overdentures and patients with conventional complete dentures. Int J Oral Maxillofac Implants. 2001; 16(5): 700-12.

[32] Sadowsky, S.J. and Zitzmann, N.U. Protocols for the Maxillary Implant Overdenture: A Systematic Review. Int J Oral Maxillofac Implants. 2016; 31 Suppl: s182-91.

[33] Van Steenberghe, D., Quirynen, M., Calberson, L., and Demanet, M. A. Prospective evaluation of the fate of 697 consecutive intra-oral fixtures ad modum Branemark in the rehabilitation of edentulism. J Head Neck Pathol 1987; 6: 53-8.

[34] Mericske-Stern, R., Steinlin Schaffner, T., Marti P, and Geering A.H. Peri-implant mucosal aspects of ITI implants supporting overdentures. A five-year longitudinal study. Clin Oral Implants Res 1994; 5: 9-18.

[35] Jemt, T., Chai, J., Harnett, J., Heath, M.R., Hutton, J.E., Johns, R.B., et al. A 5-year prospective multicenter follow-up report on overdentures supported by osseointegrated implants. Int J Oral Maxillofac Implants 1996; 11: 291-8.

[36] Naert, I., Gizani, S., Vuylsteke, M., and van Steenberghe D. A 5-year prospective randomized clinical trial on the influence of splinted and unsplinted oral implants retaining a mandibular overdenture: prosthetic aspects and patient satisfaction. J Oral Rehabil 1999; 26: 195-202.

[37] Chiapasco M, Gatti C, Rossi E, and Haeflige W. Implant-retained mandibular overdentures with immediate loading. Clin Oral Implants Res. 1997; 8(1): 48-57.

[38] Gatti, C., Haefliger, W., and Chiapasco, M. Implant-retained mandibular overdentures with immediate loading: a prospective study of ITI implants. Int J Oral Maxillofac Implants. 2000; 15(3): 383-8.

[39] Chiapasco, M., Abati, S., Romeo, E., and Vogel, G. Implant-retained mandibular overdentures with Branemark System MKII implants: a prospective comparative study between delayed and immediate loading. Int J Oral Maxillofac Implants. 2001; 16(4): 537-46.

[40] Hjørting-Hansen, E., Laney, W., Broggini, N., Buser, D., Cochran D, Garcia, L., et al. Glossary of oral and maxillofacial implants: Quintessence Publishing Ltd.; 2007.

[41] Balaji, A., Mohamed, J.B., abd Kathiresan, R. A pilot study of mini implants as a treatment option for prosthetic rehabilitation of ridges with sub-optimal bone volume. J Maxillofac Oral Surg. 2010; 9(4): 334-8.

[42] Shatkin, T.E., Shatkin, S., Oppenheimer, B.D., abd Oppenheimer, A.J. Mini dental implants for long-term fixed and removable prosthetics: a retrospective analysis of 2514 implants placed over a five-year period. Compend Contin Educ Dent (Jamesburg, NJ: 1995). 2007; 28(2): 92-9; quiz 100-1.

[43] Jeong, S-M., Choi, B-H., Li, J., Kim, H-S., Ko, C-Y., Jung, J-H., et al. Flapless implant surgery: an experimental study. Oral Surg Oral Med Oral Pathol Oral Radiol Endod. 2007; 104(1): 24-8.

[44] Ahn, M-R., An, K-M., Choi, J-H., Sohn, and D-S. Immediate loading with mini dental implants in the fully edentulous mandible. Implant Dent. 2004; 13(4): 367-72.

[45] Mundt, T., Schwahn, C., Stark, T., andf Biffar, R. Clinical response of edentulous people treated with mini dental implants in nine dental practices. Gerodontology. 2015; 32(3): 179-87.

[46] Kim, H.Y., Lee, J.Y., Shin, S.W., and Bryant, S.R. Attachment systems for mandibular implant overdentures: a systematic review. J Adv Prosthodont. 2012; 4(4): 197-203.

[47] Gotfredsen, K. Masticatory function and patient satisfaction with implant-supported mandibular overdentures: a prospective 5-year study. Int J Prosthodont. 2002; 15(6): 575.

[48] Den Dunnen, A.C., Slagter, A.P, de Baat, C., and Kalk, W. Professional hygiene care, adjustments and complications of mandibular implant-retained overdentures: a three-year retrospective study. J Prosthet Dent. 1997; 78(4): 387-90.

[49] Al-Ghafli, S.A., Michalakis, K.X., Hirayama, H., and Kang, K. The in Vitro Effect of Different Implant Angulations and Cyclic Dislodgement on the

Retentive Properties of an Overdenture Attachment System. J Prosthet Dent. 2009; 102(3): 140-7.

[50] Teimoori, H., Shayegh, S.S., Zavaree, M.A., Hakimaneh, S.M., Khodadad, F., Shidfar, S., and Baghani, M.T. Effects of Excessive Implant Angulation on Retention of Two Types of Overdenture Attachments during Cyclic Loading. J Contemp Dent Pract. 2018; 19(10): 1221-1227.

[51] Tehini, G., Baba, N., Majzoub, Z., Nahas, P., Berberi, A., and Rifai, K. In Vitro Effect of Mastication on the Retention and Wear of Locator Attachments in a Flat Mandibular Ridge Model. J Prosthodont. 2018; 28(2): e74-e751.

[52] Evtimovska, E., Masri, R., F. Driscoll C, et al. The Change in Retentive Values of Locator Attachments and Hader Clips over Time. J Prosthodont. 2009; 18(6): 479-83.

[53] Aroso, C., Silva, A.S., Ustrell, R., Mendes, J.M., Braga, A.C., Berastegui, E., and Escuin, T. Effect of abutment angulation in the retention and durability of three overdenture attachment systems: An in vitro study. J Adv Prosthodont. 2016; 8(1): 21-9.

[54] Rabbani, S., Juszczyk, A.S., Clark, R.K., and Radford, D.R. Investigation of Retentive Force Reduction and Wear of the Locator Attachment System with Different Implant Angulations. Int J Oral Maxillofac Implants. 2015; 30(3): 556-63.

[55] Besimo, C., and Guarneri, A. In vitro retention force changes of prefabricated attachments for overdentures. J Oral Rehabil. 2003; 30(7): 671-8.

[56] Setz, I., Lee, S.H., and Engel, E. Retention of prefabricated attachments for implant stabilized overdentures in the edentulous mandible: an in vitro study. J Prosthet Dent. 1998; 80(3): 323-9.

[57] Katsuta, Y. and Watanabe, F. Abutment screw loosening of endosseous dental implant body/abutment joint by cyclic torsional loading test at the initial stage. Dent Mater J. 2015; 34(6): 896-902.

[58] Pintinha, M., Camarini, E.T., Sábio, S., and Pereira, J.R. Effect of mechanical loading on the removal torque of different types of tapered connection abutments for dental implants. J Prosthet Dent. 2013; 110(5): 383-8.

[59] Paepoemsin, T., Reichart, P.A., Chaijareenont, P., Strietzel, F., and Khongkhunthian, P. Removal torque evaluation of three different abutment screws for single implant restorations after mechanical cyclic loading. Oral Implantol (Rome). 2016; 9(4): 213-221.

[60] Benjaboonyazit, K., Chaijareenont, P., and Khongkhunthian, P. Removal torque pattern of a combined cone and octalobule index implant-abutment connection at different cyclic loading: an in-vitro experimental study. Int J Implant Dent. 2019; 5(1): 1.

[61] Winkler, S., Ring, K., Ring, J.D., and Boberick, K.G. Implant screw mechanics and the settling effect: overview. J Oral Implantol. 2003; 29(5): 242-5.

[62] Jabbour, Z., Fromentin, O., Lassauzay, C., Abi Nader, S., Correa, J.A., Feine, J., and de Albuquerque Junior, R.F. Effect of Implant Angulation on Attachment Retention in Mandibular Two-Implant Overdentures: A Clinical Study. Clin Implant Dent Relat Res. 2014; 16(4):565-71.

APPENDIX

Cycle effect of each insert by straight method

Summary Black

	Df	Sum Sq	Mean Sq	F value	Pr(>F)
Cycle	4	22.474	5.618	22.52	3.6e-07 ***
Residuals	20	4.989	0.249		

TukeyHSD

Tukey multiple comparisons of means

95% family-wise confidence level

Cycle	Df	Lower	Upper	p-adjusted
360-0	-1.0473333	-1.992588	-0.10207847	0.0254057
720-0	-1.6306667	-2.575922	-0.68541180	0.0004096
1440-0	-2.3146667	-3.259922	-1.36941180	0.0000040
2880-0	-2.6680000	-3.613255	-1.72274513	0.0000005
720-360	-0.5833333	-1.528588	0.36192154	0.3762263
1440-360	-1.2673333	-2.212588	-0.32207846	0.0054853
2880-360	-1.6206667	-2.565922	-0.67541180	0.0004397
1440-720	-0.6840000	-1.629255	0.26125487	0.2328465
2880-720	-1.0373333	-1.982588	-0.09207847	0.0271823
2880-1440	-0.3533333	-1.298588	0.59192153	0.7950108

Summary Yellow

	Df	Sum Sq	Mean Sq	F value	Pr(>F)
Cycle	4	52.96	13.241	156.3	8.75e-15 ***
Residuals	20	1.69	0.085		

TukeyHSD

Tukey multiple comparisons of means

95% family-wise confidence level

Cycle	Df	Lower	Upper	p-adjusted
360-0	-0.870	-1.420817	-0.3191834	0.0010928
720-0	-1.512	-2.062817	-0.9611834	0.0000007
1440-0	-3.034	-3.584817	-2.4831834	0.0000000
2880-0	-4.018	-4.568817	-3.4671834	0.0000000
720-360	-0.642	-1.192817	-0.0911834	0.0175195
1440-360	-2.164	-2.714817	-1.6131834	0.0000000
2880-360	-3.148	-3.698817	-2.5971834	0.0000000
1440-720	-1.522	-2.072817	-0.9711834	0.0000006
2880-720	-2.506	-3.056817	-1.9551834	0.0000000
2880-1440	-0.984	-1.534817	-0.4331834	0.0002718

Summary Pink

	Df	Sum Sq	Mean Sq	F value	Pr(>F)
Cycle	4	159.28	39.82	113.1	1.96e-13 ***
Residuals	20	7.04	0.35		

TukeyHSD

Tukey multiple comparisons of means

95% family-wise confidence level

Cycle	Df	Lower	Upper	p-adjusted
360-0	-2.203333	-3.326387	-1.08028011	0.0000854
720-0	-4.398000	-5.521053	-3.27494677	0.0000000
1440-0	-5.829333	-6.952387	-4.70628011	0.0000000
2880-0	-7.030000	-8.153053	-5.90694677	0.0000000
720-360	-2.194667	-3.317720	-1.07161344	0.0000898
1440-360	-3.626000	-4.749053	-2.50294678	0.0000001
2880-360	-4.826667	-5.949720	-3.70361344	0.0000000
1440-720	-1.431333	-2.554387	-0.30828011	0.0085431
2880-720	-2.632000	-3.755053	-1.50894678	0.0000076
2880-1440	-1.200667	-2.323720	-0.07761344	0.0325294

Summary White

	Df	Sum Sq	Mean Sq	F value	Pr(>F)
Cycle	4	356.7	89.18	99.49	6.62e-13 ***
Residuals	20	17.9	0.90		

TukeyHSD

Tukey multiple comparisons of means

95% family-wise confidence level

Cycle	Df	Lower	Upper	p-adjusted
360-0	-3.422667	-5.214440	-1.6308935	0.0001198
720-0	-5.463333	-7.255107	-3.6715601	0.0000001
1440-0	-9.252000	-11.043773	-7.4602268	0.0000000
2880-0	-10.282000	-12.073773	-8.4902268	0.0000000
720-360	-2.040667	-3.832440	-0.2488935	0.0208237
1440-360	-5.829333	-7.621107	-4.0375601	0.0000000
2880-360	-6.859333	-8.651107	-5.0675601	0.0000000
1440-720	-3.788667	-5.580440	-1.9968935	0.0000319
2880-720	-4.818667	-6.610440	-3.0268935	0.0000010
2880-1440	-1.030000	-2.821773	0.7617732	0.4447046

Summary Violet

	Df	Sum Sq	Mean Sq	F value	Pr(>F)
Cycle	4	376.6	94.14	112.3	2.09e-13 ***
Residuals	20	16.8	0.84		

TukeyHSD

Tukey multiple comparisons of means

95% family-wise confidence level

Cycle	Df	Lower	Upper	p-adjusted
360-0	-3.702000	-5.434479	-1.969521	0.0000277
720-0	-6.304667	-8.037145	-4.572188	0.0000000
1440-0	-8.441333	-10.173812	-6.708855	0.0000000
2880-0	-11.290667	-13.023145	-9.558188	0.0000000
720-360	-2.602667	-4.335145	-0.870188	0.0018427
1440-360	-4.739333	-6.471812	-3.006855	0.0000008
2880-360	-7.588667	-9.321145	-5.856188	0.0000000
1440-720	-2.136667	-3.869145	-0.404188	0.0112296
2880-720	-4.986000	-6.718479	-3.253521	0.0000003
2880-1440	-2.849333	-4.581812	-1.116855	0.0007036

Cycle effect of each insert by angulation method

Summary Black angle

	Df	Sum Sq	Mean Sq	F value	Pr(>F)
Cycle	1	0.8188	0.8188	11.77	0.00228 **
Residuals	23	1.6002	0.0696		

TukeyHSD

Tukey multiple comparisons of means

95% family-wise confidence level

Cycle	Df	Lower	Upper	p-adjusted
360-0	-0.3673333336	-0.8160405	0.08137387	0.1428679
720-0	-0.5266666666	-0.9753739	-0.07795946	0.0166077
1440-0	-0.5273333334	-0.9760405	-0.07862613	0.0164474
2880-0	-0.6586666666	-1.1073739	-0.20995946	0.0023253
720-360	-0.1593333330	-0.6080405	0.28937387	0.8230701
1440-360	-0.1599999998	-0.6087072	0.28870721	0.8209054
2880-360	-0.2913333330	-0.7400405	0.15737387	0.3282406
1440-720	-0.0006666668	-0.4493739	0.44804054	1.0000000
2880-720	-0.1320000000	-0.5807072	0.31670721	0.9008144
2880-1440	-0.1313333332	-0.5800405	0.31737387	0.9024203

Summary Yellow angle

	Df	Sum Sq	Mean Sq	F value	Pr(>F)
Cycle	1	26.243	26.243	66	3.29e-08 ***
Residuals	23	9.145	0.398		

TukeyHSD

Tukey multiple comparisons of means

95% family-wise confidence level

Cycle	Df	Lower	Upper	p-adjusted
360-0	-0.8226667	-1.658263	0.01292948	0.0549475
720-0	-1.8513333	-2.686929	-1.01573718	0.0000168
1440-0	-2.5293333	-3.364929	-1.69373718	0.0000002
2880-0	-3.0913333	-3.926929	-2.25573718	0.0000000
720-360	-1.0286667	-1.864263	-0.19307052	0.0113973
1440-360	-1.7066667	-2.542263	-0.87107052	0.0000506
2880-360	-2.2686667	-3.104263	-1.43307052	0.0000008
1440-720	-0.6780000	-1.513596	0.15759615	0.1485506
2880-720	-1.2400000	-2.075596	-0.40440385	0.0020859
2880-1440	-0.5620000	-1.397596	0.27359615	0.2959437

Summary Pink angle

	Df	Sum Sq	Mean Sq	F value	Pr(>F)
Cycle	1	141.30	141.30	127.3	7.49e-11 ***
Residuals	23	25.53	1.11		

TukeyHSD

Tukey multiple comparisons of means

95% family-wise confidence level

Cycle	Df	Lower	Upper	p-adjusted
360-0	-1.6266667	-2.363951	-0.88938271	0.0000178
720-0	-4.3133333	-5.050617	-3.57604938	0.0000000
1440-0	-5.1480000	-5.885284	-4.41071604	0.0000000
2880-0	-7.2080000	-7.945284	-6.47071604	0.0000000
720-360	-2.6866667	-3.423951	-1.94938271	0.0000000
1440-360	-3.5213333	-4.258617	-2.78404938	0.0000000
2880-360	-5.5813333	-6.318617	-4.84404938	0.0000000
1440-720	-0.8346667	-1.571951	-0.09738271	0.0217620
2880-720	-2.8946667	-3.631951	-2.15738271	0.0000000
2880-1440	-2.0600000	-2.797284	-1.32271604	0.0000005

Summary White angle

	Df	Sum Sq	Mean Sq	F value	Pr(>F)
Cycle	1	249.66	249.7	108.4	3.57e-10 ***
Residuals	23	52.99	2.3		

TukeyHSD

Tukey multiple comparisons of means

95% family-wise confidence level

Cycle	Df	Lower	Upper	p-adjusted
360-0	-2.462667	-3.366159	-1.5591739	0.0000008
720-0	-5.412667	-6.316159	-4.5091739	0.0000000
1440-0	-7.905333	-8.808826	-7.0018406	0.0000000
2880-0	-9.424667	-10.328159	-8.5211739	0.0000000
720-360	-2.950000	-3.853493	-2.0465072	0.0000000
1440-360	-5.442667	-6.346159	-4.5391739	0.0000000
2880-360	-6.962000	-7.865493	-6.0585072	0.0000000
1440-720	-2.492667	-3.396159	-1.5891739	0.0000007
2880-720	-4.012000	-4.915493	-3.1085072	0.0000000
2880-1440	-1.519333	-2.422826	-0.6158406	0.0005485

Summary Violet angle

	Df	Sum Sq	Mean Sq	F value	Pr(>F)
Cycle	1	414.0	414.0	108.7	3.46e-10 ***
Residuals	23	87.6	3.8		

TukeyHSD

Tukey multiple comparisons of means

95% family-wise confidence level

Cycle	Df	Lower	Upper	p-adjusted
360-0	-3.768000	-4.631553	-2.9044468	0.0000000
720-0	-6.640667	-7.504220	-5.7771135	0.0000000
1440-0	-10.648000	-11.511553	-9.7844468	0.0000000
2880-0	-12.216000	-13.079553	-11.3524468	0.0000000
720-360	-2.872667	-3.736220	-2.0091135	0.0000000
1440-360	-6.880000	-7.743553	-6.0164468	0.0000000
2880-360	-8.448000	-9.311553	-7.5844468	0.0000000
1440-720	-4.007333	-4.870887	-3.1437801	0.0000000
2880-720	-5.575333	-6.438887	-4.7117801	0.0000000
2880-1440	-1.568000	-2.431553	-0.7044468	0.0002236

CURRICULUM VITAE

Author's Name	Mr. Theerayut Rattanadech	
Date/Year of Birth	27 March 1986	
Education	2005-2010	Doctor of Dental Surgery (D.D.S.), Faculty of Dentistry, Chiang Mai University, Chiang Mai, Thailand.
Position held and office	2011-2012	Dental department, Boklua hospital, Nan, Thailand
	2013-2014	Dental department, Maeai hospital, Chiang Mai, Thailand