การเปรียบเทียบความต้านทานเสียดทานของลวดเหล็กกล้าไร้สนิมเคลือบเทฟลอนกับลวดเหล็กกล้าไร้สนิมที่มัดด้วยตัวมัดชนิดต่างๆ ในแบร็กเกตเซรามิก

Comparison of Frictional Resistance of Teflon-coated Stainless Steel and Stainless Steel Wires Ligated with Various Types of Ligature in Ceramic Brackets

จิรวรรณ ชาติพิทักษ์[1], สโรชินี โกศัลวิตร์[2], ณัฐวิทย์ พรหมมา[3], จรรยา อภิสริยะกุล[4], วิกันดา เขมาลีลากุล[4]
[1]นักศึกษาหลักสูตรการฝึกอบรมทันตแพทย์ประจำบ้านเพื่อวุฒิบัตร สาขาทันตกรรมจัดฟัน คณะทันตแพทยศาสตร์ มหาวิทยาลัยเชียงใหม่
[2]คลินิกเอกชน จ.อุบลราชธานี
[3]ภาควิชาวิศวกรรมเครื่องกล คณะวิศวกรรมศาสตร์ มหาวิทยาลัยเชียงใหม่
[4]ภาควิชาทันตกรรมจัดฟันและทันตกรรมสำหรับเด็ก คณะทันตแพทยศาสตร์ มหาวิทยาลัยเชียงใหม่
Jirawan Chartpitak[1], Sarochinee Gosalwit[2], Nattawit Promma[3], Janya Apisariyakul[4], Wikanda Khemaleelakul[4]
[1]Residency program (Orthodontics), Faculty of Dentistry, Chiang Mai University
[2]Private Practice, Ubon Ratchathani
[3]Department of Mechanical Engineering, Faculty of Engineering, Chiang Mai University
[4]Department of Orthodontics and Pediatric Dentistry, Faculty of Dentistry, Chiang Mai University

ชม. ทันตสาร 2562; 40(3) : 67-79
CM Dent J 2019; 40(3) : 67-79

Received: 9 January, 2019
Revised: 12 February, 2019
Accepted: 28 February, 2019

บทคัดย่อ

การศึกษานี้มีวัตถุประสงค์เพื่อเปรียบเทียบความต้านทานเสียดทานของลวดเหล็กกล้าไร้สนิมกับลวดเหล็กกล้าไร้สนิมเคลือบเทฟลอนที่มัดด้วยตัวมัดชนิดต่าง ๆ ในแบร็กเกตเซรามิก

วัสดุที่ใช้ในการทดลองประกอบด้วยลวดเส้นหลักขนาด 0.019x0.025 นิ้ว 2 ชนิด ได้แก่ 1) ลวดเหล็กกล้าไร้สนิมและ 2) ลวดเหล็กกล้าไร้สนิมเคลือบเทฟลอน โดยใช้ตัวมัด 3 ชนิด ได้แก่ 1) ยางมัดลวด 2) ลวดมัดเหล็กกล้า

Abstract

The aim of the study was to compare frictional resistance of stainless steel (SS) and Teflon-coated SS wires ligated with various types of ligature in ceramic brackets. Six combinations of specimens, comprising two types of 0.019x0.025-inch main archwire, SS and Teflon-coated SS wires, and three types of ligation, elastomeric, SS and Teflon-coated SS ligatures were used in 0.022x0.028-inch

---

Corresponding Author:

วิกันดา เขมาลีลากุล
ผู้ช่วยศาสตราจารย์, ภาควิชาทันตกรรมจัดฟันและทันตกรรมสำหรับเด็ก
คณะทันตแพทยศาสตร์ มหาวิทยาลัยเชียงใหม่ 50200

Wikanda Khemaleelakul
Assistant Professor, Department of Orthodontics
and Pediatric Dentistry, Faculty of Dentistry,
Chiang Mai University, Chiang Mai 50200, Thailand
E-mail: ***wikandaw@hotmail.com***

ไร้สนิม และ 3) ลวดมัดเหล็กกล้าไร้สนิมเคลือบเทฟลอน รวมเป็นจำนวน 6 กลุ่ม กลุ่มละ 10 ตัวอย่าง ทดสอบในแบร็กเกตเซรามิกขนาด 0.022x0.028 นิ้ว วัดค่าความต้านทานเสียดทานของแต่ละกลุ่มโดยใช้เครื่องทดสอบสากล และทำการเปรียบเทียบค่าเฉลี่ยของความต้านทานเสียดทานสถิตสูงสุดโดยใช้สถิติการวิเคราะห์ความแปรปรวนสองทาง ตามด้วยการทดสอบสถิติชนิดดันเนต ที่ระดับนัยสำคัญทางสถิติ 0.05

ผลการวิจัยพบว่า ไม่ว่าจะใช้ตัวมัดชนิดใดความต้านทานเสียดทานของลวดเหล็กกล้าไร้สนิมเคลือบเทฟลอน (58.6±35.1 กรัม) ไม่แตกต่างอย่างมีนัยสำคัญทางสถิติกับความต้านทานเสียดทานของลวดเหล็กกล้าไร้สนิม (68.8±48.4 กรัม) นอกจากนี้ไม่ว่าจะใช้ลวดหลักชนิดใด ความต้านทานเสียดทานของยางมัดลวด (108.5±40.7 กรัม) สูงกว่าความต้านทานเสียดทานของลวดมัดเหล็กกล้าไร้สนิม (32.7±17.1 กรัม) และลวดมัดเหล็กกล้าไร้สนิมเคลือบเทฟลอน (50.0±16.0 กรัม) อย่างมีนัยสำคัญทางสถิติที่ระดับ 0.001 ขณะที่ความต้านทานเสียดทานของลวดมัดเหล็กกล้าไร้สนิมเคลือบเทฟลอน สูงกว่าความต้านทานเสียดทานของลวดมัดเหล็กกล้าไร้สนิมอย่างมีนัยสำคัญทางสถิติที่ระดับ 0.01

สรุปได้ว่า ความต้านทานเสียดทานของลวดเหล็กกล้าไร้สนิมเคลือบเทฟลอน และลวดเหล็กกล้าไร้สนิมไม่มีความแตกต่างกันอย่างมีนัยสำคัญ เมื่อมัดด้วยตัวมัดชนิดต่าง ๆ ในแบร็กเกตเซรามิก

คำสำคัญ: แรงเสียดทานทางทันตกรรมจัดฟัน ตัวมัด แบร็กเกตเซรามิก ลวดเหล็กกล้าไร้สนิมเคลือบเทฟลอน

ceramic brackets, 10 samples for each group. The frictional resistance of each combination was measured using a universal testing machine. The means of maximum static frictional resistance were compared according to types of wire and ligature using Two-way ANOVA followed by Dunnett's T3 post-hoc test ($p < 0.05$).

The results showed that the frictional resistance of Teflon-coated SS wires (58.6±35.1 g) was not significantly different from that of SS wires (68.8±48.4 g) regardless of the ligature type. The frictional resistance of elastomeric ligatures (108.5±40.7 g) was statistically significantly greater than that of SS ligatures (32.7±17.1 g) and Teflon-coated SS ligatures (50.0±16.0 g) ($p < 0.001$), whereas the frictional resistance of Teflon-coated SS ligatures was statistically significantly greater than that of SS ligatures regardless of the wire type ($p < 0.01$).

In conclusion, the frictional resistance of Teflon-coated SS and SS wires were not significantly different when used in the ceramic brackets regardless of the ligature type.

Keywords: orthodontic friction, ligature, ceramic bracket, Teflon-coated stainless steel wire

Introduction

The demand of esthetic orthodontic appliances is growing due to the increase in adult patients who are concerned about their appearance during the orthodontic treatment period.(1) Traditionally, metal alloys have been used for manufacturing both brackets and archwires, due to their suitable properties, such as tarnish- and corrosion- resistance, high formability, adequate stiffness, and low frictional resistance.(2) However, the metal brackets and archwires were compromised esthetics.(1,3)

Ceramic brackets, first introduced in 1986,(4,5) offer better esthetics than either stainless steel or polycarbonate brackets; they also exhibit good resistance to wear and deformation, as well as color stability. Esthetic brackets made of ceramic partially solve the esthetics problem. However, archwires and ligatures are still made of stainless steel, which has a metallic color. Attempts have been made to develop orthodontic appliances that provide enhanced esthetics and clinical performance in response to the demands of patients and clinicians.

Manufacturers continually produce archwire and ligature systems that provide esthetics and offer good performance, to supplement the esthetic bracket systems.(6) Currently, esthetic archwires can be separated into two categories: fiber-reinforced and coated metallic archwires.(7) Fiber-reinforced wires are in the experimental stage and not universally available commercially; there are good expectations from them for the future. Esthetically-coated archwires are available for clinical use. The coating materials can be made of Teflon, epoxy-resin, plastic, rhodium, or palladium.(8) Currently, the two most common aesthetic archwires on the US market are coated with either epoxy-resin or Teflon.(9) Epoxy is a synthetic resin made by combining epoxide with another compound. Teflon, type of plastic, is the trademark name DuPont uses for the compound polytetrafluoroethylene (PTFE). Teflon is coated on stainless steel wire by an atomic process that forms a layer of about 20-25 μm thickness on the wire that imparts to the wire a hue which is similar to that of natural teeth.(10) Similar to archwires, ligatures have been improved for esthetic concerns using a coating technique. Coating materials, such as Teflon, are used to improving the appearance of the ligatures.

The effects of epoxy-resin coating on frictional resistance are still controversial. Some studies(11,12) found that epoxy-resin coating increased frictional resistance. For example, Dickson, *et al.*(11) who compared the frictional characteristics of five initial alignment wires on stainless steel brackets, found that epoxy-coated stainless steel wire exhibited greater frictional resistance than all other archwires and it was observed that the coating was stripped from the wire; this stripping was associated with considerable binding within the system. On the other hand, some studies(13,14) found that epoxy-resin coating reduced frictional resistance. For example, Clocheret, *et al.*(13) evaluated the dynamic frictional behavior of different archwires on stainless steel brackets. The results revealed that an epoxy-coated archwire produced the lowest friction among 15 commercially-available archwires. These results might be associated with the plastic-metal contact interfaces of some of the archwires, where the plastic might provide some degree of lubrication, rather than the metal-metal interfaces of other archwires.

For Teflon-coated wire, many studies(15-18) showed that Teflon-coated wire reduced frictional resistance. For example, Husmann, *et al.*(15) evaluated the frictional behaviour of archwires coated with Teflon or polyethylene, compared with uncoated archwire. They found that the coating could reduce the frictional resistance compared to uncoated reference archwire of the same manufacturer.

Various types of bracket have been used to investigate the frictional resistance of esthetic archwire. Many studies(15-18) found that Teflon coating reduced frictional resistance, regardless types of bracket. For example, Sukh, *et al.*(16) studied the frictional resistance between three modern orthodontic brackets, including stainless steel, ceramic, and ceramic with metal slot brackets, against seven different archwires. They found that the stainless steel brackets with Teflon-coated stainless steel archwires ligated with stainless steel ligatures produced the lowest mean frictional resistance. Moreover, Farronato, *et al.*(18) evaluated, *in vitro*, the influence of Teflon coating on the resistance to sliding of orthodontic achwires using twelve types of archwire with round and rectangular cross-sections and of different materials along with self-ligating brackets. They found that Teflon-coated archwires produced lower friction than the corresponding uncoated archwires.

The combination of ceramic brackets, esthetic archwires and esthetic ligatures provides an ultimately esthetically pleasing fixed orthodontic appliance. However, the physical properties of the material, especially frictional resistance, should be considered in appliance selection, because 12%-60% of the applied force is dissipated due to frictional resistance.(19) In order to move the teeth, the orthodontist needs to apply a force which is greater than the static frictional resistance.(20,21) Increased frictional resistance may reduce the effectiveness of the mechanics, decrease tooth movement efficiency, cause patient discomfort, increase the risk of tissue damage, and further complicate anchorage control.(22)

Thus, the aim of the study was to compare frictional resistance of Teflon-coated stainless steel and stainless steel wires ligated with various types of ligature in ceramic brackets.

Materials and methods

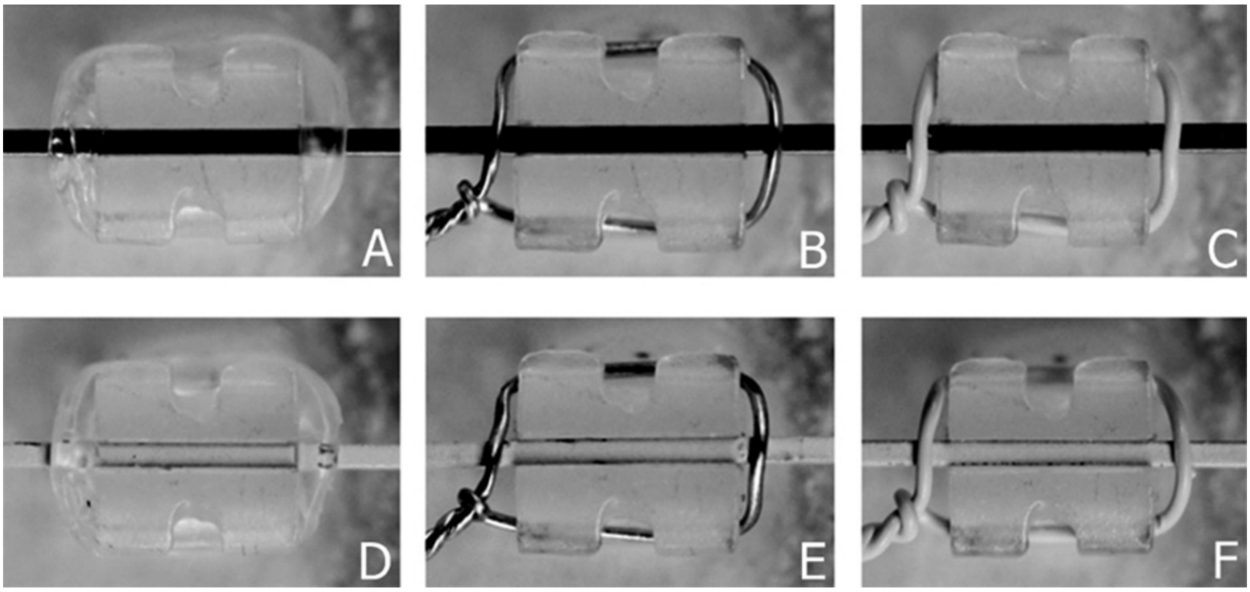
Six combinations of specimens, comprising two types of 0.019x0.025-inch main archwire, stainless steel wires (Resilient Orthoform, 3M Unitek, Monrovia, California, USA) and Teflon-coated stainless steel wires (Micro Dental White Arch, Modern Arch Orthodontics Supplies, Morgan Hill, California, USA), and three types of ligature, clear elastomeric ligatures (Quik-Stik, 3M Unitek), 0.010-inch stainless steel ligatures (Preformed Lig Ties Shorty, Ortho Technology, Tampa, Florida, USA) and 0.012-inch Teflon-coated stainless steel ligatures (Tooth Tone Preformed Shorty Ties, Ortho Technology), were used in 0.022x0.028-inch ceramic brackets (Reflections, Ortho Technology). There were 10 samples in each combination (Table 1). The experimental models are shown in Figure 1.

Frictional resistance was measured on the models in a universal testing machine (Instron model 5566, Instron Limited, Norwood, Massachusetts, USA). A wire holder was attached to the superior clamp of the universal testing machine, and an acrylic base holder was attached to the inferior clamp (Figure 2A). The wire was inserted into the wire holder. Acrylic bases were prepared from PVC rings. The lower part of each ring was filled with plaster, and the upper part was filled with self-cured acrylic resin. The acrylic surfaces were ground and polished using a grinder polisher machine (Metpol

Table 1 *The experimental groups.*

ตารางที่ 1 *กลุ่มทดลอง*

Group	Archwire	Ligature	Bracket	N
1	Stainless steel wire (Resilient Orthoform)	Clear elastomeric ligature (Quik-Stik)	Ceramic brackets (Reflections)	10
2	Stainless steel wire (Resilient Orthoform)	Stainless steel ligature (Preformed Lig Ties Shorty)	Ceramic brackets (Reflections)	10
3	Stainless steel wire (Resilient Orthoform)	Teflon-coated stainless steel ligature (Tooth tone Preformed Shorty Ties)	Ceramic brackets (Reflections)	10
4	Teflon-coated stainless steel wire (Micro Dental White Arch)	Clear elastomeric ligature (Quik-Stik)	Ceramic brackets (Reflections)	10
5	Teflon-coated stainless steel wire (Micro Dental White Arch)	Stainless steel ligature (Preformed Lig Ties Shorty)	Ceramic brackets (Reflections)	10
6	Teflon-coated stainless steel wire (Micro Dental White Arch)	Teflon-coated stainless steel ligature (Tooth tone Preformed Shorty Ties)	Ceramic brackets (Reflections)	10



รูปที่ 1 *กลุ่มทดลองทั้งหมด 6 กลุ่มที่ทำการจับคู่ระหว่างลวดและตัวมัดที่ต่างกัน*

(A) กลุ่มที่ 1: ลวดเหล็กกล้าไร้สนิมมัดด้วยยางมัดลวด

(B) กลุ่มที่ 2: ลวดเหล็กกล้าไร้สนิมมัดด้วยลวดมัดเหล็กกล้าไร้สนิม

(C) กลุ่มที่ 3: ลวดเหล็กกล้าไร้สนิมมัดด้วยลวดมัดเหล็กกล้าไร้สนิมเคลือบเทฟลอน

(D) กลุ่มที่ 4: ลวดเหล็กกล้าไร้สนิมเคลือบเทฟลอนมัดด้วยยางมัดลวด

(E) กลุ่มที่ 5: ลวดเหล็กกล้าไร้สนิมเคลือบเทฟลอนมัดด้วยลวดมัดเหล็กกล้าไร้สนิม

(F) กลุ่มที่ 6: ลวดเหล็กกล้าไร้สนิมเคลือบเทฟลอนมัดด้วยลวดมัดเหล็กกล้าไร้สนิมเคลือบเทฟลอน

Figure 1 *The experimental models of six combinations of wires and ligatures.*

(A) Group 1: stainless steel wire ligated with elastomeric ligature.

(B) Group 2: stainless steel wire ligated with stainless steel ligature.

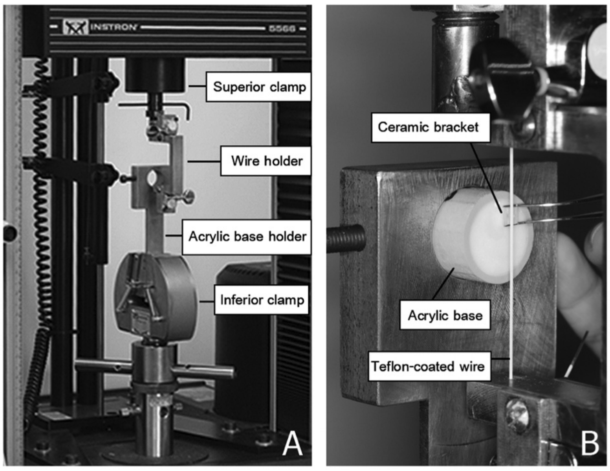
(C) Group 3: stainless steel wire ligated with Teflon-coated stainless steel ligature.

(D) Group 4: Teflon-coated stainless steel wire ligated with elastomeric ligature.

(E) Group 5: Teflon-coated stainless steel wire ligated with stainless steel ligature.

(F) Group 6: Teflon-coated stainless steel wire ligated with Teflon-coated stainless steel ligature

220, Shenzhen Pride Instrument Inc., Shenzhen, China). Then, the acrylic base was inserted into the acrylic base holder. The bracket was bonded on the acrylic base using Transbond XT Light Cure Adhesive system (3M Unitek) in a position where the wire was passively seated into the bracket slot (Figure 2B). In order to polymerize the adhesive, a light cure unit (Mini LEDTM) (Satelec, Acteon, Mount Laurel, New Jersey, USA) provided light, which was applied to the bracket from four directions (Upper-Left, Upper-Right, Lower-Left, and Lower-Right) for ten seconds in each direction before ligation of each combination. After complete polymerization, the holding wire was ligated into the bracket slot using three types of ligature (clear elastomeric ligature for Groups 1 and 4, stainless steel ligature for Groups 2 and 5, and Teflon-coated stainless steel for Groups 3 and 6) (Figure 1). For elastomeric ligation, the ligature was held and tied on the bracket wing with a Mathieu plier. For stainless steel and Teflon-coated stainless steel ligation, the Mathieu plier was used to hold the ligature at the



รูปที่ 2 *(A) การจัดเตรียมตัวยึดลวดและตัวยึดฐานอะคริลิกบนเครื่องทดสอบ*

(B) การจัดเตรียมลวดใส่ในตัวยึดลวดและการจัดเตรียมแบร็กเกตวางบนฐานอะคริลิก

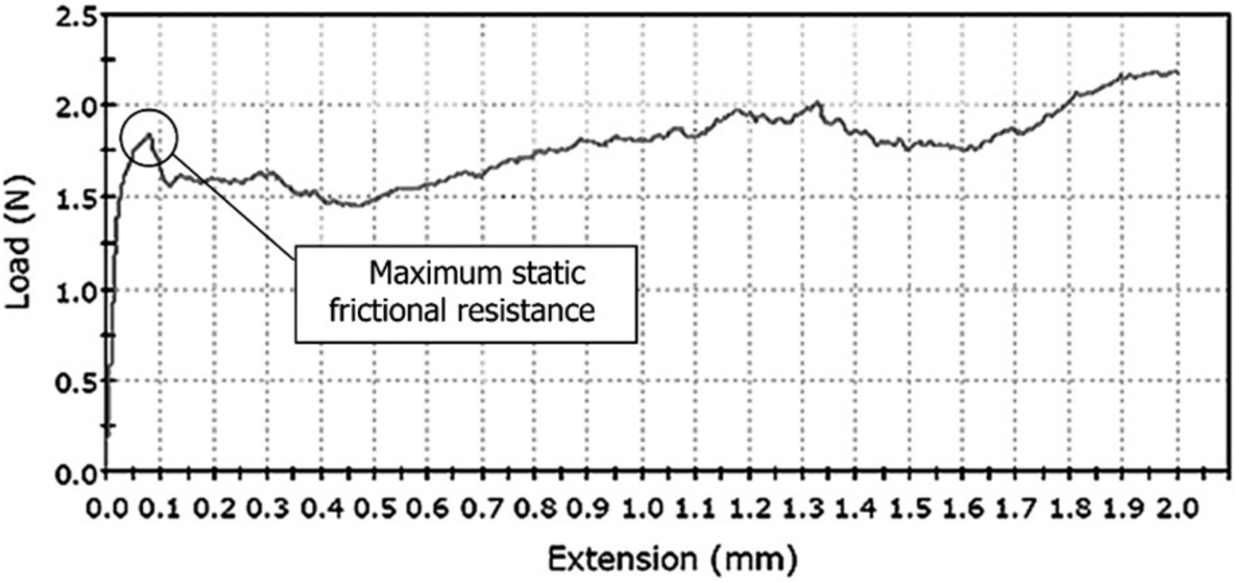
Figure 2 *(A) Setting of the wire holder and acrylic base holder on the universal testing machine.*

(B) Setting of the wire in the wire holder and the bracket on the acrylic base.

beginning point of the twist and to turn the ligature 13 times in the same direction.

The static frictional resistance value of each sample was measured using the experimental models mounted on the crosshead of the universal testing machine with a 50 N load cell, while 2 mm of wire was drawn vertically through the bracket at a speed of 0.1 mm/min in the wet state; a drop of artificial saliva was applied on the ligated bracket before the experiment was performed. The artificial saliva was manufactured by the Faculty of Pharmacy, Chiang Mai University. The composition of the artificial saliva, was as proposed by Fusayama.(23)

The frictional resistance test was performed on 10 samples in each combination. A new ceramic bracket, wire and ligature were used for each test. All experiments were performed by one examiner. The data were recorded on an X-Y recorder. The X–axis represented the extension of the wire beyond the bracket in millimeters and the Y–axis represented the



รูปที่ 3 *กราฟแสดงการกำหนดจุดที่เกิดความต้านทานเสียดทานสถิตสูงสุด*

Figure 3 *Graph indicating a specific maximum static frictional resistance.*

resistance to the crosshead movement in newtons. The maximum static frictional resistance was indicated from the load-extension graph as a first highest load value before a continuous decrease (Figure 3) and directly recorded in newtons, then converted into grams.

Statistical analysis

The normal distribution of the maximum frictional resistance values was determined using the Shapiro-Wilk's test. The differences in means of maximum frictional resistance among the test groups were determined using the two-way ANOVA test followed by Dunnett's T3 post-hoc test ($p < 0.05$). The data were analyzed using the Statistical Package for Social Sciences program version 17 for Windows (SPSS Inc., Chicago, Illinois, USA).

Results

The descriptive statistics of the mean maximum static frictional resistance values of stainless steel wires and Teflon-coated stainless steel wires, ligated with three types of ligature in ceramic brackets are shown in Table 2. The Teflon-coated stainless steel wires ligated with stainless steel ligatures (Group 5) provided the lowest mean maximum static frictional resistance, whereas the stainless steel wires ligated with elastomeric ligatures (Group 1) provided the greatest mean maximum static frictional resistance.

The data satisfied the normality of distribution, and were required for parametric statistical tests, but the homogeneity of variance assumptions was unequal. Thus, the obtained data were statistically calculated through two-way ANOVA followed by Dunnett's T3 post-hoc test. No interaction was detected in the frictional resistance tests between the types of wire and types of ligature in any of the combinations of brackets and archwires. Moreover, there was no statistically significant difference in mean maximum static frictional resistance between stainless steel wire and Teflon-coated wire. This finding shows that, regardless of the types of ligature, the mean maximum static frictional

ตารางที่ 2 *ค่าเฉลี่ย ค่าเบี่ยงเบนมาตรฐานและค่าพิสัยของค่าความต้านทานเสียดทานสถิตสูงสุดของลวดเหล็กกล้าไร้สนิมกับลวดเหล็กกล้าไร้สนิมเคลือบเทฟลอนที่มัดด้วยตัวมัด 3 ชนิดในแบร็กเกตเซรามิก*

Table 2 *Mean, standard deviation and ranges of the maximum static frictional resistance values of stainless steel and Teflon-coated stainless steel wires ligated with three types of ligature in ceramic brackets.*

Group	Wire	Ligature	Maximum static frictional resistance (gram)			
			Mean	SD	Min	Max
1	Stainless steel wire	Elastomeric ligature	118.6	52.5	54.6	190.2
2	Stainless steel wire	Stainless steel ligature	36.5	16.6	19	67.4
3	Stainless steel wire	Teflon-coated stainless steel ligature	51.4	16.1	23.7	75.8
4	Teflon-coated stainless steel wire	Elastomeric ligature	98.4	22.7	61.2	136.1
5	Teflon-coated stainless steel wire	Stainless steel ligature	28.9	17.7	11.5	64.2
6	Teflon-coated stainless steel wire	Teflon-coated stainless steel ligature	48.6	16.6	33.2	86.4

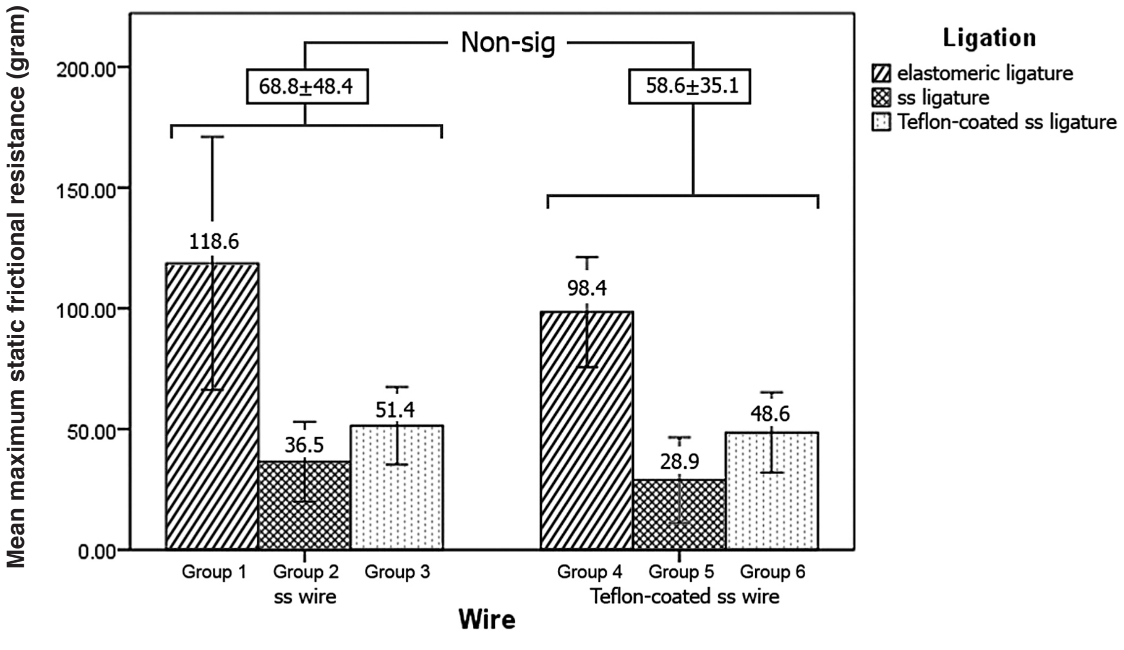
resistance of Teflon-coated stainless steel wires (58.6±35.1 g) was not significantly different from that of stainless steel wires (68.8±48.4 g) (Figure 4).

On the other hand, two-way ANOVA showed a statistically significant difference in the mean maximum static frictional resistance among the different types of ligature. Therefore, Dunnett's T3 post-hoc test was used to determine the statistical difference in mean frictional resistance values between three types of ligature, and showed that the mean frictional resistance of elastomeric ligatures (108.5±40.7 g) was significantly greater than that of stainless steel ligatures (32.7±17.1 g) and Teflon-coated stainless steel ligatures (50.0±16.0 g) ($p < 0.001$), whereas the mean maximum static frictional resistance of the Teflon-coated stainless steel ligatures was significantly greater than that of stainless steel ligatures, regardless of wire type ($p < 0.01$) (Figure 5).

Discussion

Theoretically, frictional force is directly proportional to the normal force and perpendicular to the contacting surfaces, such that $F = \mu N$ (F = frictional force, μ = coefficient of friction, N = normal force). Thus, frictional resistance depends on two factors, the coefficient of friction and the normal force. The coefficient of friction can be altered, depending on many factors, such as the material type of the object, surface hardness, surface chemistry and surface roughness.(19) In this study, the ligation force that was perpendicular to the direction of archwire movement was the normal force.

Regardless of ligature type, the Teflon-coated stainless steel archwires in this study showed no significant difference in frictional resistance from the stainless steel wire when used in ceramic brackets. Different outcomes were observed by Katta, *et al.*(24) and Sukh, *et al.*(16) Their studies revealed that

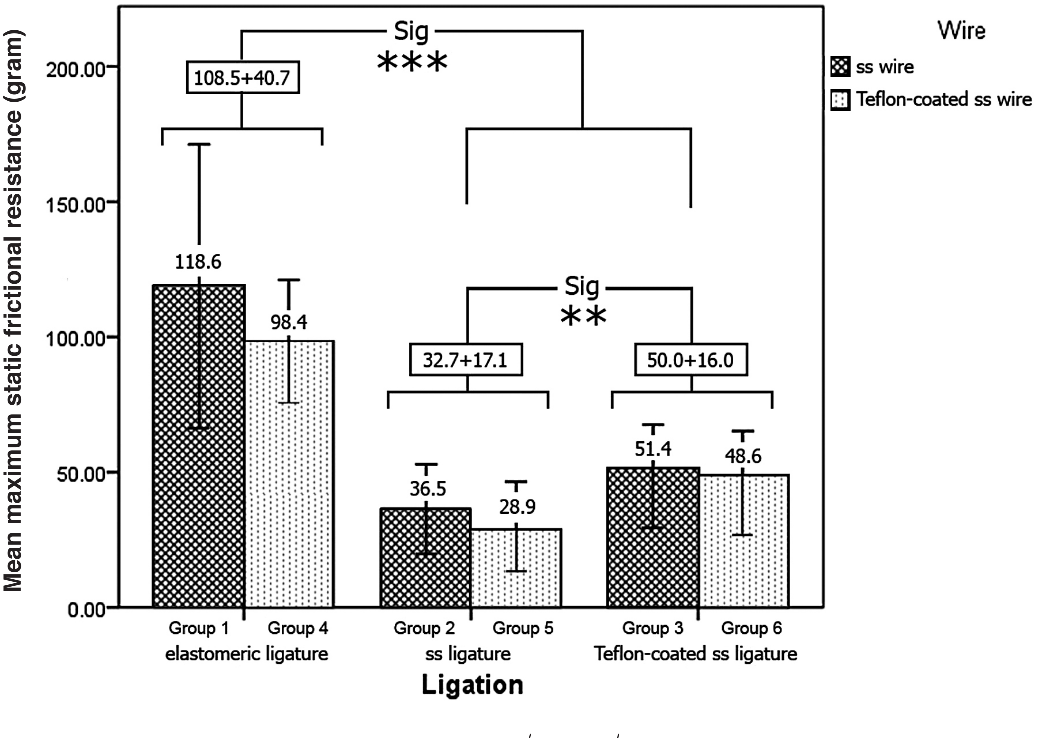


รูปที่ 4 *การเปรียบเทียบค่าความต้านทานเสียดทานสถิตสูงสุด (ค่าเฉลี่ย ± ค่าเบี่ยงเบนมาตรฐาน) ระหว่างลวดเหล็กกล้าไร้สนิมและลวดเหล็กกล้าไร้สนิมเคลือบเทฟลอน ค่าเฉลี่ยความต้านทานเสียดทานสถิตสูงสุดแสดงเหนือแท่งกราฟ*

Figure 4 *Comparison of the maximum static frictional resistance values (Mean ± SD) between stainless steel and Teflon-coated stainless steel wires. Mean maximum static frictional resistance values are shown above each bar.*

Teflon-coated stainless steel archwires generated significantly lower frictional resistance than stainless steel archwires when used in ceramic brackets. Furthermore, with stainless steel brackets, Husmann, *et al.*(15), Farronato, *et al.*(18) and Kim, *et al.*(25) showed that coated stainless steel archwires generated significantly lower frictional resistance than stainless steel archwires. On the other hand, Dickson, *et al.*(11) reported that coated stainless steel archwires generated greater frictional resistance than did stainless steel archwires. The rationale for the different outcomes was not obvious. However, one factor to consider would be the use of different types of bracket. Ceramic-slot ceramic brackets were used in this study, whereas Katta, *et al.*(24) and Sukh, *et al.*(16) used metal-slot ceramic brackets, and Husmann, *et al.*(15), Farronato, *et al.*(18) and Kim, *et al.*(25) used stainless steel brackets. Further study on the influence of bracket type and slot type on frictional resistance using Teflon-coated stainless steel archwires should be conducted to explore the causes of different outcomes among the studies, and to determine the ideal combination of esthetic archwires and ceramic brackets to provide the least frictional resistance.

In comparing ligatures, this study showed that the mean maximum static frictional resistance of elastomeric ligatures was significantly greater than that of stainless steel ligatures and Teflon-coated



รูปที่ 5 *การเปรียบเทียบค่าความต้านทานเสียดทานสถิตสูงสุด (ค่าเฉลี่ย ± ค่าเบี่ยงเบนมาตรฐาน) ระหว่างยางมัดลวด ลวดมัดเหล็กกล้าไร้สนิมและลวดมัดเหล็กกล้าไร้สนิมเคลือบเทฟลอน ค่าเฉลี่ยความต้านทานเสียดทานสถิตสูงสุดแสดงเหนือแท่งกราฟ โดย ** แสดงความแตกต่างอย่างมีนัยสำคัญทางสถิติที่ระดับ 0.01*
**** แสดงความแตกต่างอย่างมีนัยสำคัญทางสถิติที่ระดับ 0.001*

Figure 5 *Comparison of the maximum static frictional resistance values (Mean ± SD) among elastomeric, stainless steel and Teflon-coated stainless steel ligatures. Mean maximum static frictional resistance values are shown above each bar. The statistically significant differences are presented by ** ($p < 0.01$), *** ($p < 0.001$).*

ligatures. A similar outcome was observed by De Franco, *et al.*(26) who reported that elastomeric ligatures also generated greater frictional resistance than Teflon-coated stainless steel ligatures when used in ceramic brackets. They explained that Teflon-coated materials had a lower coefficient of friction than did polyurethane elastomers. In agreement, Bortoly, *et al.*(27) using stainless steel brackets, found that elastomeric ligatures generated greater frictional resistance than did stainless steel ligatures and Teflon-coated stainless steel ligatures. Moreover, many studies(28-31) have shown that the elastomeric ligatures generated greater frictional resistance than loose stainless steel ligatures when used in stainless steel brackets. However, the frictional resistance depends on a force of engagement known as a ligation force. Another possible explanation for lower frictional resistance is that lighter forces generated by Teflon-coated and stainless steel ligatures (compared to those generated by elastomeric ligatures) produce lower frictional resistance. These lighter forces vary with the number of turns during ligation(32) (the greater the number of turns, the greater is the ligation force).

There is controversy regarding the frictional resistance generated by stainless steel ligatures and Teflon-coated stainless steel ligatures. Katta, *et al.*(24) and Khamatkar, *et al.*(33) concluded that the frictional resistance of Teflon-coated stainless steel ligatures is significantly less than that of stainless steel ligatures. In contrast, this study shows that the mean maximum frictional resistance of the Teflon-coated stainless steel ligatures was significantly greater than that of the stainless steel ligatures. Although this study tried to standardize the size and length of both the Teflon-coated stainless steel and the stainless steel ligatures, the diameter of the Teflon coating ligature wires was increased by 0.002 inches from the conventional stainless steel ligatures due to the coating thickness indicated by a description of the ligature and by a digital veneer caliper measurement. The same number of turns to tighten the ligatures might have resulted in a greater force of engagement in the Teflon-coated stainless steel ligatures. Thus, the frictional resistance of the Teflon-coated stainless steel ligatures might have been greater than that of the stainless steel ligatures with the same diameter. However, additional studies of the relationship between coating thickness and frictional resistance are still needed.

Several studies have investigated the effect of artificial saliva on frictional resistance. Baker, *et al.*(34) and Tselepis, *et al.*(35) found that during the sliding of wires in brackets, artificial saliva reduced frictional resistance. On the other hand, Downing, *et al.*(36), Stannard, *et al.*(37) and Pratten, *et al.*(38) reported that artificial saliva increased the frictional resistance, and Ireland, *et al.*(39) and Andreasen, *et al.*(40) found no significant difference in frictional resistance between tests with and without saliva. Regardless of whether artificial saliva increased or decreased frictional resistance between archwires and brackets, in this study we chose to apply artificial saliva on the brackets before testing to simulate the oral environment.

Teflon coating protects the underlying wire from the corrosion process. However, corrosion of the underlying wire likely to take place if it is used for longer period in the oral cavity since this coating is subject to flaws that may occur during clinical use. Silva, *et al.*(41) identified the problems of greater deterioration and surface roughness of various types of coated archwire (Tooth Tone Plastic Coated, Esthetic Shiny Bright, Esthetic Flexy Supper Elastic, and Coated NiTi) than of conventional stainless steel or NiTi archwires occurring after clinical use. This finding corresponds with that of Katta, *et al.*(24) who found that Teflon-coated archwires expressed more (sic) irregularities after frictional resistance testing than before testing. This finding might lead to greater frictional resistance in used archwire. To eliminate error from using tested materials, new archwires, new brackets and new ligatures were used in each test.

However, the large standard deviation values may have resulted from a limitation of the sample size in this study. Thus, further study should have a larger sample to find if there are small statistically significant differences.

In choosing between stainless steel and Teflon-coated stainless steel archwires for esthetic orthodontic treatment with ceramic brackets, there is no difference in frictional resistance. However, in situations demanding maximal esthetics, the Teflon-coated archwires would be good options.

As for ligature selection, both clear elastomeric and Teflon-coated stainless steel ligatures are esthetically appropriate for use with Teflon-coated stainless steel wires and ceramic brackets. However, Teflon-coated stainless steel ligatures show significantly less frictional resistance than do elastomeric ligatures, but greater frictional resistance than stainless steel ligatures. Therefore, selecting Teflon-coated stainless steel ligatures would have benefit over elastomeric ligatures due to their low frictional resistance.

However, in clinical practice, consideration should also be given to other factors than frictional resistance and esthetic appearance, such as the cost of materials, availability of materials in the market, reputation and production standard of the supplier, the result of the clinical studies, etc., in order to provide appropriate and effective treatment.

Conclusions

1. Regardless of ligature type, the mean maximum static frictional resistance of Teflon-coated stainless steel and stainless steel wires were not significantly different when used in ceramic brackets.

2. Regardless of wire type, the mean maximum static frictional resistance of elastomeric ligatures was significantly greatest followed by Teflon-coated stainless steel ligatures and stainless steel ligatures respectively, when used in ceramic brackets. ($p < 0.001$).

Acknowledgement

The authors would like to express our recognition to Dr. Thanapat Sastraruji, Faculty of Dentistry, Chiang Mai University for his suggestions and valuable guidance on statistical analysis, and Dr. M. Kevin O Carroll, Professor Emeritus of the University of Mississippi, School of Dentistry, USA and Faculty Consultant at Faculty of Dentistry, Chiang Mai University, Thailand, for language editing of the manuscript.

References

1. Feu D, Catharino F, Duplat CB, Capelli JJ. Esthetic perception and economic value of orthodontic appliances by lay Brazilian adults. *Dental Press J Orthod* 2012; 17: 102-114.
2. Kusy RP. A review of contemporary archwires: Their properties and characteristics. *Angle Orthod* 1997; 67: 197-207.
3. Elayyan F, Silikas N, Bearn D. Mechanical properties of coated superelastic archwires in conventional and self-ligating orthodontic brackets. *Am J Orthod Dentofacial Orthop* 2010; 137: 213-217.
4. Karamouzos A, Athanasiou AE, Papadopoulos MA. Clinical characteristics and properties of ceramic brackets: A comprehensive review. *Am J Orthod Dentofacial Orthop* 1997; 112: 34-40.
5. Jena AK, Duggal R, Mehrotra AK. Physical properties and clinical characteristics of ceramic brackets: A comprehensive review. *Trends Biomater Artif Organs* 2007; 20: 101-115.

6. Kusy RP. Orthodontic biomaterials: from the past to the present. *Angle Orthod* 2002; 72: 501-512.
7. Aksakalli S, Malkoc S. Esthetic orthodontic archwires: Literature review. *J Orthod Res* 2013; 1: 2-4.
8. Arango S, Peláez-Vargas A, García C. Coating and surface treatments on orthodontic metallic materials. *Coatings* 2012; 3: 1-15.
9. Rafiuddin S, Abraham R. Metal free orthodontics: A review. *J Pre Clin Dent Res* 2014; 1: 100-106.
10. Sekhar Kotha R, Alla APRK, Mohammed S, Krishna Ravi R. An overview of orthodontic wires. *Trends Biomater Artif Organs* 2014; 18: 32-36.
11. Dickson JA, Jones SP, Davies EH. A comparison of the frictional characteristics of five initial alignment wires and stainless steel brackets at three bracket to wire angulations-an in vitro study. *Br J Orthod* 1994; 21: 15-22.
12. Muguruma T, Iijima M, Yuasa T, Kawaguchi K, Mizoguchi I. Characterization of the coatings covering esthetic orthodontic archwires and their influence on the bending and frictional properties. *Angle Orthod* 2017; 87: 610-617.
13. Clocheret K, Willems G, Carels C, Celis JP. Dynamic frictional behaviour of orthodontic archwires and brackets. *Eur J Orthod* 2004; 26: 163-170.
14. Usui T, Iwata T, Miyake S, et al. Mechanical and frictional properties of aesthetic orthodontic wires obtained by hard chrome carbide plating. *J Dent Sci* 2018; 13: 151-159.
15. Husmann P, Bourauel C, Wessinger M, Jager A. The frictional behavior of coated guiding archwires. *J Orofac Orthop* 2002; 63: 199-211.
16. Sukh R, Singh GK, Tandon P, Singh GP, Singh A. A comparative study of frictional resistance during simulated canine retraction on typodont model. *J Orthod Sci* 2013; 2: 61-66.
17. Abbas AA, Alhuwaizi AF. The effect of wire dimension, type and thickness of coating layer on friction of coated stainless-steel arch wires. *Int J Med Res Health Sci* 2018; 7: 115-121.
18. Farronato GP, Casiraghi G, Gianni AB, Salvato A. The use of PTFE in orthodontics. *Mondo Ortod* 1988; 13: 83-89.
19. Kusy RP, Whitley JQ. Friction between different wire-bracket configurations and materials. *Semin Orthod* 1997; 3: 166-177.
20. Drescher D, Bourauel C, Schumacher HA. Frictional forces between bracket and arch wire. *Am J Orthod Dentofacial Orthop* 1989; 96: 397-404.
21. Loftus BP, Artun J, Nicholls JI, Alonzo TA, Stoner JA. Evaluation of friction during sliding tooth movement in various bracket-arch wire combinations. *Am J Orthod Dentofacial Orthop* 1999; 116: 336-345.
22. Braun S, Bluestein M, Moore BK, Benson G. Friction in perspective. *Am J Orthod Dentofacial Orthop* 1999; 115: 619-627.
23. Fusayama T, Katayori T, Nomoto S. Corrosion of gold and amalgam placed in contact with each other. *J Dent Res* 1963; 42: 1183-1197.
24. Katta A, Vannala V, Navaneethakrishnan KK, Kandasamy R, Venkatachalam B, Arafath M. Coated, uncoated stainless steel ligatures versus self ligation- In the perspective of friction. *Pakistan Orthod J* 2013; 5: 60-66.
25. Kim Y, Cha JY, Hwang CJ, Yu HS, Tahk SG. Comparison of frictional forces between aesthetic orthodontic coated wires and self-ligation brackets. *Korean J Orthod* 2014; 44: 157-167.
26. De Franco DJ, Spiller RE, Jr., von Fraunhofer JA. Frictional resistances using Teflon-coated ligatures with various bracket-archwire combinations. *Angle Orthod* 1995; 65: 63-72; discussion 73-64.

27. Bortoly TG, Guerrero AP, Rached RN, Tanaka O, Guariza-Filho O, Rosa EA. Sliding resistance with esthetic ligatures: An in-vitro study. *Am J Orthod Dentofacial Orthop* 2008; 133: 340.e341-347.
28. Bednar JR, Gruendeman GW, Sandrik JL. A comparative study of frictional forces between orthodontic brackets and arch wires. *Am J Orthod Dentofacial Orthop* 1991; 100: 513-522.
29. Thorstenson GA, Kusy RP. Effects of ligation type and method on the resistance to sliding of novel orthodontic brackets with second-order angulation in the dry and wet states. *Angle Orthod* 2003; 73: 418-430.
30. Khambay B, Millett D, McHugh S. Evaluation of methods of archwire ligation on frictional resistance. *Eur J Orthod* 2004; 26: 327-332.
31. Taylor NG, Ison K. Frictional resistance between orthodontic brackets and archwires in the buccal segments. *Angle Orthod* 1996; 66: 215-222.
32. Kusy RP. Orthodontic biomaterials: from the past to the present. *Angle Orthod* 2002; 72: 501-512.
33. Khamatkar A, Sonawane S, Narkhade S, et al. Effects of different ligature materials on friction in sliding mechanics. *J Int Oral Health* 2015; 7: 34-40.
34. Baker KL, Nieberg LG, Weimer AD, Hanna M. Frictional changes in force values caused by saliva substitution. *Am J Orthod Dentofacial Orthop* 1987; 91: 316-320.
35. Tselepis M, Brockhurst P, West VC. The dynamic frictional resistance between orthodontic brackets and arch wires. *Am J Orthod Dentofacial Orthop* 1994; 106: 131-138.
36. Downing A, McCabe JF, Gordon PH. The effect of artificial saliva on the frictional forces between orthodontic brackets and archwires. *Br J Orthod* 1995; 22: 41-46.
37. Stannard JG, Gau JM, Hanna MA. Comparative friction of orthodontic wires under dry and wet conditions. *Am J Orthod Dentofacial Orthop* 1986; 89: 485-491.
38. Pratten DH, Popli K, Germane N, Gunsolley JC. Frictional resistance of ceramic and stainless steel orthodontic brackets. *Am J Orthod Dentofacial Orthop* 1990; 98: 398-403.
39. Ireland AJ, Sherriff M, McDonald F. Effect of bracket and wire composition on frictional forces. Eur J Orthod 1991; 13: 322-328.
40. Andreasen GF, Quevedo FR. Evaluation of friction forces in the 0.022 x 0.028 edgewise bracket in vitro. *J Biomech* 1970; 3: 151-160.
41. Silva DL, Mattos CT, Araujo MV, Ruellas ACO. Color stability and fluorescence of different orthodontic esthetic archwires. *Angle Orthod* 2013; 83: 127-132.

เปิดบริการ

ศูนย์เอกซเรย์ทางทันตกรรม

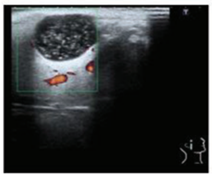
โรงพยาบาลทันตกรรม คณะทันตแพทยศาสตร์ มหาวิทยาลัยเชียงใหม่

ให้บริการถ่ายภาพรังสี ทางทันตกรรม (เอกซเรย์) แก่ผู้ป่วยทั้งใน-นอกเวลาราชการ

▶ บริการถ่ายภาพรังสีทางทันตกรรมทั่วไป (<u>ชนิดภาพรังสีนอกช่องปาก</u>) ด้วยระบบดิจิตอล (Digital Radiograph)

Panoramic

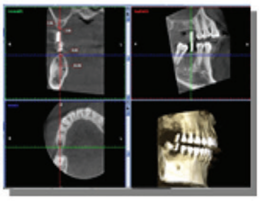
▶ การตรวจด้วยอัลตราซาวด์ (บริเวณขากรรไกร-ใบหน้า)



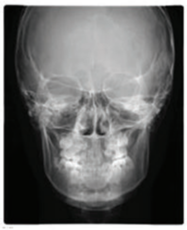
Ultrasound

Cephalometric

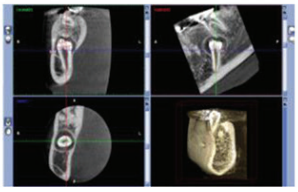
▶ ภาพถ่ายรังสีโคนบีมซีที (Cone beam CT : CBCT) ด้วยเครื่องถ่ายภาพซึ่งเป็นเทคโนโลยีอันทันสมัย สามารถแสดงภาพของฟัน กระดูกขากรรไกรและใบหน้า ได้ในหลายระนาบและสร้างเป็นภาพสามมิติ พร้อมรายงานผลอ่านภาพโดยทันตแพทย์เฉพาะทาง



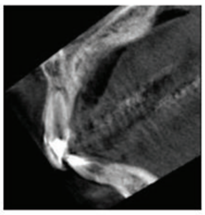
การวางแผนเพื่อฝังรากเทียม



PA



ระบุตำแหน่งของฟันฝังคุด



การตรวจการแตกหักของรากฟัน

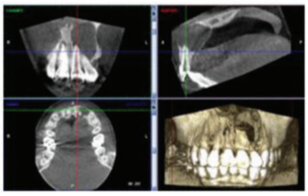
เปิดให้บริการ

จันทร์-ศุกร์ : เวลา 09.00 - 20.00 น.

เสาร์-อาทิตย์ : เวลา 09.00 - 16.00 น.

ศูนย์เอกซเรย์ทางทันตกรรม โรงพยาบาลทันตกรรม คณะทันตแพทยศาสตร์ ม.ช. ตั้งอยู่ชั้น 1 อาคาร 6 (ติดห้องเอกซเรย์เบอร์ 2)

โทรศัพท์ : 053-941-605 E-Mail address : dentxraycenter@gmail.com



การตรวจรอยโรคของฟันและกระดูก

ศูนย์เอกซเรย์ทางทันตกรรมเป็นสถานพยาบาลของทางราชการ สามารถเบิกค่ารักษาพยาบาลจากทางราชการได้ตามระเบียบกระทรวงการคลัง