CHANGES OF RETENTION UNIT AND KEEPER-SURFACE STRUCTURE OF NEODYMIUM-IRON-BORON MAGNETIC ATTACHMENTS UPON IMMERSION IN LACTIC ACID, ACETIC ACID, AND ARTIFICIAL SALIVA

TRINUCH EIAMPONGPAIBOON

**A THESIS SUBMITTED IN PARTIAL FULFILLMENT
OF THE REQUIREMENTS FOR
THE DEGREE OF MASTER OF SCIENCE
(PROSTHODONTICS)
FACULTY OF GRADUATE STUDIES
MAHIDOL UNIVERSITY
2005**

ISBN 974-04-5581-6
COPYRIGHT OF MAHIDOL UNIVERSITY

Copyright by Mahidol University

Thesis
Entitled

CHANGES OF RETENTION UNIT AND KEEPER-SURFACE STRUCTURE OF NEODYMIUM-IRON-BORON MAGNETIC ATTACHMENTS UPON IMMERSION IN LACTIC ACID, ACETIC ACID, AND ARTIFICIAL SALIVA

Miss Trinuch Eiampongpaiboon
Candidate

Assoc. Prof. Jurai Nakaparksin,
D.D.S., Cert. in Dental Material Sc.,
M.S.D.
Major-Advisor

Asst. Prof. Dr. Somchai Urapepon,
D.D.S.,Cert.in Prosthodontics,
Ph.D.
Co-Advisor

Lect. Chotiros Kuphasuk,
D.D.S.,M.Sc.(Prosthodontics)
Diplomate American Board of
Prosthodontics
Co-Advisor

Assoc. Prof. Rassmidara Hoonsawat,
Ph.D.
Dean
Faculty of Graduate Studies

Assoc. Prof .Benjapote Yotnuengnit,
Diplomate Thai Board of Prosthodontics
Chair
Master of Science Programme in
Prosthodontics
Faculty of Dentistry

Copyright by Mahidol University

Thesis
Entitled

CHANGES OF RETENTION UNIT AND KEEPER-SURFACE STRUCTURE OF NEODYMIUM-IRON-BORON MAGNETIC ATTACHMENTS UPON IMMERSION IN LACTIC ACID, ACETIC ACID, AND ARTIFICIAL SALIVA

was submitted to the Faculty of Graduate Studies, Mahidol University
for the degree of Master of Science (Prosthodontics)
on
17 January, 2005

Miss Trinuch Eiampongpaiboon
Candidate

Assoc. Prof. Jurai Nakaparksin
Chair

Asst. Prof. Dr. Widchaya Kanchanavasita, Ph.D.
Member

Lect. Chotiros Kuphasuk
Member

Assoc. Prof. Dr. Apirat Siritaratiwat, Ph.D. (Electrical Engineer)
Member

Asst. Prof. Dr. Somchai Urapepon
Member

Assoc. Prof. Rassmidara Hoonsawat, Ph.D.
Dean
Faculty of Graduate Studies
Mahidol University

Asst. Prof. Theeralaksna Suddhasthira, Ph.D.
Dean
Faculty of Dentistry
Mahidol University

Copyright by Mahidol University

ACKNOWLEDGEMENT

The success of this thesis can be attributed to the extensive support and assistance from my major advisor, Assoc.Prof. Jurai Nakaparksin and my co-advisor, Asst.Prof. Somchai Urapepon and Lect. Chotiros Kuphasuk. I deeply thank them for their kindness, valuable advice and guidance in this research.

I wish to thank Assoc. Prof. Apirat Siritaratiwat for his kindness and providing suggestions for improvement, and who was the external examiner of the thesis defense.

I would like to thank the Research Unit, Faculty of Dentistry for providing the research instrument. In particular, I would like to thank Miss Vassana Wichai, Mrs.Nongnuch Teanchai, and staffs of the Research Unit for their generous assistances.

I would like to thank Dr. Onanong Prombut for her valuable advice and thanks for her kind support.

I am grateful to all the lecturers and staffs of the Department of Prosthodontics for their valuable advice and thanks for their kind support.

Finally, I am grateful to my parents for their love, understanding and encouragement throughout my studies.

Trinuch Eiampongpaiboon

Copyright by Mahidol University

CHANGES OF RETENTION UNIT AND KEEPER-SURFACE STRUCTURE OF NEODYMIUM-IRON-BORON MAGNETIC ATTACHMENTS UPON IMMERSION IN LACTIC ACID, ACETIC ACID, AND ARTIFICIAL SALIVA

TRINUCH EIAMPONGPAIBOON 4536022 DTPT/M

M.Sc. (PROSTHODONTICS)

THESIS ADVISORS: JURAI NAKAPARKSIN, Cert. IN DENTAL MATERIAL Sc., M.S.D., CHOTIROS KUPHASUK, M.Sc. (PROSTHODONTICS), DIPLOMATE AMERICAN BOARD OF PROSTHODONTICS, SOMCHAI URAPEPON, Ph.D.

ABSTRACT

Magnetic attachments are used as aids to increase retention of removable partial dentures to overdentures by magnetic forces of them. Previous studies have proved that the magnets have poor corrosive resistance in oral fluids**.** When the magnet is corroded, the attractive force will be lost**.** Keepers as the component of magnetic attachment are used in oral cavity. Therefore they should not easily interfere with attractive force of magnetic attachment from oral fluid.

Attractive forces of magnetic attachment were tested by Universal Testing Machine before and after immersion in various media: lactic acid, acetic acid, and artificial saliva. The amount of elements and surface structure of the keepers were evaluated by Energy Dispersive X-ray Spectrometer Analysis (EDS) and Scanning Electron Microscope (SEM), respectively.

The outcomes of this study showed that after immersed keeper in three solutions did not affect the attractive force of magnetic attachment. There was no significant difference between before and after immersion ($p>0.05$). The three solutions did not affect the attractive force of magnetic attachment. There was no significant difference in the mean attractive force among keepers group ($p>0.05$). The Scanning Electron Microscope studies showed that the surfaces of keepers before and after immersion in media were different. The Energy Dispersive X-ray Spectrometer Analysis studies showed the amount of elements on keeper surfaces. Chromium was more than 90% with 2-3% Iron, and 1-2% Aluminum respectively before immersion. After immersion, the amount of Chromium was still more than 90% same as before immersion in each solution as well as Iron and Aluminum where no significant difference between before and after immersion ($p>0.05$).

KEY WORDS: MAGNETIC ATTACHMENT / KEEPER / ATTRACTIVE FORCE

43 P. ISBN 974-04-5581-6

Copyright by Mahidol University

การเปลี่ยนแปลงของแรงยึดอยู่และลักษณะโครงสร้างพื้นผิวของคีปเปอร์ของตัวยึดแม่เหล็กชนิดนีโอไดเมียมไอรอนโบรอน ภายใต้การแช่ในกรดแลคติก,กรดอะซิติก,และน้ำลายเทียม. (CHANGES OF RETENTION UNIT AND KEEPER-SURFACE STRUCTURE OF NEODYMIUM-IRON-BORON MAGNETIC ATTACHMENTS UPON IMMERSION IN LACTIC ACID, ACETIC ACID, AND ARTIFICIAL SALIVA)

ตรีนุช เอี่ยมพงษ์ไพบูลย์ 4536022 DTPT/M

วท.ม.(ทันตกรรมประดิษฐ์)

คณะกรรมการควบคุมวิทยานิพนธ์: จุไร นาคะปักษิณ, Cert. IN DENTAL MATERIAL Sc., M.S.D., โชติรส คูผาสุข, M.Sc. (PROSTHODONTICS), DIPLOMATE AMERICAN BOARD OF PROSTHODONTICS, สมชาย อุรพีพล, Ph.D.

บทคัดย่อ

ตัวยึดแม่เหล็กถูกนำมาใช้เพื่อเพิ่มการยึดอยู่ของฟันเทียมบางส่วนถอดได้ รวมไปถึงฟันเทียมทับรากด้วยแรงยึดของแม่เหล็ก.มีการศึกษาหลายการศึกษาได้พิสูจน์ได้ว่าแม่เหล็กมีความต้านทานต่อการสึกกร่อนที่ต่ำ เมื่อแม่เหล็กถูกทำให้สึกกร่อนแรงดึงดูดของมันก็จะสูญเสียไป คีปเปอร์ซึ่งเป็นส่วนหนึ่งในตัวยึดแม่เหล็กก็ถูกนำมาใช้ในช่องปาก ดังนั้นคีปเปอร์เหล่านี้จึงไม่ควรถูกรบกวนต่อแรงดึงดูดของตัวยึดแม่เหล็กด้วยของเหลวในช่องปาก.

แรงดึงดูดของตัวยึดแม่เหล็กถูกทดสอบด้วยเครื่องทดสอบสากลก่อนและหลังแช่ในสารละลายชนิดต่างๆได้แก่ กรดแลคติก, กรดอะซิติก,และน้ำลายเทียม. ปริมาณแร่ธาตุบนพื้นผิวของคีปเปอร์ถูกทดสอบด้วยเครื่องวิเคราะห์ธาตุระบบX-rayและตรวจสอบลักษณะพื้นผิวของคีปเปอรีด้วยกล้องจุลทรรศน์อิเลคตรอน แบบส่องกราด.

ผลที่ได้จากการศึกษาครั้งนี้พบว่าหลังจากแช่คีปเปอร์ในสารละลาย3ชนิดดังกล่าวมาแล้วไม่มีความแตกต่างของค่าแรงดึงดูดก่อนแช่และหลังแช่ในสารละลายอย่างมีนัยสำคัญทางสถิติที่ระดับ 0.05และในแต่ละชนิดของสารละลายก็ไม่มีความแตกต่างกันของแรงดึงดูดอย่างมีนัยสำคัญทางสถิติที่ระดับ0.05. การศึกษาพื้นผิวของคีปเปอร์ด้วยกล้องจุลทรรศน์แบบส่องกราดพบว่าพื้นผิวของคีปเปอร์มีการเปลี่ยนแปลงไป. การใช้เครื่องวิเคราะห์ธาตุระบบX-ray แสดงปริมาณแร่ธาตุบนพื้นผิวของคีปเปอร์ก่อนการแช่พบว่ามีโครเมียมมากกว่า 90% เหล็ก 2-3% และอลูมินัม1-2%และภายหลังการแช่พบว่าปริมาณโครเมียม เหล็ก และอลูมินัม ไม่มีความแตกต่างอย่างมีนัยสำคัญทางสถิติที่ระดับ 0.05 เมื่อเทียบกับก่อนแช่สารละลาย

43 หน้า ISBN 974-04-5581-6

Copyright by Mahidol University

CONTENTS

	Page
ACKNOWLEDGEMENT	iii
ABSTRACT	iv
LIST OF TABLES	vii
LIST OF FIGURES	viii
LIST OF ABBREVATIONS	x
CHAPTER	
I INTRODUCTION	1
II LITERATURE REVIEW	3
III MATERIALS AND METHODS	17
IV RESULTS	21
V DISCUSSION	32
VI CONCLUSION	37
REFERENCES	38
BIOGRAPHY	43

Copyright by Mahidol University

LIST OF TABLES

	Page
Table 4-1: Attractive forces between magnetic assembly and keeper of MAGFIT EX 600	21
Table 4-2: Test of homogeneity of variances of attractive forces	22
Table 4-3: One-way analysis of variance compares means of attractive forces among 3 groups	22
Table 4-4: Paired t-test compares means of attractive forces between before and after immersion in lactic acid.	23
Table 4-5: Paired t-test compares means of attractive forces between before and after immersion in artificial saliva.	23
Table 4-6: Paired t-test compares means of attractive forces between before and after immersion in acetic acid.	24
Table4-7: Table shows the amount of element on keeper surface by Energy Dispersive X-ray Spectrometer Analysis (EDS)	31

Copyright by Mahidol University

LIST OF FIGURES

	Page
Figure 2-1: Samarium-Cobalt magnet	3
Figure 2-2: That shows progression of magnetic attachment	4
Figure 2-3: Neodymium-Iron-Boron magnetic attachment	5
Figure 2-4: Image show model of magnetic field	6
Figure 2-5: Magnetic field around the bar magnet	7
Figure 2-6: Image show magnetic line of force	8
Figure 2-7: Image show hysteresis loop of magnetic properties	10
Figure 2-8: Open-field magnet	13
Figure 2-9: Closed-field magnet	14
Figure 3-1: MAGFIT EX600	17
Figure 3-2: Keeper	17
Figure 3-3: Magnetic assembly was attached with upper jig of Instron	19
Figure 3-4: Magnetic assembly was attached with keeper	20
Figure 4-1: Keeper-surface before immersion in lactic acid (500X)	25
Figure 4-2: Keeper-surface after immersion in lactic acid (500X)	25
Figure 4-3: Keeper-surface before immersion in artificial saliva (500X)	26
Figure 4-4: Keeper-surface after immersion in artificial saliva (500X)	26
Figure 4-5: Keeper-surface before immersion in acetic acid (500X)	27
Figure 4-6: Keeper-surface after immersion in acetic acid (500X)	27
Figure 4-7: Keeper-surface before immersion in lactic acid (1000X)	28
Figure 4-8: Keeper-surface after immersion in lactic acid (1000X)	28
Figure 4-9: Keeper-surface before immersion in artificial saliva (1000X)	29
Figure 4-10: Keeper-surface after immersion in artificial saliva (1000X)	29
Figure 4-11: Keeper-surface before immersion in acetic acid (1000X)	30
Figure 4-12: Keeper-surface after immersion in acetic acid (1000X)	30

Copyright by Mahidol University

LIST OF FIGURES (CONT.)

Page

Figure 5-1 Component of magnetic attachment 32
Figure 5-2 In any normal oxidizing environment a protective coating of passive Chromium rich oxide films is automatically formed on stainless steel 33
Figure 5-3 When scratched damages or machined this protective film is denuded exposing the steel to the atmosphere 34
Figure 5-4 The protective coating is quickly restored through the rapid self-repairing quality of the Chromium rich film. 34
Figure 5-5 Magnetic field surrounding the Iron bar 35
Figure 5-6 Image show magnetic field of magnetic attachment around keeper and magnetic assembly 36

Copyright by Mahidol University

LIST OF ABBREVIATIONS

mm	millimeters
Nd	Neodymium
Fe	Iron
B	Boron
Pd	Palladium
Al	Aluminium
Co	Cobalt
Ni	Nickle
N	Newton
B	magnetic induction
H	Applied field
M	Magnetization
A	Ampere
^{0}C	degree Celsius
et al	et alii
Fig.	Figure
cont.	Continue
Inc.	Incorporation
Co.,	Company
SD	Standard deviation
df	degree of freedom

Copyright by Mahidol University

CHAPTER I
INTRODUCTION

The use of magnets was reported in dentistry as early as the 1940s. However, the easily disturbed magnetic retention systems failed due to several reasons. A major factor was magnet size, which was solved with the development of $SmCO_5$ and $Nd_2Fe_{14}B$ magnets. Such magnets have subsequently been applied to various dental prostheses, such as removable partial dentures, overdentures, maxillofacial prostheses, and dental implants. The reason for their initial widespread use is related to their small size combined with strong attractive forces. Other advantages include ease of cleaning, ease of placement, automatic reseating, and constant retention force over a relatively long period of time. Nevertheless, the magnets have poor corrosive resistance in oral fluids and thus require encapsulation within a relatively inert alloy such as stainless steel or titanium. However, keepers as the component of magnetic attachment should have corrosive resistance because they are used in oral cavity and they should not be easily interfered to attractive force of attachment by oral fluids.

Objectives of the study

1. To compare the attractive forces of magnetic attachments when keepers are immersed separately in two kinds of acid solution and artificial saliva.
2. To determine whether reduction of attractive force of magnetic attachments occurred when keepers are immersed separately in two kinds of acid solution and artificial saliva.
3. To evaluate the amount of elements and surface structure of the keeper before and after keepers are immersed separately in two kinds of acid solution and artificial saliva.

Copyright by Mahidol University

Research hypothesis

1. The attractive forces of magnetic attachments when keepers are immersed in lactic acid, acetic acid, and artificial saliva are not equal.

2. Before and after keepers are immersed in two kinds of acid solution and artificial saliva, the attractive forces of magnetic attachments are not equal.

3. Loss of element and change of surface structure of the keeper after immersion in two kinds of acid solutions and artificial saliva.

Statistical hypothesis

1. Ho: Means attractive forces of magnetic attachment when keepers are immersed in lactic acid, acetic acid, and artificial saliva are equal ($\mu b1=\mu b2=\mu b3$).

H1: Means attractive forces of magnetic attachment that keepers are immersed in lactic acid, acetic acid, and artificial saliva are not equal ($\mu b1\neq\mu b2\neq\mu b3$).

2 Ho: Means attractive forces of magnetic attachments before and after keepers are immersed separately in two kinds of acid solution and artificial saliva are equal ($\mu a1=\mu a2$).

H1: Means attractive forces of magnetic attachments before and after keepers are immersed separately in two kinds of acid solution and artificial saliva are different ($\mu a1\neq \mu a2$).

Copyright by Mahidol University

CHAPTER II
LITERATURE REVIEW

The use of magnetic materials as an aid to denture retention is not new. Magnets have been used clinically for maxillofacial prostheses, overdentures, removable partial denture, dental implants, and orthodontic treatment.

In the first, repulsive forces have been utilized in complete dentures with like magnetic poles opposing each other in the molar region (1,2,3). Afterwards, the attractive forces have been utilized in endosseous and subperiosteal implantation, but they had much disadvantages such as exfoliation of magnets or insufficiency of retentive forces (4,5,6).

Therefore, the unlike magnetic pole had been giving retentive force for removable denture by magnetic attachment (7,8,9). The first rare earth magnet to be commercially produced was fabricated from the transition element Cobalt and the rare earth element Samarium. The Cobalt-Samarium magnet has a much greater magnetic strength than a conventional Aluminium-Nickle-Chromium, or Platinum-Cobalt alloy.

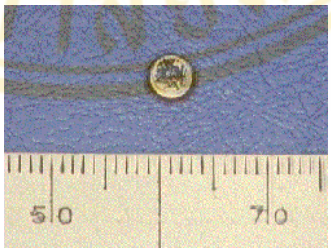

Figure2-1: Samarium-Cobalt magnet (10)

Copyright by Mahidol University

The second-generation rare earth magnet was produced from the transitional element Iron and the rare earth element Neodymium (10). The addition of the third element Boron was to increase the fundamental stability of the crystalline structure (10). The newer Neodymium- Iron-Boron alloy is about 20% stronger per unit volume than the Samarium Cobalt alloy (11,12). The alloys will oxidize and corrode slightly in the oral environment. Therefore, it is necessary to encapsulate or electroplate the magnetic component of the attachment.

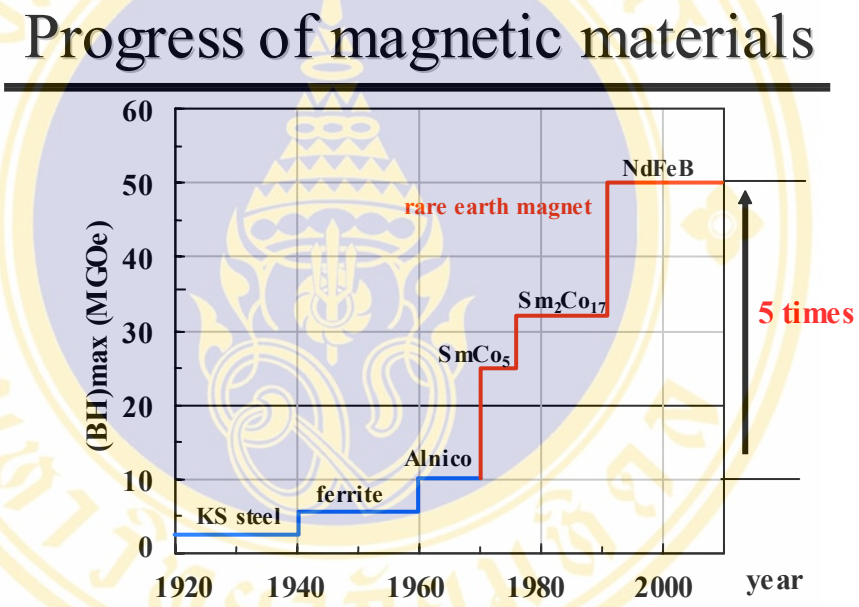

Figure2-2: That shows progression of magnetic attachment.

Keepers

The keeper, an integral part of the magnetic retentive system, is a device for channeling the magnetic field from the North Pole to the South Pole in the closed field system. The main advantage of the keeper is used instead of a magnet in root part of the magnetic retention system. It can provide almost as much retention as two magnets because it can be magnetically induced when contact the magnet. Another advantage is to avoid a long-term effect on tissue from the magnetic fields.

Copyright by Mahidol University

A soft magnetic material was developed for using in the root face such as Pd-Co, Pd-Co-Cr, and Pd-Co-Ni alloy. The magnetic physical properties and corrosion resistance of Pd-Co, Pd-Co-Cr, and Pd-Co-Ni were found that the Pd-Co-Ni alloy was the most suitable. However, it was also shown that Pd-Co-Cr alloys were the most corrosive resistance (7). Pd-Co system alloys as casting alloy exhibited soft ferromagnetic characteristics, which it was used as a keeper. The alloys will virtually act non-ferromagnetically except when placed near a magnet (13). Afterward, cytotoxicity of Pd-Co system alloys; Pd-Co, Pd-Co-Cr, and Pd-Co-Ni alloy were tested and the result indicated that the ternary alloys (Pd-Co-Ni alloy) may have little cytotoxicity and, therefore, would be appropriate to use as a part of magnetic attachment (14).

In 1992, a new method in keeper fabrication was developed. A ferromagnetic stainless steel type 447J1 (79%Fe, 19%Cr, 2% etc) was used instead of Pd-Co-Ni alloy. The manufacturer claimed that it had better magnetic properties and higher corrosion resistance.

Magnetic assembly keeper Magnetic attachment

Figure2-3: Neodymium-Iron-Boron magnetic attachment (MAGFIT EX600, Aichi steel Co., Japan)

Copyright by Mahidol University

The magnetic fields

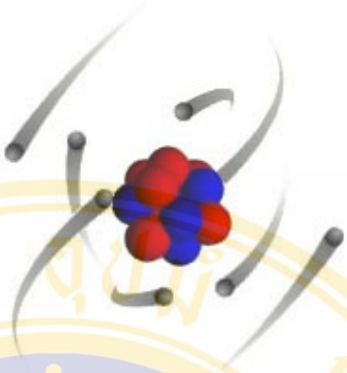

Figure 2-4: Image show model of magnetic field. (15)

The term "**magnetic field**" simply describes a volume of space where there is a change in energy within that volume. This change in energy can be detected and measured. The location where a magnetic field can be detected exiting or entering a material is called a magnetic pole. Magnetic poles have never been detected in isolation but always occur in pairs and, thus, the name dipole. Therefore, a **dipole** is an object that has a magnetic pole on one end and a second equal but opposite magnetic pole on the other. A bar magnet can be considered a dipole with a north pole at one end and a south pole at the other. A magnetic field can be measured leaving the dipole at a north pole and returning the magnet at a south pole. If a magnet is cut in two, two magnets or dipoles are created out of one. This sectioning and creation of dipoles can continue to the atomic level. (15,16)

Magnetic Field Characteristics: Magnetic field in and around a bar magnet

As discussed previously a magnetic field is a change in energy within a volume of space. The magnetic field surrounding a bar magnet can be seen in the figure 2-5. Placing a piece of paper over a magnet and sprinkling the paper with iron fillings can create a magnetograph. The particles align themselves with the lines of magnetic force produced by the magnet. The magnetic lines of force show where the magnetic field exits the material at one pole and reenters the material at another pole along the length of the magnet. It should be noted that the magnetic lines of force exist in three-dimensions but are only seen in two dimensions in the image. (15,16)

Copyright by Mahidol University

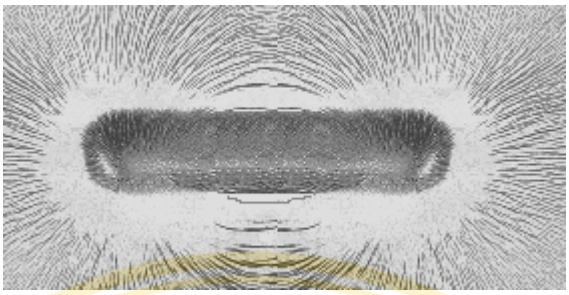

Figure2-5: Magnetic field around the bar magnet (16)

It can be seen in the magnetograph that there are poles all along the length of the magnet but the poles are concentrated at the ends of the magnet. The area where the exit poles are concentrated is called the magnet's North Pole and the area where the entrance poles are concentrated is called the magnet's South Pole.

General Properties of Magnetic Lines of Force

Magnetic lines of force have a number of important properties, which include:

- They seek the path of least resistance between opposite magnetic poles. In a single bar magnet as shown to the left, they attempt to form closed loop from pole to pole.
- They never cross one another.
- They have the same strength.
- Their density decreases (they spread out) when they move from an area of higher permeability to an area of lower permeability.
- Their density decreases with increasing distance from the poles.
- They are considered to have direction as if flowing, though no actual movement occurs. They flow from a south pole to a north pole within the material and a north pole to a south pole in air. (15)

Copyright by Mahidol University

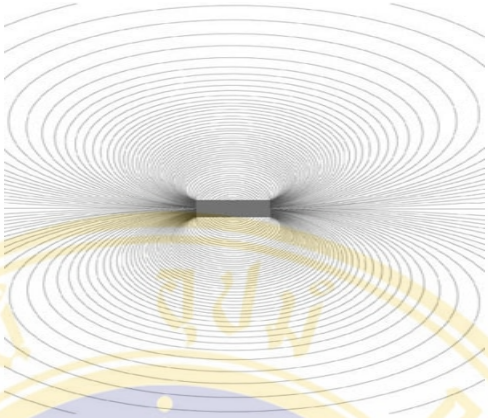

Figure 2-6: Image show magnetic line of force (15)

Quantifying Magnetic Properties
(Magnetic Field Strength, Flux Density, Total Flux and Magnetization)

Until now, only the qualitative features of the magnetic field have been discussed. However, it is necessary to be able to measure and express quantitatively the various characteristics of magnetism. Unfortunately, a number of unit conventions are in use as shown below. SI units will be used in this material. The advantage of using SI units is that they are traceable back to an agreed set of four base units – meter, kilogram, second, and Ampere.

Quantity	SI Units (Sommerfeld)	SI Units (Kennelly)
Field(H)	A/m	A/m
Flux Density(B) (Magnetic Induction)	tesla	tesla
Magnetic Flux	weber	weber
Magnetization(M)	A/m	-

Copyright by Mahidol University

The units for magnetic field strength **H** are ampere/meter. A magnetic field strength of 1 ampere/meter is produced at the center of a single circular conductor of diameter 1 meter carrying a steady current of 1 ampere.

The number of magnetic lines of force cutting through a plane of a given area at a right angle is known as the **magnetic flux density B**. The flux density or magnetic induction has the tesla as its unit. One tesla is equal to 1 Newton/(A/m). From these units it can be seen that the flux density is a measure of the force applied to a particle by the magnetic field.

The total number of lines of magnetic force in a material is called **magnetic flux.** The number of magnetic domains that are aligned within a material determines the strength of the flux. The total flux is simply the flux density applied over an area. Flux carries the unit of a weber, which is simply a tesla-square meter.

The magnetization is a measure of the extent to which an object is magnetized. It is a measure of the magnetic dipole moment per unit volume of the object. Magnetization carries the same units as a magnetic field;amperes/meter.(15,16,17,18)

The Hysteresis Loop and Magnetic Properties

A great deal of information can be learned about the magnetic properties of a material by studying its hysteresis loop. A hysteresis loop shows the relationship between the induced magnetic flux density **B** and the magnetizing force **H.** It is often referred to as the B-H loop. An example hysteresis loop is shown in figure2-7.

Copyright by Mahidol University

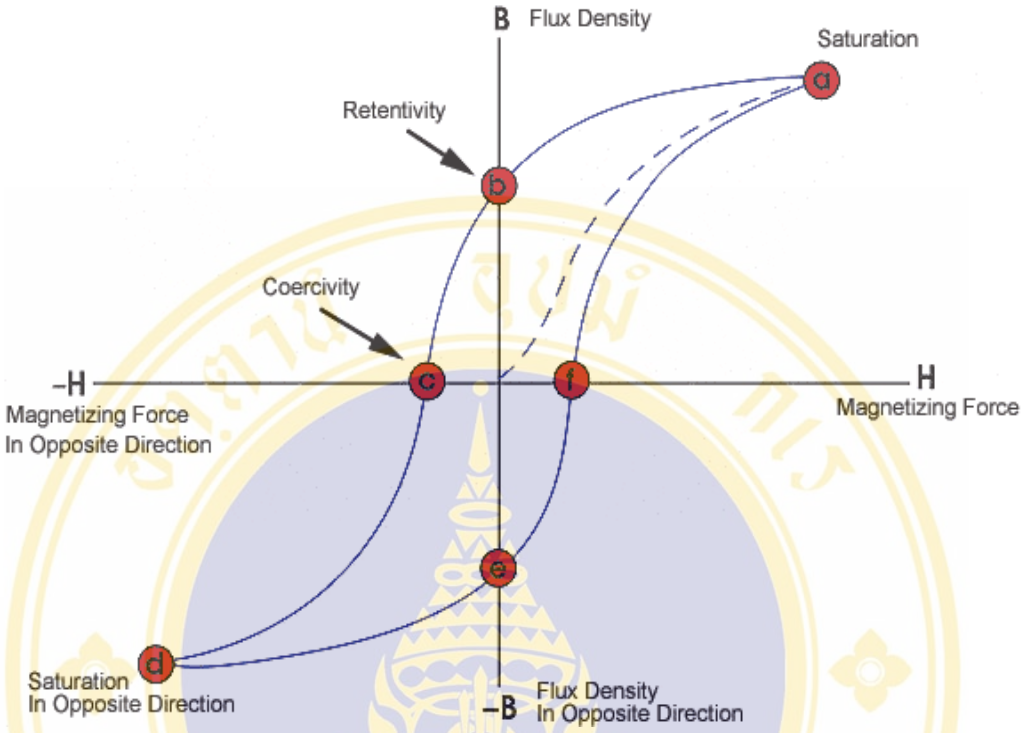

Figure 2-7: Image show hysteresis loop of magnetic properties. (15)

Measuring the magnetic flux **B** of a ferromagnetic material while the magnetizing force **H** is changed generates the loop. A ferromagnetic material has never been previously magnetized or has been thoroughly demagnetized will follow the dashed line as **H** is increased. As the line demonstrates, the greater the amount of current applied **(H+)**, the stronger the magnetic field in the component **(B+)**. At point "a" almost all of the magnetic domains are aligned and an additional increase in the magnetizing force will produce very little increase in magnetic flux. The material has reached the point of magnetic saturation. When **H** is reduced back down to zero, the curve will move from point "a" to point "b." At this point, it can be seen that some magnetic flux remains in the material even though the magnetizing force is zero. This is referred to as the point of retentivity on the graph and indicates the remanence or level of residual magnetism in the material. (Some of the magnetic domains remain aligned but some have lost their alignment.) As the magnetizing force is reversed, the curve moves to point "c", where the flux has been reduced to zero. This is called the point of coercivity on the curve. (The reversed magnetizing force has flipped enough of the domains so that the net flux within the material is zero.) The force required to

Copyright by Mahidol University

remove the residual magnetism from the material, is called the coercive force or coercivity of the material. (15,16,17,18)

As the magnetizing force is increased in the negative direction, the material will again become magnetically saturated but in the opposite direction (point "d"). Reducing **H** to zero brings the curve to point "e." It will have a level of residual magnetism equal to that achieved in the other direction. Increasing **H** back in the positive direction will return **B** to zero. Notice that the curve did not return to the origin of the graph because some force is required to remove the residual magnetism. The curve will take a different path form point "f" back the saturation point where it with completes the loop.

From the hysteresis loop, a number of primary magnetic properties of a material can be determined. (15)

1. Retentivity – A measure of the residual flux density corresponding to the saturation induction of a magnetic material. In other words, it is a material's ability to retain a certain amount of residual magnetic field when the magnetizing force is removed after achieving saturation. (The value of **B** at point B on the hysteresis curve.)

2. Residual Magnetism or Residual Flux – the magnetic flux density that remains in a material when the magnetizing force is zero. Note that residual magnetism and retentivity are the same when the material has been magnetized to the saturation point. However, the level of residual magnetism may be lower than the retentivity value when the magnetizing force did not reach the saturation level.

3. Coercive Force – The amount of reverse magnetic field which must be applied to a magnetic material to make the magnetic flux return to zero. (The value of **H** at point C on the hysteresis curve.)

4. Permeability. - A property of a material that describes the ease with which a magnetic flux is established in the component.

5. Reluctance – Reluctance is analogous to the resistance in an electrical circuit.

Copyright by Mahidol University

Diamagnetic, Paramagnetic, and Ferromagnetic Materials

When a material is placed within a magnetic field, the magnetic forces of the material's electrons will be affected. However, materials can react quite differently to the presence of an external magnetic field. This reaction is dependent on a number of factors such as the atomic and molecular structure of the material, and the net magnetic field associated with the atoms. The magnetic moments associated with atoms have three origins. These are the electron orbital motion, the change in orbital motion caused by an external magnetic field, and the spin of the electrons.

In most atoms, electrons occur in pairs. Each electron in a pair spins in the opposite direction. So when electrons are paired together, their opposite spins cause there magnetic fields to cancel each other (17). Therefore, no net magnetic field exists. Alternately, materials with some unpaired electrons will have a net magnetic field and will react more to an external field. Most materials can be classified as ferromagnetic, diamagnetic or paramagnetic (15,16,18).

Diamagnetic metals have a very weak and negative susceptibility to magnetic fields. Diamagnetic materials are slightly repelled by a magnetic field and the material does not retain the magnetic properties when the external field is removed. Diamagnetic materials are solids with all paired electron and, therefore, no permanent net magnetic moment per atom. Diamagnetic properties arise from the realignment of the electron orbits under the influence of an external magnetic field. Most elements in the periodic table, including copper, silver, and gold, are diamagnetic.

Paramagnetic metals have a small and positive susceptibility to magnetic fields. These materials are slightly attracted by a magnetic field and the material does not retain the magnetic properties when the external field is removed. Paramagnetic properties are due to the presence of some unpaired electrons and from the realignment of the electron orbits caused by the external magnetic field. Paramagnetic materials include Magnesium, molybdenum, lithium, and tantalum.

Copyright by Mahidol University

Ferromagnetic materials have a large and positive susceptibility to an external magnetic field. They exhibit a strong attraction to magnetic fields and are able to retain their magnetic properties after the external field has been removed. Ferromagnetic materials have some unpaired electrons so their atoms have a net magnetic moment. They get their strong magnetic properties due to the presence of magnetic domains. In these domains, large numbers of atoms moments are aligned parallel so that the magnetic force within the domain is strong. When a ferromagnetic material is in the unmagnitized state, the domains are nearly randomly organized and the net magnetic field for the part as a whole is zero. When a magnetizing force is applied, the domains become aligned to produce a strong magnetic field within the part. Iron, Nickel, and cobalt are examples of ferromagnetic materials. Components with these materials are commonly inspected using the magnetic particle method.

The magnetic systems

: Open- field systems

The first magnetic retention system was a magnet-magnet system which consisted of a miniature $SmCo_5$ magnet cemented into a root-filled, decoronated abutment root and a similar but opposite polarity magnet processed into denture base.

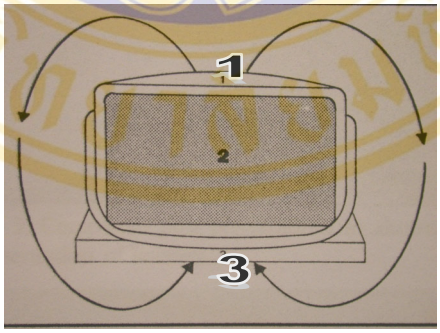

Figure 2-8: Open-field magnet 1) inert encapsulating material; (2) magnet; (3) detachable keeper (18)

In the open-field system the magnetic field runs outside the magnet from North to South Pole, and a long magnetic path is created. When the magnet moves away from the keeper, the magnetic field extends and brings the prosthesis back to its position. The retention force of this system is dependent on the magnet size and alloy used. The

Copyright by Mahidol University

disadvantage of this system is that it uses only one pole of the magnet so, when the denture is in place, there is an unavoidable external magnetic field surrounding the magnetic pair and this field can radiate into tooth roots and surrounding tissue (17,18,19). Even when the denture is removed, an unavoidable external magnetic field remains around the root (20,21,22), and it can cause problems by attracting metal eating utensils such as stainless steel forks and spoons.

Although no local damaging or systemic effects arising from the dental use of magnets have been reported (23,24), high magnetic flux fields have been questioned as to their long-term effects on the surrounding tissue.

: Closed –field systems

In closed- field systems: placing the magnetic components in a series eliminates the external magnetic flux fields. A magnetic flux is a current that similar in nature to an electric circuit (17,25). When any ferromagnetic material such as iron or stainless steel connects the two poles of a magnet, the external magnetic flux field is shunted through the steel plate (keeper), because this is a path of least resistance. This procedure not only eliminated much of the external magnetic flux field, but it also made the attachment more efficient by use of both the North and South Poles (11). This system thus ensures that when the denture is out of the mouth, the patient's tissue is free of any magnetic field (19).

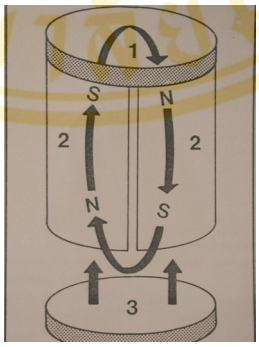

Figure 2-9: Closed-field magnet(18);
(1) magnetizable keeper; (2)paired,reverse-pole magnets;(3) detachable keeper

Copyright by Mahidol University

Dental application of magnets

: Magnetic repulsion

The use of magnets in dentistry involved using the repulsion effect of like poles to maintain and improve the denture seating force (1,2,3). As the patient closed his or her jaws together, mutual repulsion of the like poles magnets seated the denture against the alveolar ridges. However, the constant repelling force promoted bone resorption in the alveolar ridge, and the seating effect fell dramatically when the jaws were apart.

: Magnetic attraction

The use of the attractive forces between two magnets for denture retention was reported in the early 1960s. Bar magnets have also been used as implants in the bone of the lower jaw as retention aids for mandible complete dentures containing opposite polarity magnets (4,5,6). However, they were unsuitable for long-term use within the body because they had diffusion of moisture through the polymer results in inadequate corrosion protection of the magnet material.

Afterwards, the availability of rare earth magnet alloy has greatly enlarged the potential as used in removable partial denture, complete dentures, sectional denture, and dental implant (26,27,28,29).

At the present, the magnetic systems consist of two component systems as magnetic assembly and keeper. The magnetic assembly is made of rare earth magnets such as Cobalt- Samarium and Neodymium-Iron-Boron sealed with stainless steel yoke and ring (30) or stainless steel ion-plated with titanium nitride (31). The magnetic assembly can be fitted into a denture base. The keeper is made of magnetizable alloy such as stainless steel or high- palladium alloy in the form of cast dowel cores for endodontically treated teeth or restorative castings. When the denture is seated, the keeper becomes an induced magnet because of its contact with the magnet in the denture. When the denture is removed, the keeper reverts to its unmagnetized state, and the magnetic field around the keeper disappears.

Copyright by Mahidol University

Corrosion of magnet

The main problem associated with the use of magnets as retentive devices is corrosion by oral fluid (32,33,34). Corrosion is particularly marked in the presence of bacterial plaque. Neodymium-Iron-Boron magnets suffered a 3.2% decrease in mass over 21 days period in the presence of a plaque biofilm(35).

The original magnetic retention system has some disadvantages (23). One is corrosion of the magnet alloy when exposed to the oral environment (33,34,36,37). When the magnet assembly is corroded, the retention force will be lost, therefore, the magnetic assembly needs to be plated or coated in-order to sufficiently increase its corrosion resistance when its surface is exposed in the mouth (34).

The corrosion behavior between Pd-Co ferromagnetic alloy and three different types of caps (stainless steel, titanium, and palladium) has been studied under static and dynamic condition (32). The result showed that mechanical abrasion signs are only in superficial surface of alloys and the severity is in accordance with the hardness of alloys used.

Hai K. et al evaluated the corrosion resistance of a magnetic stainless steel (447J1) after immersion in lactic acid and 0.1mol/L phosphate buffered saline (PBS). They found that the amount of ions released into the lactic acid solution was generally greater than into PBS. The 447J1 alloy released 2460 and 260 ng/cm^2 of ferric ions into lactic acid solution and PBS, respectively. However, the attractive forces were not tested which they were changed after released ions. (31)

Consequently, corrosion may negatively influence the properties of a material, and its products may also cause biocompatibility problems. In general, mechanical properties are not critical in the overdenture situation, because the alloys concerned are an integrated part of the denture or remaining biological structure. However, corrosion resistance of these alloys remains a special point of interest as to the interaction with the biological consequence may be found. In addition, corrosion may cause poor quality of product which may interfere with the retention of the magnetic attachment.

Copyright by Mahidol University

CHAPTER III
MATERIALS AND METHODS

MATERIALS

1.The magnetic attachment

The magnets used in this study were closed-field Neodymium-Iron-Boron magnets (MAGFIT EX600 Aichi Steel Co., Japan). The magnet is sandwiched by two yokes made of magnetic, corrosion resistant stainless steel. The sides of the magnet assembly are covered by a non-magnetic stainless steel case. The magnet is sealed inside the magnetic assembly by a micro-laser welding technique. MAGFIT EX600 has an elliptical cross section: MAGFIT EX600 is 3.8 x 2.8 mm. in cross section and 1.8 mm. in height.

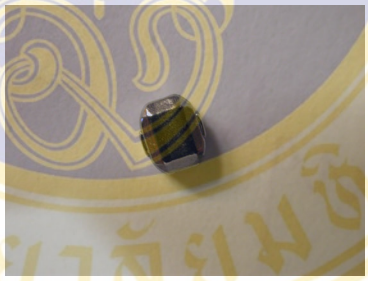

Figure 3-1: MAGFIT EX600

The MAGFIT EX keeper is made of the same magnetic stainless steel as the yokes. It has a holder to retain it in the investment during burnout procedure. The keepers have the same diameter corresponding to their pairs with heights of 1.0 mm. for EX600, respectively.

Figure 3-2: Keeper

Copyright by Mahidol University

2. 1% lactic acid, 1% acetic acid, artificial saliva
3. Distilled water
4. Cyanoacrylate glue (Zapit®)
5. Glass 9 pieces

TOOLS

1. Universal testing machine (Floor model 5566)
2. Ultrasonic cleaner (Elma, Germany)
3. Temperature controlling container (Shel Lab Model 1545 Sheldon Manufacturing, Inc., Gregon, USA.) at 37+/- 1 ˚C
4. Scanning electron microscope (SEM)
5. Energy Dispersive X-ray Spectrometer (EDS)

SAMPLE POPULATION

MAGFIT EX 600

One sample of closed field Neodymium-Iron-Boron magnet and nine samples of keeper were used.

METHODS

1. All keepers were cleaned with distilled water by ultrasonic cleaning equipment.

2. Surface structures of all keepers were inspected by Scanning Electron Microscope (SEM) and quantitative amount of element were analyzed by Energy Dispersive X-ray Spectrometer Analysis (EDS).

3. Attractive forces of all keepers were measured by Universal testing machine at crosshead speed of 0.1 mm. /min.

4. Nine keepers were divided into 3 groups

Group 1: Each keeper was immersed in 20 ml of 1% lactic acid

Group 2: Each keeper was immersed in 20 ml of 1% acetic acid

Group 3: Each keeper was immersed in 20 ml of artificial saliva

5. All keepers were kept in temperature controlling container at 37+/- 1˚C for 28 days and every 7 days solution was changed.

6. After 28 days, the keepers were rinsed in distilled water and dried by air.

Copyright by Mahidol University

7. The process of inspection by Scanning Electron Microscope (SEM) and analysis of elements on the surface structure of all keepers by Energy Dispersive X-ray Spectrometer Analysis (EDS) were repeated.

8. Attractive forces of all keepers were re-measured by Universal testing machine at crosshead speed of 0.1 mm. /min.

Sample preparation:

1. The magnet assembly was placed on a horizontal plate form ensuring that the surface is parallel to the horizontal plane, and then the upper vertical rod was moved downwards until it touched the back of the magnet, and then fixed with cyanoacrylate glue.

Figure 3-3: Magnetic assembly was attached with upper jig of Instron.

2. The lower vertical rod was fixed to the lower part of the Universal testing machine by the use of air compression. The center of this vertical rod is opposite to the center of the upper vertical rod.

Copyright by Mahidol University

3. The keeper part was fitted to the magnet assembly utilizing their attractive forces.

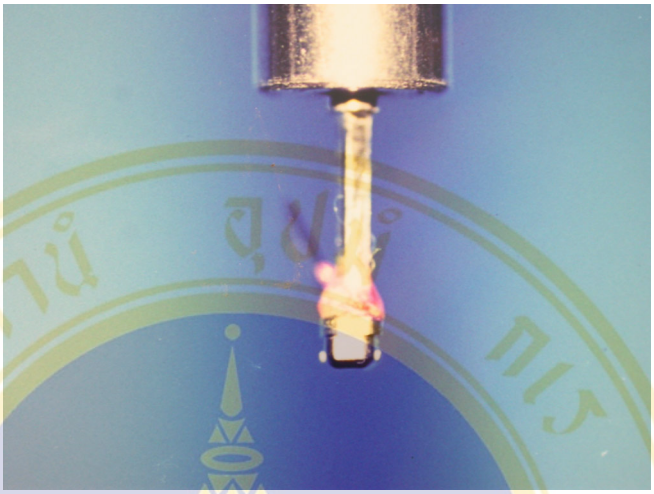

Figure 3-4: Magnetic assembly was attached with keeper.

4. The upper vertical rod was moved downwards until the back of the keeper touched the lower vertical rod. It was fixed with cyanoacrylate glue.

5. After the glue was completely set, the measurement of attractive forces was made at a crosshead speed of 0.1 mm. /min with an Universal testing machine (Floor model 5566).

Copyright by Mahidol University

CHAPTER IV
RESULTS

Part I: Attractive forces between magnetic assembly and keeper of MAGFIT EX600

Table 4-1: Attractive forces between magnetic assembly and keeper of MAGFIT EX 600

Solution	Attractive forces between magnetic assembly and keeper of MAGFIT EX 600(N)	
	Before	After
Lactic acid	38.66 39.92 39.71	37.82 38.24 39.21
Mean ±SD	39.43±0.68	38.42±0.71
Artificial saliva	37.69 38.87 38.85	38.34 39.77 37.15
Mean ±SD	38.47±0.67	38.42±1.32
Acetic acid	39.14 38.51 37.77	39.62 38.36 37.39
Mean ±SD	38.48±0.69	38.46±1.12

Copyright by Mahidol University

One-way analysis of variance

One-way analysis of variance can be applied to compare means of attractive forces among 3 groups. There were no significant difference between means of attractive forces among keeper groups ($p>0.05$)

Test of Homogeneity of Variances

Table 4-2: Test of homogeneity of variances of attractive forces

DIFF

Levene statistics	df1	df2	Sig.
4.457	2	6	.065

ANOVA

Table 4-3: One-way analysis of variance compares means of attractive forces among 3 groups

DIFF

	Sum of squares	df	Mean square	F	Sig.
Between Groups	1.878	2	.939	1.068	.401
Within Groups	5.273	6	.879		
Total	7.150	8			

Copyright by Mahidol University

Paired t-test

Lactic acid

Paired t-test can be applied to compare means of attractive forces between before and after immersion in lactic acid. There were no significant difference between before and after immersion ($p>0.05$).

Table 4-4: Paired t-test compares means of attractive forces between before and after immersion in lactic acid.

	t	df	Sig. (2-tailed)
Pair1 Before-After	2.841	2	.105

Artificial saliva

Paired t-test can be applied to compare means of attractive forces between before and after immersion in artificial saliva. There were no significant difference between before and after immersion ($p>0.05$).

Table 4-5: Paired t-test compares means of attractive forces between before and after immersion in artificial saliva.

	t	df	Sig. (2-tailed)
Pair1 Before-After	.062	2	.956

Copyright by Mahidol University

Acetic acid

Paired t-test can be applied to compare means of attractive forces between before and after immersion in acetic acid. There were no significant difference between before and after immersion ($p>0.05$)

Table 4-6: Paired t-test compares means of attractive forces between before and after immersion in acetic acid.

	t	df	Sig. (2-tailed)
Pair1 Before-After	.072	2	.949

Copyright by Mahidol University

Part II: Scanning electron microscope (SEM)

The images showed keeper surfaces before and after immersion in each solution. The magnifications used in this experiment were 500X and 1000X. The following images showed that the keeper surfaces after immersion in solutions is smoother than before immersion. Crevice or pitting corrosion did not appear in 500X and 1000X magnifications. Using three solutions was not different in keeper surfaces after immersion.

Figure 4-1: Keeper-surface before immersion in lactic acid (500X)

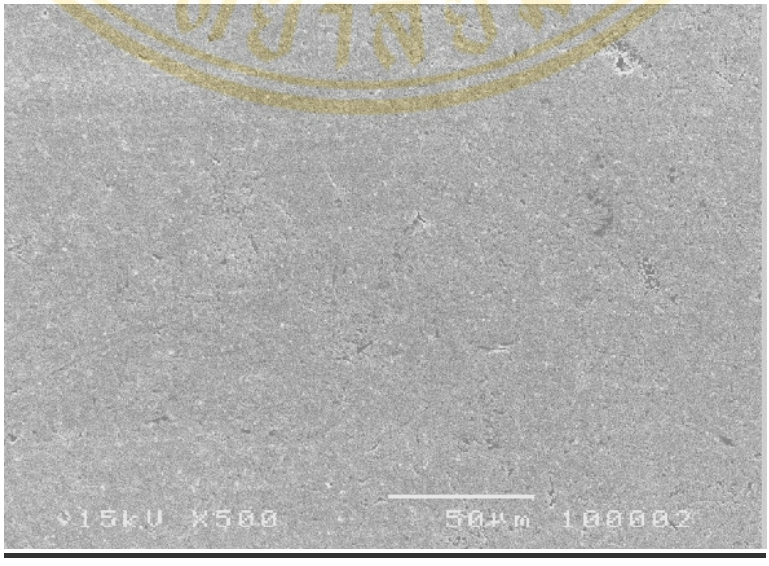

Figure 4-2: Keeper-surface after immersion in lactic acid (500X)

Copyright by Mahidol University

Figure4-3: Keeper-surface before immersion in artificial saliva (500X)

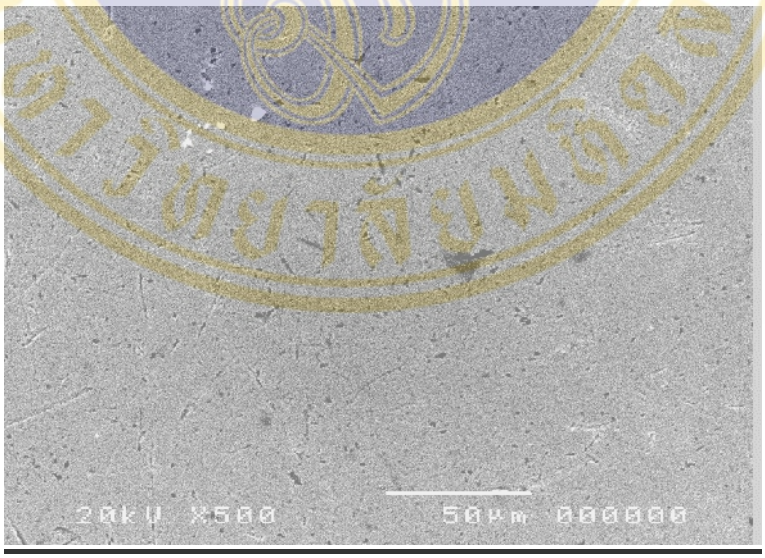

Figure 4-4: Keeper-surface after immersion in artificial saliva (500X)

Copyright by Mahidol University

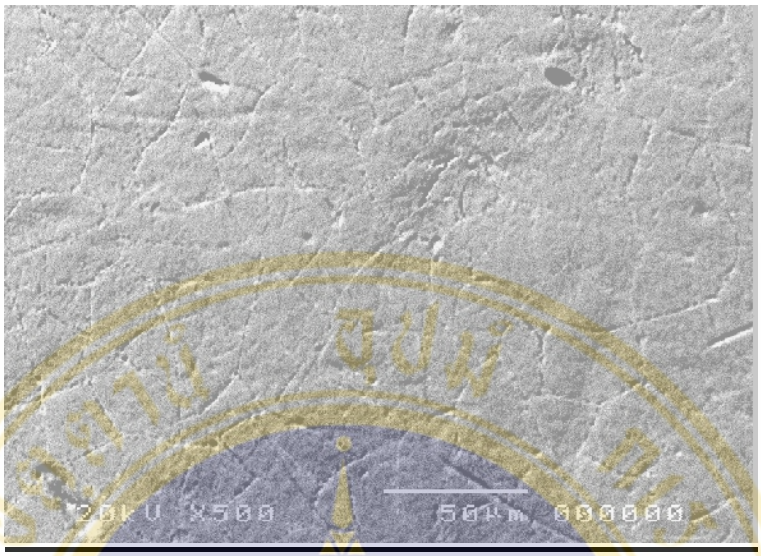

Figure 4-5: Keeper-surface before immersion in acetic acid (500X)

Figure 4-6: Keeper-surface after immersion in acetic acid (500X)

Copyright by Mahidol University

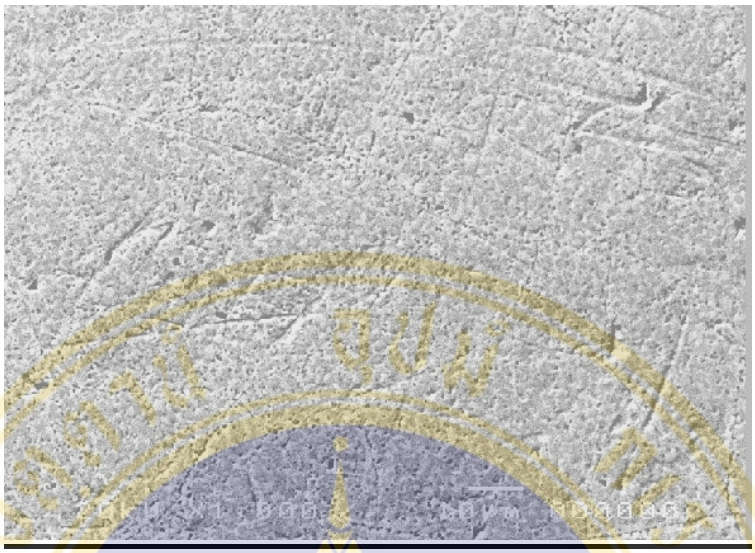

Figure 4-7: Keeper-surface before immersion in lactic acid (1000X)

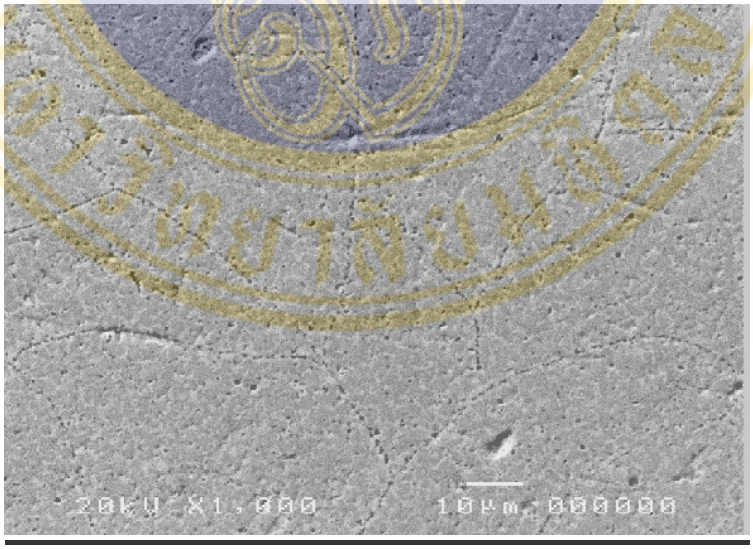

Figure 4-8: Keeper-surface after immersion in lactic acid (1000X)

Copyright by Mahidol University

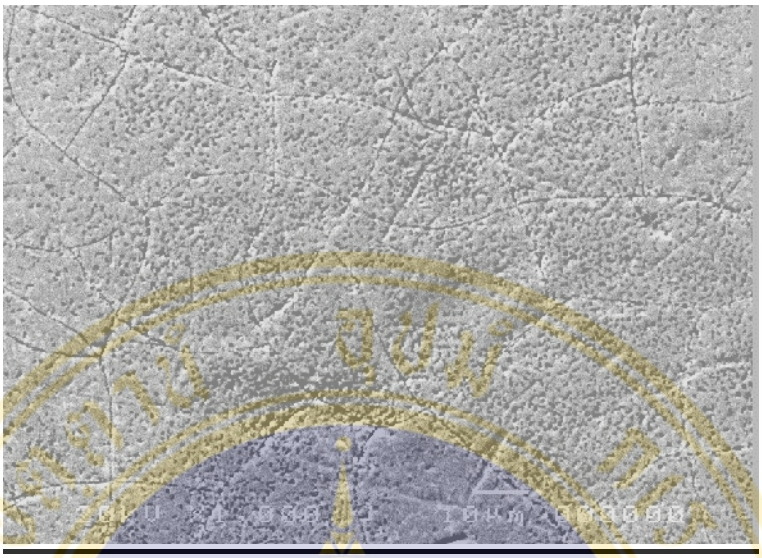

Figure 4-9: Keeper-surface before immersion in artificial saliva (1000X)

Figure 4-10: Keeper-surface after immersion in artificial saliva (1000X)

Copyright by Mahidol University

Figure 4-11: Keeper-surface before immersion in acetic acid (1000X)

Figure 4-12: Keeper-surface after immersion in acetic acid (1000X)

Copyright by Mahidol University

Part III: Energy Dispersive X-ray Spectrometer Analysis (EDS)

The amount of chromium, iron, and aluminum was shown by Energy Dispersive X-ray Spectrometer Analysis (EDS). The table showed percentages of element on keeper surfaces before and after immersion in three solutions separately. On keeper surfaces, Cr was more than 90% with 2-3% Fe, and 1-2% Al respectively before immersion. After immersion, the amount of Cr was still more than 90% same as before immersion in each solution, as well as Fe and Al where no significant difference between before and after immersion shown (Paired t test).

Table4-7: Table shows the amount of element on keeper surface by Energy Dispersive X-ray Spectrometer Analysis (EDS).

Before immersion in solutions			After immersion in solutions		
Spectrum label: keeper (artificial saliva)			Spectrum label: keeper (artificial saliva)		
	Element %	SD %		Element %	SD %
Al K	2.37	0.233	Al K	1.93	0.724
Cr K	94.29	1. 215	Cr K	95.21	1.009
Fe K	3.37	1.419	Fe K	2.86	0.995
Spectrum label: keeper (lactic acid)			Spectrum label: keeper (lactic acid)		
	Element %	SD %		Element %	SD %
Al K	1.99	1.107	Al K	1.62	0.314
Cr K	94.91	0.828	Cr K	94.55	1.596
Fe K	3.09	1.289	Fe K	3.84	1.467
Spectrum label: keeper (acetic acid)			Spectrum label: keeper (acetic acid)		
	Element %	SD %		Element %	SD %
Al K	1.56	0.368	Al K	1.29	0.337
Cr K	96.26	0.703	Cr K	95.92	1.031
Fe K	2.59	0.215	Fe K	2.80	0.742

Copyright by Mahidol University

CHAPTER V
DISCUSSION

Since the permanent magnet was discovered in 1940s, many researchers have been undertaken in the field of retention force of magnetic system including property of corrosive resistance. They found that the attractive force was damaged when the magnet corroded (34). Actually, keepers are used in magnetic system and they are fixed with the root cap in the tooth. All the time of use, keepers are exposed to oral fluid so this study tested the keeper after immersion in artificial saliva representing oral situation. However, oral fluid after meal has acid from bacterial fermentation, and the acid that found in saliva is lactic acid and acetic acid so in this experiment they were used as testing solution. All keepers were kept in temperature controlling container at 37+/- 1˚C as the body temperature because temperature has effect to mechanism of corrosion of material. If temperature is increase, the mechanism is more rapid.

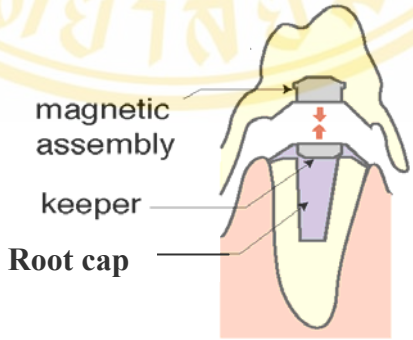

Figure 5-1: Component of magnetic attachment (38)

Copyright by Mahidol University

In this experiment, we observed keeper surface by Scanning Electron Microscope (SEM) before and after immersion in three solutions separately. The study showed that the surfaces of keeper after immersion in solution were smoother than those before immersion and they did not have crevice or pitting corrosion characteristic after immersion in artificial saliva as well as in lactic acid and acetic acid. The results showed characteristic of stainless steel for corrosion resistance. The mechanism of stainless steel to resist corrosive media is known as “Passivity”. The phenomenon is found in many type of stainless steel including 447J1. All metals react with oxygen in the air to form a film of oxide on the surface. The oxide formed on ordinary steel allows the oxidation to continue producing the typical rusty appearance. As stainless steels contain more than 10.5% Chromium, the characteristics of the oxide are changed. The Chromium reacts with oxygen to form Chromium-rich oxide protective film or passive layer. It gives to the surface of the stainless steel a remarkable resistance to attack and inhibit corrosion. Inert film is tightly adherent and very protective in a wide range of corrosion media. When damaged this protective film is denuded exposing the stainless steel to atmosphere. The protective coating is quickly restored though the rapid self-repairing quality of the Chromium-rich film. Pictures 5-2,5-3,5-4 show corrosion resistance mechanism of stainless steel.

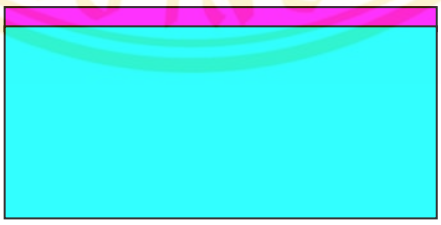

Figure5-2 In any normal oxidizing environment a protective coating of passive Chromium rich oxide films is automatically formed on stainless steel.

Copyright by Mahidol University

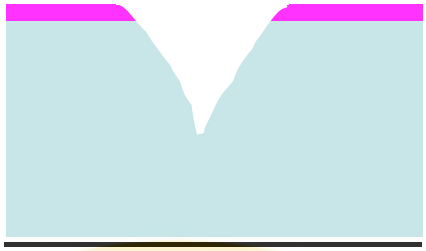

Figure5-3 When scratched damages or machined this protective film is denuded exposing the steel to the atmosphere.

Figure5-4 The protective coating is quickly restored through the rapid self-repairing quality of the Chromium rich film.

Energy Dispersive X-ray Spectrometer Analysis (EDS) confirmed this result. Amount of elements before immersion were more than 90%Chromium, 2-4% Iron, and 1-3% Aluminum even through the company showed that components of keeper are 79%Iron, 19%Chromium, and 2% etc. In addition, after immersion in solution the amount of elements of keeper surface were not different.

Copyright by Mahidol University

However, Chromium rich protective films maybe interfered to attractive force of magnetic attachment. This experiment tested retention unit of magnetic attachment before and after immersion in three solutions. Attractive forces were tested by Universal testing machine at crosshead speed 0.1 mm. / min. A slow speed of separation was used to test the maximum retention force of magnet (38). The result showed that there was no significant difference of attractive forces before and after immersions of keepers in three kinds of solutions: namely artificial saliva, lactic acid, and acetic acid separately.

Magnetic properties

The motion of the intrinsic spin of electrons and their orbital motion about their nuclei produce the magnetic field and force in material. Since a moving charge set up a magnetic field around it, the moving and spinning electrons act as tiny magnets. In many atoms, the opposite spin in one direction a magnetic field is produced. Except for ferromagnetic materials, which can form permanent magnets, all substance exhibit magnetic effects only when subjected to an external electromagnetic field. The presence of a magnetic field surrounding a magnetized Iron bar can be revealed by scattering small Iron particles on a sheet of paper held just above the Iron bar (Figure3)

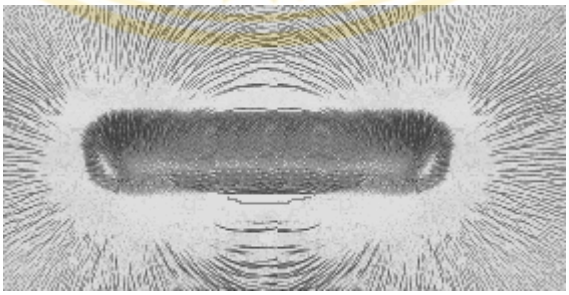

Figure 5-5: Magnetic field surrounding the Iron bar(16)

Copyright by Mahidol University

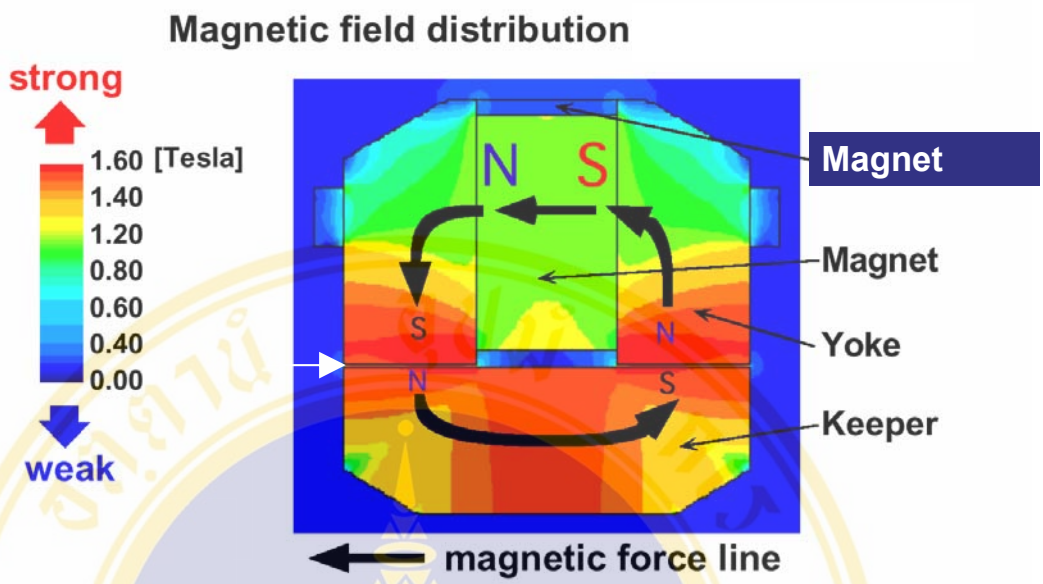

Figure5-6: Image show magnetic field of magnetic attachment around keeper and magnetic assembly. (38)

From figure4, magnetic field does not appear at surface of keeper and magnetic assembly but it is around them. Through keeper surface has Chromium rich oxide layer which is the property of stainless steel, attraction between keeper and magnetic assembly can occur. Thus, in this study testing attractive force before and after immersion confirmed that magnetic properties of stainless steel are useful for magnetic attachment.

Copyright by Mahidol University

CHAPTER VI
CONCLUSION

The results of this study can be concluded as following:

1. Type of storage media did not have an effect on attractive force of magnetic attachment.
2. Status for 28 days storage did not have an effect on attractive force of magnetic attachment.
3. From SEM images, keeper surfaces after immersion in solution are smoother than before immersion but the amount of elements on keeper surface are not different between before and after immersion.

Further study is required to confirm that attractive forces of magnetic attachment are still sufficient for using denture in clinical study.

Copyright by Mahidol University

REFERENCES

1. Freedman H. Magnets to stabilize dentures. JADA 1953; 47:288-97
2. Grimaldi RM. Use of magnetic forces in Prosthetic dentistry. Dent Digest 1954 : 205- 207
3. Freedman H. Magnetic counter-influence in full denture retention. Dent Digest 1941:498-503
4. Behrman SJ. The implantation of magnets in the jaw to aid denture retention. J Prosthet Dent 1960; 10:807-41
5. Behrman SJ. Magnets implanted in the mandible: aid to denture retention. JADA 1964; 68:206-15
6. Schmitz JF and Colonel L. Measurement of the efficiency of the platinum-cobalt magnetic implant. J Prosthet Dent 1966; 16:1151-8
7. Laird WRE and Grant AA. The use of magnetic forces in prosthetic dentistry. J Dent 1981; 9:328-35
8. D.J. Maroso, P. Tischler, and J.R. Schmidt. A simplified technique for magnetic retention of overdentures.J Prosthet Dent1984:51:5:599-601
9. H.Sasaki, Y. Kinouchi, H. Tsutsui, Y. Yoshida, and T. Ushita. A magnetic attachment for overdenture. J Prosthet Dent 1984:51:4:450-455
10. Smith GA, Laird WRE, and Grant AA. Magnetic retention units for overdenture. J Oral Rehabil 1983; 10:481-8
11. Funda Akaltan, and Gulsen Can. Retentive characteristics of different dental magnetic systems. J Prosthet Dent 1995:74:4:422-427
12. Jackson TR. New Rare earth magnetic technology: The Jackson solid state attachment system. Trends Tech Contemp Dent Lab 1986; 3:31-9
13. Kinouchi Y, Ushita T, Tsutsui H, Yoshida Y, Sasaki H and Miyazaki T. Pd-Co Dental casting ferromagnetic alloys. J Dent Res 1981; 60:50-8
14. Kawata Y, Shiota M, Tsutsui H, Yoshida Y, Sasaki H and Kinouchi Y. Cytotoxicity of Pd-Co dental casting ferromagnetic alloys. J Dent Res 1981; 60:1403-9

Copyright by Mahidol University

15. www.ndt-ed.org/ Education resources/ CommunityCollege/ MagParticle
16. Smith WF. Magnetic materials. In: Bever MB, Gibala R, Tirrell M, Wert CA, editors.Foundations of materials science and engineering. 2nd ed. Singapore: McGraw-Hill; 1993:809-56
17. Melissa Alessandra Riley, Anthony Damien Walmsley, and Ivor Rex Harris. Magnets in prosthetic dentistry. J Prosthet Dent 2001:86:2:137-142
18. Becker JJ. Permanent magnets. Sci Am 1970; 223:92-100
19. Ronald J. Hayes, and Ann Sue Von Gonten. Clinical application of rare-earth magnets. Gen Dent 1990; 357-360
20. Haley TJ. Pharmacology and toxicology of the rare earth elements. J Pharm Sci 1965; 54:663-70
21. Becker RO. The biological effects of magnetic fields- a survey. Med Electron Biol Eng 1963; 1:293-303
22. Cerny R. Biomagnetics and magnetodontics. J Dent Res 1980; 59:1774 (Abst.No.11)
23. Tsutsui H, Kinouchi Y, Sasaki H, Shiota M and Ushita T. Studies on the Sm-Co magnet as a dental material. J Dent Res 1979; 58:1597-606
24. Cerny R. The reaction of dental tissue to magnetic fields. Aust Dent J 1980; 25:264-8
25. Jackson TR. The application of rare earth magnetic retention to osseointegrated implants. Int J Oral Maxillofac Implants 1986; 1:81-92
26. Jackson TR and Healey KW. Rare earth magnetic attachments: The state of the art in removable prosthodontics. Quintessence Int 1987; 18:41-51
27. Gendusa NJ. Magnetically retained overlay dentures. Quintessence Int 1988; 19:265-71
28. Krooner H. B., and Bates J.F. Overdenture with magnetic retainers. Br Dent J 1982; 152:310-313
29. Gilling BRD and Samant A. Overdentures with magnetic attachments. Dent Clin North Am 1990; 34:683-708
30. Okuno O, Ishikawa S, Iimuro FT et al. Development of sealed cup yoke type dental magnetic attachment. Dent Mat J 1991; 10:172-84

Copyright by Mahidol University

31. Hai K, Sawase T. Matsumura H., Atsuta M., Baba K., and Hatada R. Corrosion resistance of a magnetic stainless steel ion-plated with titanium nitride. J Oral Rehabil 2000; 27:361-3

32. Angelini E, Pezzoli M and Zucchi F. Corrosion under static and dynamic conditions of alloys used for magnetic retention in dentistry. J Prosthet Dent 1991; 65:848-53

33. Drago CJ. Tarnish and corrosion with the use of intraoral magnets. J Prosthet Dent 1991; 66:536-40

34. Kitsugi A, Okuno O, Nakano T, Hamanaka H and Kuroda T. The corrosion behavior of $Nd_2Fe_{14}B$ and $SmCo_5$ magnets. Dent Mater 1992; 11:119-129

35. Wilson M., Patel H.,Kpendema H., Noar J.H. ,Hunt N.P., Mordan N.J. Corrosion of intra- oral magnets by multi-species biofilms in the presence and absence of sucrose. Biomaterial 1997; 18:53-57

36. Vardimon AD and Mueller HJ. In-vivo and In-vitro corrosion of permanent magnets in orthodontic therapy. J Dent Res 1985; 64: (abst.No.89)

37. Gilling BRD. Corrosion protection for magnetic denture retention units. J Dent Res 1993; 72: (abst. No.104)

38. Dias AP and Honkura Y. Retentive prostheses with magnets. Proceeding of the symposium on magnetic attachment system in Hong Kong 1998

39. Ion Coca, Ulrich Lotzmann , and Kriszti Prisender. A clinical follow-up study of magnetically retained overdenture (Dyna system).Eur. J. Prosthodont. Rest. Dent.,Vol. 10,No. 2:73-78.

40. Gillings BRD. Magnetic denture retention systems : in expensive and efficient. Int Dent J 1984; 34:184-97

41. Joseph H. Noar, Asiah Wahab, Robert D. Evans , and Adam G. Wojcik. Thedurability of parylene coating on Neodymium-Iron-Boron magnets. European Jounal of orthodontics 1999; 2,685-693.

42. Vrijhoef MMA, Mezger PR, VanDerzel JM and Greener EH. Corrosion of ferromagnetic alloys used for magnetic retention of overdentures. J Dent Res 1987; 66:1456-9

43. Sarnat AE. The efficiency of Cobalt sarmarium ($C0_5Sm$) magnets as retention untis for overdentures. J Dent 1983; 11:324-33

Copyright by Mahidol University

44. Ignace Naert, Stella Gizani.Magda Vuylsteke, Daniel van Steenberghe.A 5-years randomized clinical trial on the influence of splinted and unsplinted oral implants in the mandibular overdenture therapy:Part I peri-implant outcome. Clin Oral Impl Res 1998:9:170-177

45. Cerny R. Magnetodontics.The use of magnetic forces in dentistry. Aust Dent J 1978; 23:392-4

46. John F. Schmitz, Lieutenant Colonel.Measurement of the efficiency of the platinum-cobalt magnetic implant. J prosthet Dent 1966:1151-1158

47. Federick DR. A magnetically retained interim maxillary obturator. J Prosthet Dent 1976;36:671-5

48. Gillings BRD. Magnetic retention for complete and partial overdentures. Part I. J Prosthet Dent 1981;45:484-91

49. Gillings BRD. Magnetic retention for overdentures. Part II. J Prosthet Dent 1983;49:607-18

50. Ron Highton, A. A Caputo,Mario Pezzoli, and Joseph Matyas.Retentive characteristics of different magnetic systems for dental applications. J Prosthet Dent1986:56:1:104-106

51. Pezzoli M, Highton R, Caputo A and Matyas J. Retention magnets in guiding plate of distal-extension removable partial dentures. J Prosthet Dent 1988; 60:577-82

52. Joseph A. Lewandowski, K.C. White, Dorsey Moore, and Charles Johnson. An investigation of two rare earth magnetic systems by measuring grip force and reseating force. J Prosthet Dent 1988:60:6:705-711

53. Kim A. Laurell, Anthony G. Gegauff, and Stephen F. Rosenstiel. Magnetic resonance image degradation from prosthetic magnet keepers. J Prosthet Dent 1989:62:3:344-348

54. Obatake RM, Collard SM, Martin J and Ladd GD. The effects of sodium fluoride and stannous fluoride on the surface roughness of intraoral magnet systems. J Prosthet Dent 1991; 66:553-8

55. Haim Hiller, Nerri Weissberg, Gershon Horowitz, and Micheal Ilan. The safety of dental mini-magnets in patients with permanent cardiac pacemakers. J Prosthet Dent1995:74:4:420-421

Copyright by Mahidol University

56. Hideo Matsumura, Koji Kawasaki. Magnitically connected removable sectional denture for a maxillary defect with severe undercut: A clinical report. J Prosthet Dent 2000:84:1:22-26

57. Melissa Alessandra Riley, Andrew John Williams, John Donald Speight, Anthony Damien Walmsley, and Ivor Rex Harris.Investigations into the failure of dental magnets. Int J Prosthodont 1999:12:3:249-254

58. Ilary P.Y. Thean, Stephen K.L. Khor, and Poey-Ling Loh.Viability of Magnetic denture retainers:A 3- years case report. Quintessence Int 2001:32:517-520

59. Craig S. Miller, Fabio M. Leonelli, and Emma Latham. Selective interference with pacemaker activity by electrical dental devices. Oral Surg Oral Med Oral Pathol Oral Radiol Endod 1998; 85:33-36

60. Mensor MC. Removable partial overdentures with mechanical (precision) attachments. Dent Clin North Am 1990; 34:669-81

61. Sasaki H, Kinouchi Y, Tsutsui H and Yoshida Y. Case studies of sectional dentures using Sm-Co magnets. J Dent Res 1979; 58:314 (abst.No. 890)

62. Bormes T. Magnets-Myth and Magic. Trend & Tech 1988:42-7

63. Gillings BRD. Magnetic retention for the overdenture. In : Brewer AA and MorrowRM, editors.Overdentures.2nd ed. Toronto: The C.V. Mosby; 1980.376-97

64. Iimuro FT, Yoneyama T and Okuno O. Corrosion of coupled metal magnetic attachment system. Dent Mater 1993; 12:136-44

65. MAGFIT EX system: Technician training instruction. Japan: Aichi Steel Works.

66. Merrill C. Mensor, and San Mateo. Compliant keeper system for magnet- and screw –retained implant prosthodontics. Int J Prosthodont 1988; 1:201-207

67. Stewart B.L., and Edwards R.O. Retention and wear of precision- type attachments. J Prosthet Dent 1983; 49:28-34

68. Gillings BRD. Co-Sm closed-field magnets as retention aids in sectional dentures and removable sectional bridges. J Dent Res 1980; 59:942 (abst.No.222a)

69. Kawata T, Matsuga M, Ritano N and Kishigami H. Further study of new orthodontic treatment with a magnetic appliance. J Dent Res 1978; 57:175 (abst.No.402)

Copyright by Mahidol University

BIOGRAPHY

NAME	Miss. Trinuch Eiampongpaiboon
DATE OF BIRTH	3 August 1979
PLACE OF BIRTH	Suphanburi, Thailand
INSTITUTIONS ATTENDED	Mahidol University, 1995-2001: Doctor of Dental Surgery Mahidol University, 2002-2005: Master of Science (Prosthodontics)
RESEARCH GRANT	Supported in part by the Thesis Grant, Faculty of Graduate Studies, Mahidol University
POSITION & OFFICE	2001 Sankaburi Hospital, Chainat, Thailand. Position: Dentist 2004-Present, Dept of Prosthodontics, Faculty of Dentistry, Mahidol University Bangkok, Thailand. Position : Lecturer
HOME ADDRESS	79/351 Patumwan Resort, Payathai Rd. Rachatewee, Bangkok, Thailand.10400

Copyright by Mahidol University