MECHANICAL PROPERTIES OF THAI ORTHODONTIC ELASTICS

CHIDRUTHAI BOONYANATE

A THESIS SUBMITTED IN PARTIAL FULFILLMENT
OF THE REQUIREMENTS FOR
THE DEGREE OF MASTER OF SCIENCE
(ORTHODONTICS)
FACULTY OF GRADUATE STUDIES
MAHIDOL UNIVERSITY
2004

ISBN 974-04-4933-6

Thesis
Entitled

MECHANICAL PROPERTIES OF THAI ORTHODONTIC ELASTICS

C. Boonyanate
Ms. Chidruthai Boonyanate
Candidate

Assoc.Prof. Niwat Anuwongnukroh,
D.D.S.,M.S.D. (Orthodontics),
Dip. American Board,
Diplomate Thai Board of Orthodontics
Major-Advisor

Ms. Chaveewan Rakdee
M.Sc. (Polymer science)
Co-Advisor

Assoc.Prof. Surachai Dechkunakorn
B.Sc., D.D.S., Dip.in Orthodontics
Diplomate Thai Board of Orthodontics
Co-Advisor

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

P. Sawaengkit
Assoc. Prof. Pornrachanee Sawaengkit
B.Sc., D.D.S., M.S. (Orthodontics)
Diplomate Thai Board of Orthodontics
Chair
Master of Science Program in Orthodontics
Faculty of Dentistry

Thesis
Entitled

MECHANICAL PROPERTIES OF THAI ORTHODONTIC ELASTICS

was submitted to the Faculty of Graduate Studies, Mahidol University
for the degree of Master of Science (Orthodontics)
on

May 20, 2004

C. Boonyanate.
………………………………………………
Ms. Chidruthai Boonyanate
Candidate

………………………………………………
Ms. Chaveewan Rakdee
M.Sc. (Polymer science)
Member

………………………………………………
Assoc.Prof. Niwat Anuwongnukroh,
D.D.S.,M.S.D. (Orthodontics),
Dip. American Board,
Diplomate Thai Board of Orthodontics
Chair

………………………………………………
Mr. Surapich Loykulnant
D.Eng. (Polymeric and organic materials)
Member

………………………………………………
Assoc.Prof. Surachai Dechkunakorn
B.Sc., D.D.S., Dip.in Orthodontics
Diplomate Thai Board of Orthodontics
Member

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

………………………………………………
Assoc.Prof. Jurai Nakaparksin
D.D.S., M.S.,
Dean
Faculty of Dentistry
Mahidol University

ACKNOWLEDGMENT

I would like to express my deep appreciation and gratitude to my advisory committee: Associate Professor Niwat Anuwongnukroh and Associate Professor Surachai Dechkunakorn for their excellent guidance, encouragement, suggestions, understanding and patience.

I wish to express my sincere thanks to Ms. Chaveewan Rakdee for her advice, supporting and providing Thai orthodontic elastics.

I wish to extend my thanks to Assistant Professor Sumol Yuthasanprasit for the helpful on statistical advice.

Thanks to all my colleagues in Orthodontic Department, Mahidol University for all their assistance.

Last of all, a very special thank to my family who strengthened me and supports needed to complete my study.

Chidruthai Boonyanate

MECHANICAL PROPERTIES OF THAI ORTHODONTIC ELASTICS.

CHIDRUTHAI BOONYANATE 4536425 DTOD/M

M.Sc.(ORTHODONTICS)

THESIS ADVISORS: NIWAT ANUWONGNUKROH, D.D.S., M.S.D. (ORTHODONTICS), SURACHAI DECHKUNAKORN, D.D.S., Dip. In Ortho., CHAVEEWAN RAKDEE, M.Sc. (Polymer science)

ABSTRACT

Although Thailand is the world's largest producer and exporter of natural rubber, Thai orthodontists have had to use imported orthodontic elastics. With the co-operation of the National Metal and Materials Technology Center (MTEC) and the Faculty of Dentistry at Mahidol University, the first Thai orthodontic elastics have been produced in 2 types, no-color (Thai) and color-added (Thai-colored) elastics.

The purpose of this study was to determine the in vitro mechanical properties of Thai orthodontic elastic brands (Thai and Thai-colored) in comparison to imported ones (Ormco and G&H) in 2 different size groups (1/4", 4.5Oz and 5/16", 4.5 Oz). The results of this study showed that most of the elastics did not match the specified force index when extended to the standard extension index of 3x internal diameter, except for the 1/4" Thai-colored and the 5/16" G&H elastics. At an equivalent extension, the 1/4" Thai brands and G&H elastics generated significantly higher force than the Ormco elastics and the 5/16" elastics of Thai brands generated significantly higher force than the imported ones. There were statistically significant differences ($P<0.05$) among all groups in breaking force and maximum elasticity. For the 1/4" elastics, the G&H elastics had significantly higher breaking force than other groups and the Thai brand of elastics had significantly lower maximum elasticity than imported brands. For the 5/16" elastics, the Ormco elastics had significantly lower breaking force than other groups and the G&H elastics had significantly higher maximum elasticity than other groups.

The force relaxation patterns of all elastic brands were similar in both the static and dynamic tests. The significant loss of force occurred immediately after the elastics were stretched for 15 minutes then continued with slower rate for 2 hours and the force continued to reduce gradually with minimal amount until the end of the 24-hour period. The difference was statistically significant ($P<0.05$) among all groups of elastics in force relaxation over the 24-hour period. In the static test, the greatest percentage of force reduction occurred within 15 minutes approximately 13.0-15.0% for Thai elastics and 11.0-13.0% for imported elastics and the force reduction of all elastics continued to reduce to 17.0-19.0% at 2 hours. At 24 hours, the force reduction was approximately 20.0-23.0% for Thai elastics and was 23.4-25.0% for imported elastics. Dynamic test caused more force loss than static test, the average force reduction was approximately 15.5-16.5% for Thai elastics and 15.4-16.0% for imported elastics at 15 minutes. The force of all elastics groups reduced to 19.0-22.0% at 2 hours. The percentages of force reduction at 24 hours were approximately 21.3-22.5% for Thai elastics and 24.0-26.8% for imported elastics. Color adding did not affect the mechanical properties of Thai elastics. The mechanical properties of the Thai elastics were comparable to those of the imported elastics.

KEY WORDS: ORTHODONTIC ELASTICS / FORCE DECAY/ NATURAL LATEX RUBBER

125pp. ISBN 974-04-4933-6

คุณสมบัติเชิงกลของยางทางทันตกรรมจัดฟันชนิดวงของไทย (MECHANICAL PROPERTIES OF THAI ORTHODONTIC ELASTICS)

วท.ม. (ทันตกรรมจัดฟัน)

ชิดฤทัย บุณยเนตร 4536425 DTOD/M

คณะกรรมการควบคุมวิทยานิพนธ์ : นิวัต อนุวงศ์นุเคราะห์, D.D.S., M.S.D. (ORTHODONTICS), สุรชัย เดชคุณากร, D.D.S., Dip In Ortho., ฉวีวรรณ รักดี, M.Sc. (Polymer science)

บทคัดย่อ

แม้ว่าประเทศไทยจะเป็นผู้ผลิตและส่งออกยางพาราได้มากที่สุดในโลก แต่ทันตแพทย์จัดฟันของไทยยังต้องใช้ยางทางทันตกรรมจัดฟันที่นำเข้าจากต่างประเทศ ยางทางทันตกรรมจัดฟันของไทยได้ถูกผลิตขึ้นเป็นครั้งแรกจากความร่วมมือระหว่างศูนย์เทคโนโลยีโลหะและวัสดุแห่งชาติ (MTEC) และคณะทันตแพทยศาสตร์ มหาวิทยาลัยมหิดล โดย ได้ผลิตออกมาใน 2 รูปแบบ คือ ยางไม่มีสี และ ยางสี

วัตถุประสงค์ของการศึกษานี้เพื่อศึกษาคุณสมบัติเชิงกลของยางทางทันตกรรมจัดฟันชนิดวงของไทย (Thai และ Thai-colored) เปรียบเทียบกับยางที่นำเข้าจากต่างประเทศ (Ormco และ G&H) โดยทดสอบคุณสมบัติเชิงกลของยางตัวอย่าง 2 ขนาด คือ 1/4 นิ้ว, 4.5 ออนซ์ และ 5/16 นิ้ว, 4.5 ผลการทดสอบพบว่ายางเกือบทุกชนิดให้แรงจากการยืดที่ 3 เท่าของเส้นผ่าศูนย์กลางวงในของยาง ไม่เท่ากับค่าที่แจ้งไว้บนซอง ยกเว้นยางขนาด 1/4 นิ้ว จาก Thai-colored และขนาด 5/16 นิ้ว จากบริษัท G&H จากการทดสอบยางขนาด 1/4 นิ้ว ที่ระยะการยืดของยางที่เท่ากันขนาดแรงของยางไทยและยางบริษัท G&H มากกว่ายางบริษัท Ormco อย่างมีนัยสำคัญทางสถิติ ($P<0.05$) และยาง G&H ให้แรงที่จุดขาดสูงกว่ายางชนิดอื่นและยางไทยมีระยะที่ยืดได้มากที่สุดน้อยกว่ายางนำเข้าอย่างมีนัยสำคัญทางสถิติ ($P<0.05$) การทดสอบยางขนาด 5/16 นิ้ว พบว่ายางไทยให้แรงมากกว่า ยางจากบริษัท Ormco และ G&H อย่างมีนัยสำคัญทางสถิติ ($P<0.05$) โดยที่จุดขาดยางบริษัท Ormco ให้แรงน้อยกว่ายางชนิดอื่นอย่างมีนัยสำคัญทางสถิติ ($P<0.05$) และยางบริษัท G&H ยืดได้มากกว่ายางกลุ่มอื่นอย่างมีความแตกต่างกันอย่างมีนัยสำคัญทางสถิติ ($P<0.05$)

จากการทดสอบคุณสมบัติของยางแบบ Static และ Dynamic พบว่าการลดลงของแรงในทุกกลุ่มยางมีลักษณะคล้ายกัน คือ มีการสูญเสียแรงของยางมากและรวดเร็วในช่วงเวลา 15 นาทีแรก หลังจากนั้นการสูญเสียแรงจะมีอัตราลดลงและแรงเกือบคงที่หลังจาก 2 ชั่วโมง โดยจากเวลา 2 ถึง 24 ชั่วโมงพบการลดลงของแรงเพียงเล็กน้อย และ พบความแตกต่างอย่างมีนัยสำคัญทางสถิติระหว่างยางจากแต่ละบริษัท จากการทดสอบแบบ Static พบว่าเปอร์เซ็นต์ของการลดลงของแรงเกิดขึ้นมากที่สุดภายใน 15 นาที ยางไทย มีการลดลงของแรงประมาณ 13.0-15.0% และยางนำเข้ามีการลดลงประมาณ 11.0-13.0% ที่เวลา 2 ชั่วโมงยางทุกชนิดมีการลดลงของแรงประมาณ 17.0-19.0% และ ที่เวลา 24 ชั่วโมง ยางไทยมีการลดลงของแรงประมาณ 20.0-23.0% และยางนำเข้ามีการลดลงประมาณ 23.4-25.0% การทดสอบแบบ dynamic มีการลดลงของแรงมากกว่าเมื่อเปรียบเทียบกับการทดสอบแบบ static ที่เวลา 15 นาที ยางไทยมีการลดลงของแรงประมาณ 15.5-16.5% และยางที่นำเข้ามีการลดลงของแรงประมาณ 15.4-16.0% ที่เวลา 2 ชั่วโมง ยางทุกชนิดมีการลดลงของแรงประมาณ 19.0-22.0% ที่เวลา 24 ชั่วโมง ยางไทยมีการลดลงของแรงประมาณ 21.3-22.5% และยางนำเข้ามีการลดลงประมาณ 24.0-26.8% การเติมสีในยาง ไม่มีผลกระทบต่อคุณสมบัติเชิงกลของยางทางทันตกรรมจัดฟันของไทย ยางทางทันตกรรมจัดฟันของไทยมีคุณสมบัติเชิงกลใกล้เคียงกับยางทันตกรรมจัดฟันจากต่างประเทศ

126 หน้า ISBN 974-04-4933-6

CONTENTS

LIST OF TABLES

LIST OF TABLES (CONT.)

LIST OF TABLES (CONT.)

LIST OF FIGURES

LIST OF FIGURES (CONT.)

CHAPTER 1

INTRODUCTION

Charles Goodyear (1839) developed the vulcanization process that gave raw rubber a durable quality. Shortly afterwards, orthodontists began to incorporate elastics in the design of fixed appliances. Calvin S. Case (1893) discussed the use of inter-maxillary elastics at the Columbia Dental Congress. Nowadays, the natural rubber orthodontic elastics have been widely used for tooth movement (such as in space closure, cross-bite correction, and intermaxillary traction: Class II or Class III traction) because of their favorable characteristics of high flexibility, high elasticity, light force production and long range of action. Elastic band may be stretched several times of its original dimension without undergo permanent deformation. The disadvantages of these materials are force relaxation after clinical used and allergic reaction due to residual rubber protein, as antigen, of latex products. However, natural rubber continues to be used for orthodontic elastics, mainly due to their favorable characteristics and low cost.

There are many kinds of products that are produced from natural rubber, such as elastic bands, rubber tubes, balloons, condoms, medical gloves, household gloves artificial nipples, etc. Orthodontic elastic is one kind of products that have been used for a long time, to transfer force to tooth. At present, there are many orthodontic companies importing natural rubber orthodontic elastics to Thai orthodontic market. Unfortunately, there is still no orthodontic elastic producer in Thailand even though Thailand is the world’s largest producer and exporter of natural rubber. A majority of Thailand's rubber plantations are located in the southern part of the country. Thailand leads the rubber producing countries in research and development of natural rubber. This makes Thai natural rubber the most dependable and consistent. The Rubber Industry has continuously provided a high income for Thailand. The values of both production and export have increased.

Recently, with co-operation of National Metal and Materials Technology Center (MTEC) and Faculty of Dentistry Mahidol University, the first Thai orthodontic elastics are produced. It is hope that if the Thai elastic properties are compatible to or better than those of oversea elastics, Thailand would be become one of the leader in the field of orthodontic elastic production due to its advantage of the natural supply of latex.

Accomplishment of orthodontic treatment requires the appropriate force applied to teeth that lead to maximum rate of tooth movement with minimal adverse effect on the teeth and supporting tissues. In order to control the force, orthodontist is necessary to understand the action of orthodontic devices. Knowledge of mechanical properties of orthodontic elastics may help orthodontist in selection elastics for particular tooth movement and enable to instruct their patients to use elastics in appropriate way.

Rationales and Significance of the Problem

Many questions are yet to be answers:

1. What are the mechanical properties of Thai orthodontic elastics?
2. Do their properties comparable to imported elastics?
3. Does the color, which is added in Thai elastics, affect the mechanical properties?

These questions will be answered in this present study.

CHAPTER 2

OBJECTIVES

This study is designed to investigate the in vitro mechanical properties of Thai orthodontic elastics by measuring of force extension, breaking force and force relaxation, in both static and dynamic conditions, and to compare mechanical properties between Thai and imported orthodontic elastics.

The Specific Aims of this Study are:

1. To investigate force extension, breaking force and force relaxation characteristics of Thai orthodontic elastics.
2. To compare force extension, breaking force and force relaxation characteristics between Thai orthodontic elastics and imported orthodontic elastics.
3. To compare force extension, breaking forces and force relaxation characteristics between non-color elastics and color-added elastics.

Limitations of the Study are:

1. This is an in vitro study, which may not correspond to the results found under intraoral conditions. However, the results may give more or less information in choosing orthodontic elastics for clinical use.
2. The result of the study may not be comparable to other studies due to the differences in study design, and materials used, etc.

Expected Benefits from the Study are:

1. To know mechanical properties of Thai orthodontic elastics.
2. Knowledge of mechanical properties of orthodontic elastics will help orthodontists in selection of the elastics for their clinical use.
3. If the results obtained from this study are positive, it may encourage the production of Thai orthodontic elastics. This will not only promote the use of domestic material but also help the economy grow by reduction of imported elastics and increasing of exported Thai elastics.

CHAPTER 3
LITERATURE REVIEW

Orthodontic Elastics

The first use of elastics in orthodontics was reported, by Calvin S. Case in 1893. Since then, orthodontic elastics have been used to generate force for tooth movement, such as in space closure, cross-bite correction, and intermaxillary traction e.g. Class II or Class III traction. Mainly, orthodontic elastics are used for both intramaxillary and intermaxillary tooth movements. An intramaxillary elastic is used between two points of application in the same dental arch, whereas an intermaxillary elastic is used between one point on the maxillary dental arch and one point on the mandibular dental arch. (Figure 1)

Figure 1. Inter/intramaxillary elastics (Intermaxillary elastic is pointed by blue arrow and intramaxillary elastic is pointed by yellow arrow)

Commercially orthodontic elastics have been mainly made from 2 types of rubber (1):

1. Natural rubber which is a hydrocarbon polymer of isoprene unit.
2. Synthetic rubber which have been developed to duplicate natural rubber.

Rubber

The application of rubbers began with the discovery of vulcanization by Charles Goodyear in 1839 (2). He added sulfur and basic lead carbonate to natural rubber, heated the mixture, and thus changed the material from a plaything or an unsatisfactory weatherproofing material to the useful product that we use today. Since that time, many developments of basic chemistry of rubber and of vulcanization methods have occurred to increase its tensile strength, tear resistance, heat resistance, and aging resistance, also (3).

The outstanding properties of rubbery material are long range of action and reversible elasticity. The characteristic property of reversible extensibility results from the randomly coiled structure of long, folded polymer chains. Upon extension, these randomly coiled chains are elongate into an ordered structure consisting of linear chains except when cross-linked. This tendency to revert to the original disorder state upon removal of stress accounts for the elastic behavior (1). A rubber band may be stretched several hundred percents yet it snaps back to its original dimension. By contrast, a steel wire can be stretched only 1% extension, otherwise irreversible deformation will occur.

The elasticity in elastomer arises through the entropic straightening and recoiling of the polymer chains. This is substantially an isovolume phenomenon. For metals, conversely, the elasticity arises through increase in the distance between atoms, removing the atoms from the equilibrium positions in the energy well. This is called an enthalpic effect (4).

The “snarls” (irregular twisted arrangement of chains) of the rubber are fastened at certain points by the covalent bonds between sulfur and two carbon atoms from the double bond. The more numerous of the linkage points are, the greater restriction of molecular slip exists. The lower the extensibility is maintained until, in the unstretched state, the snarls are in a random arrangement (amorphous state of the polymer). Conversely, on stretching, the snarls begin to disentangle and straighten out and the chain becomes oriented. This orientation result in crystallization that increases the attraction forced between the chain, causing stiff material. When this force is released, strained bonds are allowed to return to the primary random snarl arrangement of the molecules. Natural rubbers crystallize easily on stretching, which improves their tensile strength. Oppositely, synthetic rubbers, such as styrene-butadiene rubbers, do not crystallize readily when stretched. They also show poor tensile strength if not reinforced with fillers such as carbon black.

The term rubber that has been given definition by American Society for Testing and Materials (ASTM) D1566–88b, Standard terminology relating to rubber:

Rubber: A material that is capable of recovering from large deformation quickly to a state in which it is essentially insoluble (but can be swell) in boiling solvent, such as benzene, methyl ethyl ketone, and ethanoltoluene azestrope. A rubber in this modified state, free of diluents, retracts within one minute to less than 1.5 times it original length after being stretched at room temperature (18–20 °C) to twice its length and held for one minute before release (5).

Chemical Structure of Rubber

Rubber is one type of polymer, in which they have high molecular weight compounds made from low molecular weight building units called monomers, the simple molecules that are covalently bonded into long chains. Polymer, which means the long chain molecules formed from the monomer unit (2). There may be 1,000 to 20,000 repeating units of monomer. If the polymer consists solely of one monomer, it is called a homopolymer, e.g., natural rubber (polyisoprene); if it has two species, it is a copolymer, e.g., butadiene-styrene rubber; if three, it called terpolymer, e.g., ethylene propylene terpolymer, where the third monomer may be dicyclopentadiene (5).

In the early days of synthetic polymer manufacture, monomer was polymerized in bulk, often with the aid of catalyst. Then this process was superseded by emulsion polymerization, the main process used today, although solution polymerization is of growing importance. In the emulsion process, three materials are the most important:

these are monomers dispersed in water, surface-active substance such as soap, and polymerization initiator. The result of this reaction is a dispersion of minute particles of polymer in an aqueous medium called latex. The minute particles are coagulated and dried to form the rubber product. The emulsion method results in a better product at a quicker rate when compared to bulk polymerization methods. For solution polymerization, the monomer is polymerized in a suitable solvent. Butyl rubber is produced in this way (5).

Component of Rubber

Crude rubber, by it self, is not a very useful material. However, by the proper selection and mixing with other materials, the crude rubber may be compounded into products that are outstanding in tensile strength, tear resistance, abrasion resistance, chemical resistance, and heat resistance, or any other classical properties or combinations thereof. These materials are classified under the categories of vulcanisates, accelerators, antioxidants, age resistors, fillers, reinforcing agents, and colorants, which will be discussed as follows (3):

1. Vulcanisates

The vulcanisate reduces the plasticity of the rubber compound, while maintaining its elasticity. Sulfur was the original material and has still been the chief material used for this purpose. But other material, for instance, sulfurchloride, nitro compounds, silinium, and so on, can be used to perform vulcanization. Vulcanization will generally result in a marked increase in tensile strength, a reduction in tendency to loss of flexibility at low temperature and, finally, an increase in the resistance of rubber to solvents. The cross-linking of the sulfur atoms between the polymer by vulcanization increases the strength of vulcanized rubber (2).

Vulcanization is used in rubber industry and refers to variety of cross-linking processes used in either natural or synthetic rubbers. Heating raw rubber with sulfur and accelerating agents can accomplish vulcanization. Normally, vulcanized soft rubbers contain approximately 3% by Wt sulfur and are heated in the 100-200 °C range for vulcanizing. If the sulfur content is increased, the cross-linking that occurs will also increase, respectively. A fully rigid structure of hard rubber can be produced with about 45% sulfur (2).

2. Accelerators and activators

The use of an accelerator results in reduction in the amount of time necessary for the vulcanization reaction to reach completion at a given temperature. Some materials have the property of facilitating the function of accelerators and are called activators. Zinc oxide is one such material. Additional advantages of accelerators for rubber are as follows:

1) A reduction in the quantity of sulfur required and consequent elimination of "Blooming" of excess sulfur to the surface of the finished article.

2) A leveling effect on the degree of vulcanization.

3) A leveling effect on the variation of vulcanization.

4) Counteraction of the effect of carbon black to prolong the time of vulcanization.

5) Improvement in resistance to deterioration of the final product.

6) Utilization of brighter and less expensive organic colorants, which would be impaired by prolonged vulcanization time.

3. Antioxidants or age-resistors

One of the major problems of rubber is that as the time goes by under normal room-temperature conditions vulcanized natural rubber will show a decided decrease in tensile strength. Flexing operations, heat, light, elongation, presence of copper or manganese salts or soaps, and improper vulcanization might accelerate the deterioration of such rubbers. Some accelerators, e.g., phenols, amines, and waxes are incorporated into the compound to serve as antioxidants or age resistors. Although not all antioxidants have proved to be effective as age-resistors, it is almost invariably true that any good age- resistor is also a powerful antioxidant.

4. Fillers, reinforcing agents, and colorants

It is somewhat difficult to form a clearly distinction among these three terms because some substances such as zinc oxide and carbon black serve several purposes at the same time. Overall, a reinforcing agent is a material that increases the tensile strength by its incorporation into the compound. On this basis, carbon black, magnesium carbonate, zinc oxide, and China clay are outstanding for increasing tensile strength. Talc and similar materials add little increase in tensile strength and function almost exclusively as filler materials by making composites which often have desirable properties not possessed by each compartment. Eventually, colorants are usually organic material, and generally only small quantities are needed.

Classification of Rubber

Three major classes of a material which exhibit characteristics of rubber are (3):

1. Natural rubber

Natural rubber is of botanical origin and can be found in the juice of many plants, such as Russian dandelion, milkweed and many other shrubs and trees. It is note worthy that *Hevea brasiliensis* tree produces the best rubber latex. Even though much is known of the chemical characteristics of rubber, its chemical structure has not yet been fully duplicated in the laboratory.

2. Synthetic or American-made rubbers

Numerous attempts to duplicate natural rubber have led to the development of highly useful products known as the synthetic, or American-made, rubbers. Such materials as Buna N or S, Neoprene, Polyisobutylene, and Butyl come under this category.

3. Rubber-like plastics or plastic elastomers

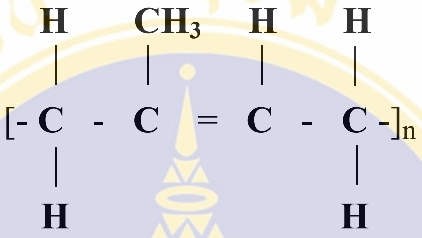
These materials exhibit the characteristics of rubber, but their basic chemical structures are different from that of natural rubber. These are silicone rubber, plasticized polyvinyls, polyethylene, flexible polyesters, ethyl cellulose, and rubber phenolics.

Natural Rubber

Natural rubber was discovered in Brazil in South America about 450 years ago as an exudated mass caused due to drying of milky liquid oozing out of certain rubber trees. Today there is not just one substance called rubber, but a class, made up of a number of materials that have the unique property of high elasticity.

Natural rubber is mainly *cis*-1,4 polyisoprene mixed with small amounts of proteins, lipids, inorganic salts, and numerous other components. The *cis*-1,4 polyisoprene is a long chain polymer which contains approximately 500 isoprene units in the natural rubber polymer chain (1) and has average molecular weight of about 500,000 g/mol (2).

Polyisoprene have two forms that occur in nature, i.e. as hard plastics called guttapercha and balata and another form as an elastomer or rubber known as hevea brasiliensis, or natural rubber. Barlow (5) suggested that more than 80% of natural rubber come from Southeast Asia. Polyisoprene has a structural formula as illustrated in Figure 2.



$$\left[-\overset{H}{\underset{H}{C}} - \overset{CH_3}{C} = \overset{H}{C} - \overset{H}{\underset{H}{C}} -\right]_n$$

Figure 2. *cis*-1,4 polyisoprene : repeating structure unit for natural rubber (2)

The *cis*-prefix indicates that the methyl group and a hydrogen atom are on the same side of the carbon-carbon double bond. The 1,4 strands for the repeating chemical units of the polymer chain covalently bonded on the first and fourth carbon atoms. The polymer chains of natural rubber are long, elongated, coiled and are in a state of continued agitation at room temperature. The arrangement of the covalent bonds in the natural rubber chain is shown in Figure 3.

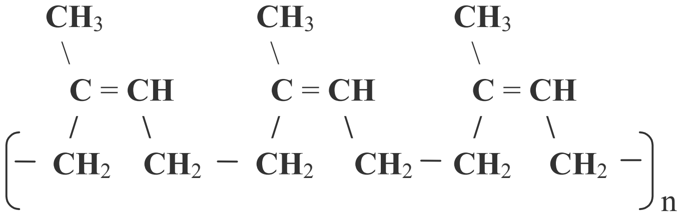


Figure 3. Segment of natural rubber polymer chain (2)

Production of Natural Rubber

Commercially, all natural rubber is derived from the latex of Hevea brasiliensis. This tree is cultivated in plantations mostly in the tropical regions in Southeast Asia: production is about equal in Malaysia and Indonesia, Thailand accounts for much of the remainder in this area (5). The plantations in this area account for over than 80% of the world's production of natural rubber. Rubber tree grows in places where the temperature is 25-35 °C, the annual rainfall exceeds 80 inch/year and low altitudes prevail. Generally, the trees are tapped when they are 5-7 years and have useful life of 25-35 years. The milky rubber-bearing fluid known as "latex" which is a suspension containing very small particles of rubber, is obtained by a process called tapping. A cut, about 22° to the horizontal, is made into the bark of tree cutting the latex vessels nearby. The latex flows for approximately 4 hours, and auto-coagulation processes are prevented by liquid ammonia.

World's Rubber Production

In 1991 Thailand replaced Malaysia as the top producer and exporter of natural rubber products.This has been the result of a re-planting program. A majority of Thailand's rubber plantations are located in the southern part of the country. Exports account for 90% of natural rubber production. The remaining 10% are utilized by local manufactures. Of the 10% of total production that is utilized domestically, 55% of this amount is processed as value-added goods. Major manufactured rubber products are tires and inner tubes for automotive. Amounts of world's rubber production are shown in Table 1.

Table 1. The world's rubber production

Production of Natural Rubber in 1994-2002

Unit : thousand tons

Country	1994	1995	1996	1997	1998	1999	2000	2001	2002**
Thailand	1717.8	1804.8	1970.4	2032.7	2075.9	2154.6	2346.4	2283.9	629.0
Indonesia	1360.8	1454.5	1527.0	1504.8	1714.0	1599.2	1501.1	1576.5	394.3
Malaysia	1100.6	1089.3	1082.5	971.1	885.7	768.9	615.5	547.0	146.5
China	374.0	424.0	430.0	444.0	450.0	460.0	445.0	451.0	120.0
Vietnam	149.0	155.0	220.0	212.0	218.0	230.0	291.0	317.0	92.0
Others	1007.8	1142.4	1210.1	1295.4	1496.4	1597.3	1541.0	1934.6	368.2
Total	5710.0	6070.0	6440.0	6460.0	6840.0	6810.0	6740.0	7110.0	1750.0

Source : The Internatinal Rubber Study Group ,July 2002.

* * : Jan.- Mar. 2002

Natural Rubber Latex

Natural rubber made by two processes, the natural rubber latex process (NRL) and the dry natural rubber process (DNR).

1. NRL process

This involves the use of natural latex in a concentrated colloidal suspension. This type of latex contains a much greater proportion of plant proteins than latex produced by the DNR process. Most immediate type reactions result from exposure to NRL products.

2. DNR process

This involves compressing the rubber at a high temperature and pressure. The plant proteins, responsible for the allergy, are denatured at these temperatures and pressures and therefore pose a lower risk than rubber made by the NRL process.

Latex is an aqueous dispersion of rubber, fresh collected of the common milkweed called whole-field latex, containing 30-40% total solids by weight and 25-40% of rubber hydrocarbon, stabilized by a small amount of protein material and fatty acids.

Natural rubber latex occurs in many plants. It is a white fluid obtained from the rubber tree, Hevea brasiliensis. It contains small particles of rubber dispersed in an aqueous medium. The aqueous medium also contains plant proteins that are thought to be responsible for triggering the allergy. It owes colloid stability to the presence of adsorbed proteins at the surface of the rubber particles. These adsorbed proteins are in the anionic state, so that the rubber particles carry negative charges at their surface (4).

Initially, the natural rubber had to be solidified within 24 hours to stop bacterial spoilage. This solidified rubber is also known as crepe. But in the 1920's it was discovered that the addition of ammonia could preserve the latex. The composition of the rubber latex is detailed in Table 2.

Table 2. Composition of the rubber latex (6)

Constituent	% Composition
Rubber particles (cis-1,4 polyisoprene)	30-40%
Protein	2-3%
Water	55-65%
Sterol glycosides	0.1-0.5%
Resins	1.5-3.5%
Ash	0.5-1.0%
Sugars	1.0-2.0%

Source: PechSiam Technotrade Ltd.

.

Natural latex is divided into 5 types as follow (6):

1. Standard grades

Natural Latex concentrate-specifications for general-purpose types.

The general-purpose grades of natural latex concentrate are subject to the requirements of international standards. They have been technically specified for many years in certain countries and the establishment of international standards indicates the substantial measure of agreement that has been achieved on the characteristics which are required of good quality natural rubber latex. The national and international standards are substantially identical in their requirements.

2. High Ammonia (HA)-centrifuged

Centrifuged natural latex preserved with ammonia only or by formaldehyde followed by ammonia. This general purpose type latex is finding application in a wide variety of products including dipped goods, extruded thread, foam rubber, adhesives and carpet backing. The ammonia (alkalinity) content of HA Latex is is not less than 0.6%* on %latex.

3. Low Ammonia (LA-TZ / TMTD/ZnO-centrifuged)

Centrifuged natural latex preserved with low ammonia with other necessary preservatives. The ammonia content of LA Latex is not exceeding 0.29%* on %latex. Low ammonia latex (LA-TZ) can replace HA latex in all normal latex application, with a little adjustment in compounding in certain cases. LA-TZ is preserved with 0.2% ammonia together with a suitable combination of zinc oxide (ZnO) and tetramethylthiuramdisulphide (TMTD) of not more than 0.1% in total, based on latex weight.

The low toxicity level and low dosage (US FDA allows up to 1.5% TMTD in products) of the secondary preservatives, which are widely used in the rubber goods manufacturing industries, ensure that this type of latex is suitable for use in all latex products including surgical goods. No additional effluent problems are expected from the use of this type of latex. The main attribute of LA-TZ latex is the greatly reduced atmospheric pollution with ammonia gas in factories. Other advantages include good film color and the elimination of the deammoniation process, e.g. in latex foam manufacture.

4. Double Centrifuged (DC)

Double centrifuged (DC) latex is a highly purified latex concentrate prepared by re-centrifuging the first centrifuged latex which has been suitably diluted. As a result, the non-rubber constituents are further reduced. Films prepared from DC latex exhibit

---

* As per ISO-2004('88E), and ASTM D1076-88

good clarity, low water absorption and high dielectric properties.DC latex finds application in surgical dipped goods and other specialized premium latex products where these properties are important. The latex is generally very stable and has good storage properties.

5. High Dry Rubber Content (DRC) Latex

A high dry rubber content (65-67%) latex is prepared by centrifugation, providing an alternative to creamed and evaporated lactices. It processes similarly to 60% DRC centrifuged latex, but dries faster. It has been used in latex thread production.

Latex is subdivided into 2 mainly grades:

1. Low Ammonia (LA) with maximum 0.29% Ammonia added
2. High Ammonia (HA) with minimum 0.60% Ammonia added

Technological Processing of Concentrated Natural Rubber Latex

The dominant area of manufacture using natural latex is the production of dipped goods. Dipped goods include a wide range of products, such as gloves, balloons, catheters, teats and dummies, all of which can be produced by immersing a rigid former into the latex compound. In this type of process the latex used must produce continuous films on the former and maintain film integrity during the drying/vulcanizing stage. Natural latex is outstanding in this respect as it can forms strong film which can withstand rapid drying. Also natural latex products are exceptional in terms of tensile strength and elongation coupled with relatively low modulus values, which are ideal characteristics for gloves, balloons and teats (7).

The Design of Latex Compounds (7)

In general, most latex compounds require three classes of additives:

1. Stabilizers to ensure adequate processing stability.
2. Vulcanizing agents to effect cross-linking of the rubber.
3. Protective agents to ensure adequate service life.

In addition, some compounds, depending on the nature of the process or on the end use, may require gelling agents, foaming agents, thickeners, flame-proofing agents, pigments, fillers, extenders, and tackifying resins.

Stabilization

The materials used as stabilizers for latex compounds are in many respects the most important additives. Unless the compound has sufficient stability to withstand the processing condition no products will be made. Natural latex already contains its own stabilizing material, proteins and soaps, and in a few cases these may be sufficient. However, the stability of the compound must be increased by the further addition of chemicals.

In latex dipping, where the compounded latex must be continually agitated to inhibit surface skin formation, extra stabilization is necessary in order to produce a mechanical stability sufficient to withstand the agitation.

Vulcanizing systems

These systems normally consist of three components, sulfur, accelerator and zinc oxide. The amount of sulfur varies with the nature of product. The modulus and hardness of the vulcanizate increase with increasing sulfur content assuming that the added sulfur is utilized in cross-links. Zinc oxide is commonly used in latex compounds to provide further activation of vulcanization and to contribute to gelation processes.

Protective agents such as antioxidants or antiozonants may be required in latex formulations depending on the nature of the product.

Synthetic or American-made rubbers

In 1955, *cis*-1,4 polyisoprene with structure closely duplicating that of natural rubber began to be produced from petroleum and coal. These polymers can be synthesized by two processes that are mostly identical except for the catalyst used.

The properties of synthesized polyisoprene are very nearly identical with those of natural rubber, and these polymers are usually preferred because of their greater cleanliness and uniformity. Furthermore, synthetic rubbers have greater oil resistance, aging resistance, and low temperature flexibility. Nevertheless, natural rubber still has low cost and better energy-storing capacity compared to the artificial one (3).

The Shell Chemical Company introduced the first commercial synthetic polyisoprene in 1960, followed by one from Goodyear in 1962, and three years later Goorich Gulf introduced their version. Technically, synthetic polyisoprene is close match for natural rubber. But when compared to its cost, it has not supersede natural rubber to any significant extent (5).

Both natural and synthetic rubbers are composed of long, thread-like molecules. The characteristic property of reversible extensibility results from the randomly coiled structure of long, folded polymer chains. Upon extension, these randomly coiled chains are elongate into an ordered structure consisting of linear chains except when cross-linked. This tendency to revert to the original disordered state upon removal of elongation stress accounts for the elastic behavior (1).

Because natural rubber latex allergy is prevalent among occupationally exposed groups and patients, synthetic or non-latex rubber is an alternative way. However, natural rubber latex continues to be used for orthodontic elastics, mainly due to their favorable characteristics and low cost.

Orthodontic Force

In general, orthodontic appliances should exert the lightest force that produces the highest rate of tooth movement with minimal tissue damage. Schwartz (8) suggested that force 20-26 grams/cm^2 of root surface which equals to blood capillaries pressure in human (15-20 mm Hg) should be applied for tipping movement, whereas for translation movement, three times as much force should be employed.

Nikolai (9) defined the optimum force as the force that yielded the maximum desirable biologic response with minimum tissue injury producing rapid tooth movement with small or no clinical discomfort.

Storey and Smith (10) defined the optimum force as an optimum range of force, ranging from 150-200 grams, which is used to produce a maximum rate of cuspid retraction while the anchor unit is stable.

Lee (11) found that the optimum force for maxillary canine retraction range between 150-260 grams which produces pressure around 165 to 185 grams/cm^2.

Quinn and Yoshikawa (12) found that the force for maximum effective canine retraction ranged between 100-200 grams that equal to the pressure of about 70-140 grams/ cm^2.

In summary, the optimum force for canine movement is ranging between 100-260 grams.

Mechanical Properties of Orthodontic Elastics

There have been many experimental studies about mechanical properties of various types of natural and synthetic orthodontic elastics.

Force extension characteristics

The force extension defined as the force at different extensions of elastic. Ware (13) investigated elastics produced by the major orthodontic supply companies and found that most of elastics were made of latex rubber. Load/extension curves were plotted and the typical curve was divided into the following sections, (a), (b), (c) and (d) (Figure 5). The two important zones were noted to be (b) and (d). In zone (b) any change in length was accompanied by a minimal load change, whereas the converse applied in zone (d), a change in length being accompanied by a large load increase. Ware stated that there was a stretched length of any elastic where the force is reasonably constant and therefore most suited to tooth movement. For normal use the extension of the elastics should be within the straight part of graph.

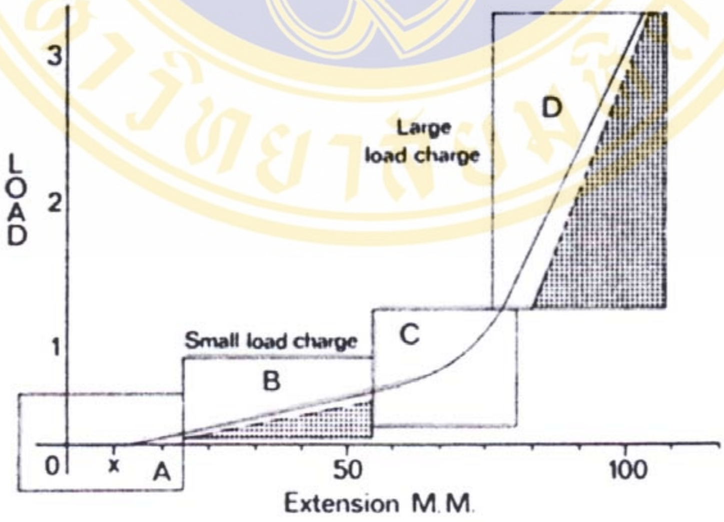


Figure 4. A typical load/ extension curve (13)

Orthodontists using elastics selected the elastic from the size and force that indicated on package. Standard index employed by orthodontic manufacturer indicated that, at three times the internal diameter, the elastic would exert the force stated on the package such as the 1/4” elastic with force indicated on package 4.5 Oz would generate the force of 4.5 Oz at an extension of 3/4”. However, many studies reported that force exerted by elastic at three times internal diameter did not correspond with standard index.

Beles et al. (14) found that three times lumen size would exert more force than indicated on the package but the force seemed to correspond with a two times lumen size. And when testing the effect of simulated oral environment in the chamber of 100% humidity and 37 °C, they found no statistically significant difference between the dry and simulated oral environment.

Kanchana and Godfrey (15) calibrated force extension characteristics of orthodontic latex elastics and also found that most of elastics did not match the specified index when extended elastic at three times the internal diameter using the dry test. But all elastics showed acceptable regularity of force extension characteristics.

Kersey et al. (16) compared 4 brands of non-latex orthodontic elastics and showed a wide range of initial force between the brands at an extension of three times the marketed internal diameter. Elastics from American Orthodontics, Ortho Organizers and Masel generated forces statistically below their marketed force levels at three times their internal diameter extensions. GAC elastics generated significantly higher forces than marketed at three times internal diameter extension.

Russell et al. (17) compared 2 brands and 3 sizes of non-latex orthodontics elastics and the equivalent latex elastics from the same manufacturer and found significant differences between the latex and the non-latex elastics and between the different brands. The results from their study suggested that the mechanical properties of elastics vary considerably with the type of material, as well as with the manufacturer.

Overall, the elastics did not generate force as indicated on package at the extension of three times internal diameter and force extension of elastic varied depend on type of material and manufacturer.

Breaking force and displacement

Breaking force of elastic is the force that elastic generates at breaking point and breaking displacement is the maximum extension of elastic before elastic failure occurs. Russell et al. (17) stated that although there are no international standards for the mechanical properties of orthodontic elastics or elastomeric material. However, Australian standards for latex orthodontic elastic bands states that the breaking strength of elastics must be greater than 150 kPa, and the extensions at which failure occur must be at least 750% of the resting internal diameter (18). Although, all the elastics met the Australian Standards for breaking force, there was a trend toward non-latex elastics having lower breaking forces than the latex elastics.

Force relaxation characteristics

As mentioned earlier, force decay or force relaxation is mainly disadvantage characteristic of elastics. Relaxation is defined as a decrease in force value carried or transmitted overtime with the element maintained in a fixed, activated state of constant strain. If elastic is stretched between two rigid points and force induced is monitored, the force magnitude will be decrease as the time goes by (Figure 5).

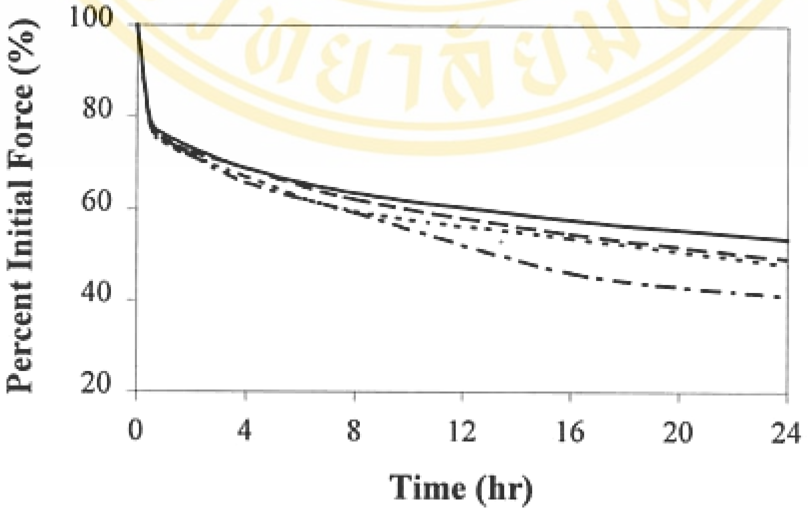


Figure 5. Force relaxation characteristic graph (16)

There were many studies that investigated force relaxation characteristic of orthodontic elastics. The results showed great variation in the amount of the force relaxation of orthodontic elastics. The loss of force occurred varied from 7.5-40%.

Newman (19) found that rubber elastics lost some forces approximately 7.5-30% after 5 days when tested under water, saliva or in the mouth. For more gentle and constant force, he suggested that elastics should be replaced every 5 days.

Bell (20) found that elastics would decrease their effectiveness in oral fluid by 20%.

Bertran (1931), cited by Bales (14), stated that during the course of a day of opening and closing the mouth, intermaxillary elastics lost about 1/3 of the elasticity. He suggested that patients should change elastics daily.

Paulson and associates (21) also found that 25% of force degradation occurred after 30 minutes.

Andreasen and Bishara (22) observed force degradation characteristics from elastics and elastomeric chains for intra-arch traction from molar to molar and found that elastic band lost about 40% of their initial force after 24 hours.

The greatest loss of force occurred immediately within ranging from 30 minutes to 3 hours (15, 21, 23-25) but the loss of force became small and almost negligible between 2 hours to 3 days. (15, 16, 25, 26)

Oliver (24) found that the greatest loss of tension occurred during the first 3 hours of activation.

Kanchana and Godfrey (15) found that there was force degradation about 30% when elastics were subjected to water immersion during the first hour, but with an average less than 7% further loss up to 3 days.

Yogosawa et al. (26) found that tensile strength of elastics in oral cavity would decrease very shortly after their insertion, but the decrement became comparatively small and almost negligible between 24 hours and 96 hours.

Bert and Droschl (25) reported that the stiffness of elastics decrease rapidly in the first three hours but after three until eight hours the stiffness did not change greatly.

Dynamic testing caused more force loss than static testing as suggested by Yogosawa et al. (26) who found a very much greater loss of force in elastics used for intermaxillary traction than in those elastics used for intramaxillary traction. The force decay of intermaxillary traction was 13-21% reduction after 6 hours in mouth, and for intramaxillary traction, there was only 8-11% reduction of force.

Barrie and Spence (23), in agreement with Yogosawa, stated that some types of elastics showed a considerable amount of creep and the force exerted by such a band would fall off even in 1 hour after use. And the situation is worse in case of elastics used for intermaxillary use. It is suggested that it might be necessary to change elastics after less than 24 hours if a reasonable force is to be maintained.

Kersey et al. (27) also found that cyclic testing caused significantly more force loss than static testing and this difference occurred primarily within the first 30 minutes and did not change the rate of force decay after this.

Furthermore, Liu et al. (28) suggested that repeated stretching significantly reduced the force magnitude since this procedure changes in the structure of elastics. However, these changes were not cumulative because their deterioration did not increase directly with the amount of re-stretching. That is, there was no statistically significant difference in the force magnitude after the elastics were stretched more than 200 times.

Bishara and Andresen (29) compared plastic alastiks with latex elastics and found that rubber elastics maintain a relatively constant force when compared with plastics alastiks in the three week period. Oral conditions affect both the appearance and the properties of both materials. The authors suggested that one should not change rubber elastics or plastic alastiks daily, but leave them in the mouth for a longer period, thus taking advantage of this relatively constant force.

Summary from earlier studies, the force relaxation of elastic was characterized by significant force reduction immediately within 30 minutes with percentage of force reduction approximately 25-30%, then the force continued to reduce with minimal amount throughout 3 days. In addition, repeated stretching of elastics from intermaxillary use caused the elastics to lose more force than static stretching.

CHAPTER 4

MATERIALS & METHODS

Materials

Latex orthodontic elastics provided from 4 sources were tested:

1. Thai(MTEC, Thailand),
2. Ormco (Ormco Corporation, Sybron Dental Specialities,Glendora,CA,USA),
3. G&H (G&H Wire Company, Hanover, Gremany),
4. Thai (colored) (MTEC, Thailand).

All samples had recent manufacturing dates and came in sealed plastic envelopes.

Study Design

There are 3 parts of experiment that are designed to measure and compare force extension, force relaxation in static and dynamic states. Fifteen samples of 1/4”, 4.5 Oz and 5/16”, 4.5 Oz were used, making a total of 360 elastics. (Table 3).

Table 3. Study design in comparing force extension, force relaxation in static and dynamic states

Measurement	Orthodontic elastics							
	Thai		Ormco		G&H		Thai (colored)	
	1/4" (4.5Oz)	5/16" (4.5Oz)	1/4" (4.5Oz)	5/16" (4.5Oz)	1/4" (4.5Oz)	5/16" (4.5Oz)	1/4" (4.5Oz)	5/16" (4.5Oz)
Force extension	15	15	15	15	15	15	15	15
Static force relaxation	15	15	15	15	15	15	15	15
Dynamic force relaxation	15	15	15	15	15	15	15	15

Methods and Procedures

Before beginning this investigation, it is necessary to know the distance which elastic is actually stretched in the mouth when used as intermaxillary traction from maxillary canine to mandibular first molar. Twenty extraction cases from Orthodontic clinic, Faculty of Dentistry, Mahidol University, were asked for measurement of the distance from hook on of the maxillary canine bracket to hook of the mandibular first molar tube. For each patient, three distances were measured and recorded.

1. When the patient occluded his/her teeth together.
2. When the patient half opened his/her mouth.
3. When the patient maximally opened his/her moth.

Means of three distances were 24, 32 and 45 mm, respectively (See appendix A). In general, patients were instructed to use elastics 24 hours except eating and brushing. When elastics are used to provide intermaxillary traction, they undergo repeated stretching as the patient talks and yawns. The extension from 24-32 mm was therefore chosen to simulate the most frequent oral function occurring daily - talking and resting. The maximum opening was not selected because yawning only occurs a few times during a day.

A measuring microscope Nikon MM-11C (Figure 6), accurate to 0.001 mm, was used to measure width, thickness, and internal diameter of elastics (Figure 7) before they were mechanically tested.

Figure 6. Measuring microscope Nikon MM-11C

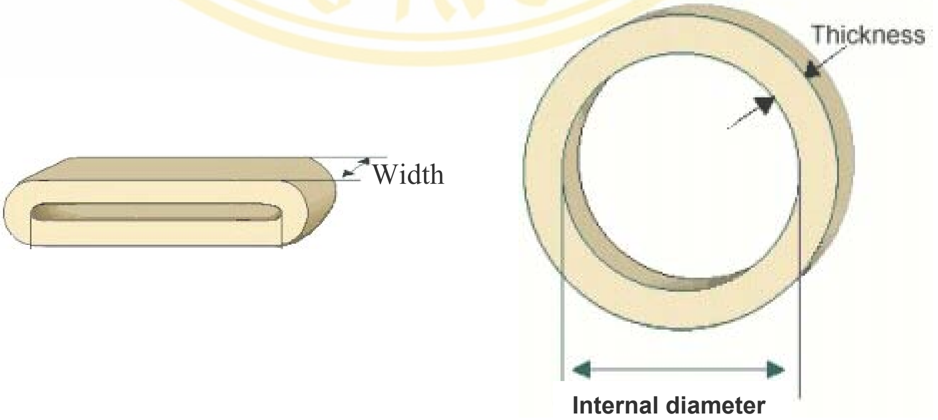


Figure 7. Width, thickness and internal diameter of an elastic, Cross-sectional area was calculated from width x thickness

To test forceextension generated by elastic, the universal testing machine, Instron Model 5566 (Figure 8) with load cell capacity of 100 Newtons was used. This machine had a self-calibrating system that performed periodically during measurement. All elastics were stretched on the Instron testing machine to test force magnitude at various distances between two hooks (diameter 0.5 mm) made of Ormco® buccal tube soldered on head of screws (Figure 9) which were connected on the stainless steel grips (Figure 10) and Instron testing machine. The load cell of Instron testing machine and crosshead was secured on the top and fixed head was fixed in the bottom. The crosshead speed was 100 mm per minute.

Figure 8. Instron testing machine

Figure 9. View of testing hooks

Figure 10. View of hooks connected to Instron testing machine

An apparatus was designed for cyclic testing of orthodontic elastics (Figure 11). This testing apparatus was custom made to simulate intermaxillary traction as when patient is talking, a geared electric motor with an eccentrically mounted axle was used. Elastics were held between hook grips attached to the axle. When the axle completed one revolution, elastics would be stretched from 24 mm to 32 mm. The frequency of the repeated stretching was 30 cycles per minute. The design was allowed to test 16 elastics submerged in 37 °C water from water bath (Figures 12 and 13) to simulate oral environment.

Figure 11. A testing apparatus to simulate intermaxillary traction

Figure 12. View of elastics in the apparatus

Figure 13. Water bath was connected to machine to control water temperature at 37 ^{o}C

Force Extension Characteristic

Width, thickness and internal diameter of each of fifteen randomly selected orthodontic elastics from 4 groups were measured. Then elastic was transferred to the Instron testing machine and stretched by means of continuous extension from slack diameter to fracture. Resultant forces versus length changes were recorded and plotted as load/deflection curve. The force extension, breaking forces and maximum displacements of each group were compared. This test was performed under room temperature (27 ^{o}C) and dry air conditions.

Force Relaxation Characteristic

Static testing

A sample size of 15 elastics per group per size was used in this study. After measuring the dimension, each of elastic was stretched and mounted in the Instron testing machine at three times the marketed internal diameter (19 mm for 1/4" size, 24 mm for 5/16" size). Forces generated by the elastics were recorded as initial forces. With a pair of tweezers, each of elastic was transferred to the simulated intermaxillary traction testing apparatus to test the force relaxation characteristic. Sixteen elastics (4 from each group) were tested at one time. Elastics were held at this stretched distance (19 mm for 1/4" size, 24 mm for 5/16" size) in the sequence of time intervals. Force measurements were made at 10 times interval: 0.25, 0.5, 0.75, 1, 1.5, 2, 4, 8, 12, 24 hours. During each measurement, a pair of tweezers was used to transfer the stretched elastics to the Instron testing machine, and vice versa.

Resultant forces versus time changes were recorded then forces and percents of force remained at different times were calculated and plotted as force extension curve to allow for comparisons among groups.

Dynamic testing

A sample size of 15 elastics per group per size was also used in the dynamic testing. After measuring the dimension, each of elastic was tested for the initial force at 24mm extension (the distance when the patient occluded the teeth together). Then the elastic was transferred with a pair of tweezers to the simulated intermaxillary traction testing apparatus and was stretched between 24-32 mm (the distance when the patient talked) with a frequency of 30 cycles per minute.

Force measurements were made at 10 times interval: 0.25, 0.5, 0.75, 1, 1.5, 2, 4, 8, 12, 24 hours. During each measurement, a pair of tweezers was used to transfer the stretched elastics to the Instron testing machine, and vice versa.

Resultant forces versus time changes were recorded then forces and percents of force remained at different times were calculated and plotted as force extension curve to allow for comparisons among groups.

Research Hypothesis

Force extension characteristic

- H_o : There is no difference in means breaking force, and maximum displacement among different groups of elastics.
- H_o : There is no difference in means force over distances among different groups of elastics.
- H_o : There is no difference in means force at 3 times internal diameter extension between each elastic group and manufacturer's specification.

Force relaxation characteristics

- H_o : There is no difference in means force remained over time among the different groups of elastics.

Statistical Analysis

Statistical analysis was performed by using Statistical Package for the Social Science (SPSS) for windows version 11.0. Results were presented as mean $\pm$ SD. One-way ANOVA and multiple comparison were used to compare the mean force-extension, breaking force, maximum displacement and percentage of force remaining among different groups. One-Sample T-test was used to compare force extension at 2 and 3 times internal diameter to manufacturer's specification. The level of statistical significant difference was considered at $P < 0.05$.

CHAPTER 5
RESULTS

There were three parts of experiment that are designed to measure and compare force extension characteristic and force relaxation characteristic in static and dynamic states among different types of elastics.

To ease for the comparison, equivalent unit of force and distance are listed below:

1 Oz = 28.35 grams
1 Newton = 101.98 grams force
1 inch = 25.4 mm

Part I: Force Extension Characteristics

Figures 14 and 15 illustrate the force extension curves for the groups of 1/4" and 5/16" elastics, respectively. It is noticed that all the curves were characterized as an elongated S-curve. The middle portion of curve, which covers a range of force appropriate for most clinical application will be focused. Tables 4 and 5 and Figures 16 and 17 demonstrated the force extension characteristic for clinical application. Statistical comparisons by one way analysis of variance (ANOVA) for the dry tests indicated significant difference ($P < 0.05$) among all groups for equivalent sizes of elastics and extensions. (Appendix C) Multiple comparisons, by Sceffe method, among the groups showed that for 1/4" internal diameter, at any given extensions, mean force generated by the Ormco elastics was statistically significant lower than those of other three groups (Table 6). The 5/16" elastics of Ormco and G&H generated forces significantly lower than Thai and Thai (colored) elastics (Table 7). There was no significant difference in force-extension values between the Ormco and G&H, and between the Thai and Thai (colored) elastics.

Tables 4 and 5 record means and standard deviations of forces in grams at different extensions for the range of elastics that may be use as reference table for clinical use.

The initial forces generated by the elastics at 2 and 3 times the internal diameter extensions can also be seen in Table 4 and 5. One sample t-tests indicated that, at 2 times diameter, all elastics had force levels that were statistically below the marketed forces. At 3 times internal diameters, all 1/4” elastics except the Thai (colored) elastics and all 5/16” elastics except the G&H elastics were statistically different from the marketed forces. This indicated that, mostly, elastics did not perform according to specifications.

Means and standard deviations of breaking forces, maximum displacements, cross-sectional areas and internal diameters of elastics are shown in Table 8 and 9.

ANOVA was used to compare four groups of elastics for statistically significant difference in breaking force, maximum displacement, cross-sectional area, and internal diameter. For the 1/4” elastic there was statistically significant differences among groups in breaking force, maximum displacement, cross-sectional area, and internal diameter. (Appendix B)

Multiple comparison by Scheffe method revealed that:

1. There was no significant difference among the Thai, Thai (colored) and Ormco elastics in means breaking forces. The G&H elastics had significant higher breaking force than other groups.

2. The Thai and Thai (colored) were not significantly different in maximum displacement from each other. The Thai and Thai (colored) differed significantly from the Ormco and G&H elastics. The G&H elastics had the largest maximum displacement.

3. The Thai elastics had means cross-sectional area being significantly larger than other three groups. There was no significant difference in cross-sectional area among the Ormco, G&H and Thai (colored) elastics.

4. The Ormco elastics had means internal diameter being larger than other three groups. There was no significant difference in internal diameter among Thai, G&H, and Th (colored) elastics.

The cross-sectional areas of 5/16” elastics were not statistically significant difference among all groups. There were statistically significant difference among groups of 5/16” elastics in breaking force, maximum displacement, and internal diameter.

Multiple comparison by Scheffe method revealed that:

1. There was no statistically significant difference among the Thai, G&H and Thai (colored) elastics with respect to breaking force. The Ormco elastics had significantly lower breaking force than other groups.

2. The G&H elastics had significantly larger maximum displacement than other groups.

3. With respect to internal diameter, the Thai and Thai (colored) elastics were not significantly different from each other. The Thai elastics had significant smaller diameter than the Ormco and G&H elastics, while the Thai (colored) had significant smaller diameter than the Ormco elastics.

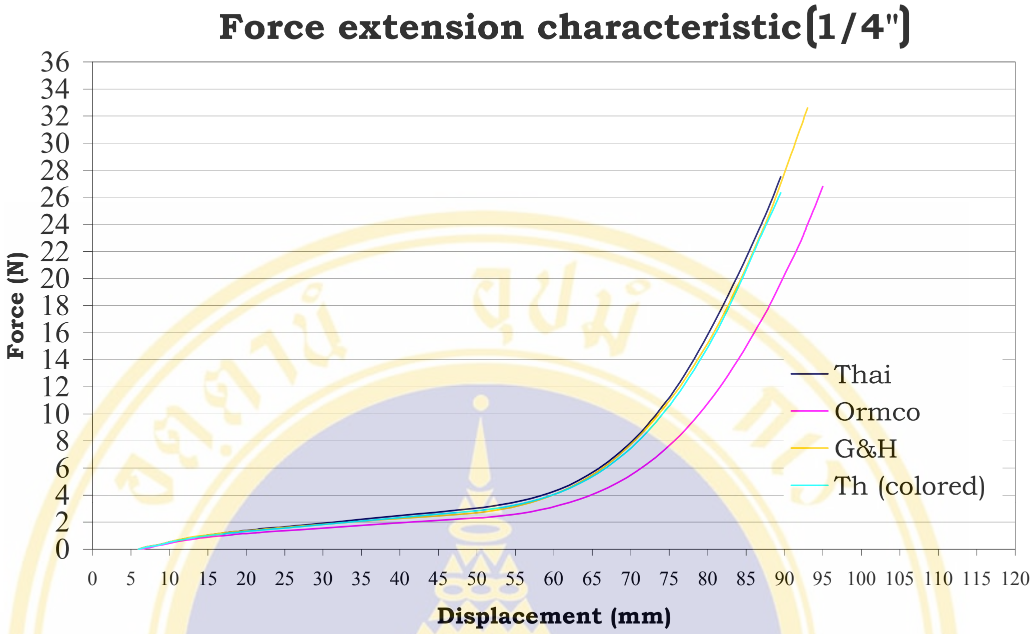


Figure 14. Graph of force extension of 1/4" elastics at different extension

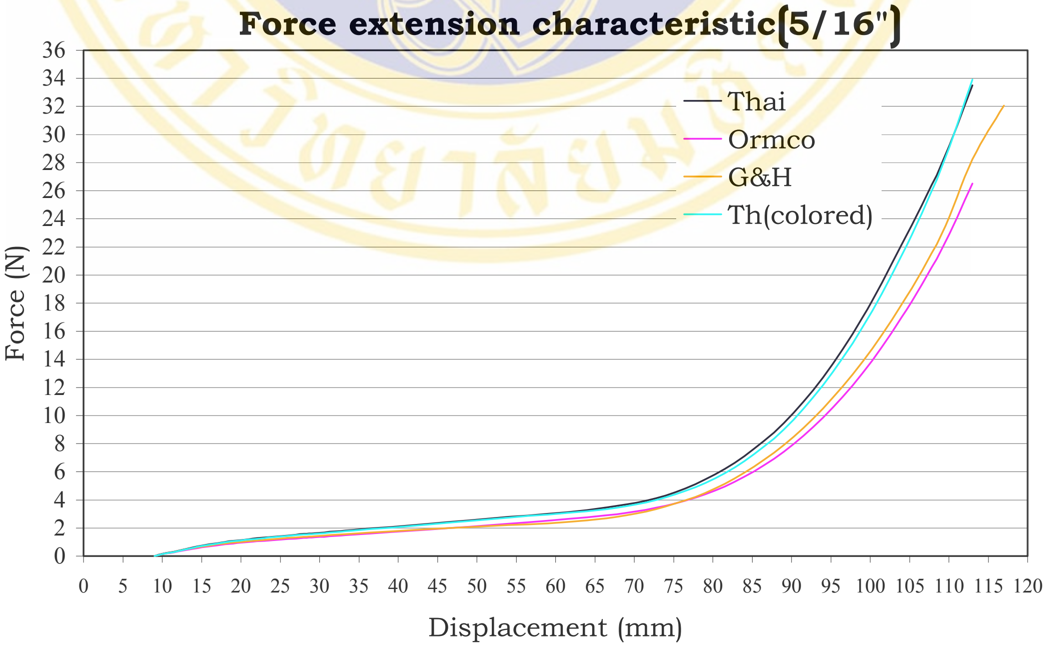


Figure 15. Graph of force extension of 5/16" elastics at different extensions

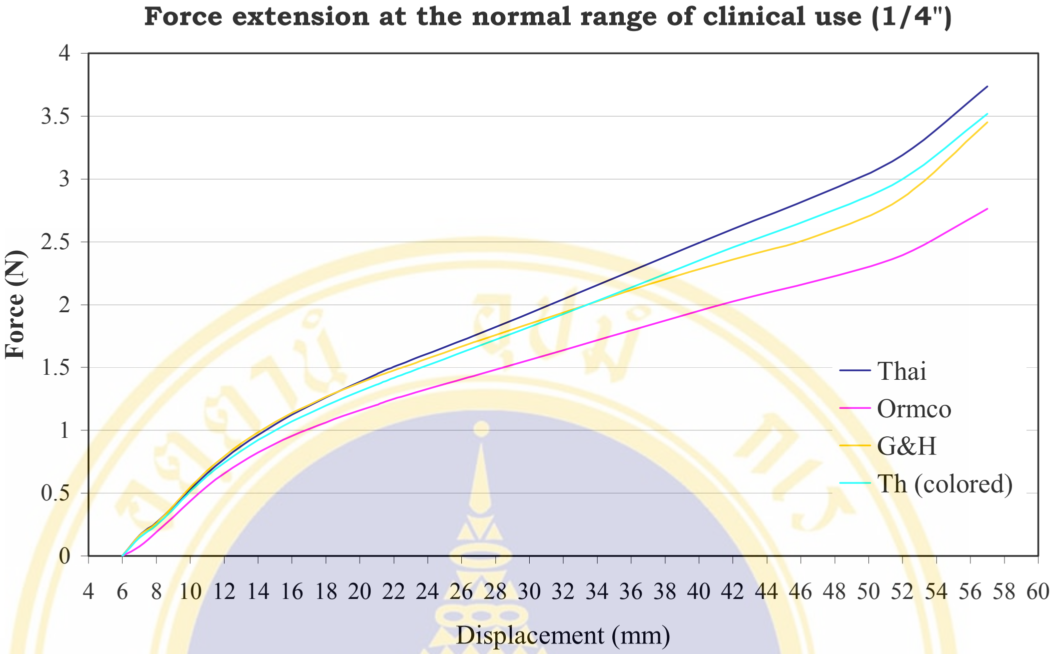


Figure 16. Graph of force extension characteristic at the normal range of clinical use of 1/4" elastics

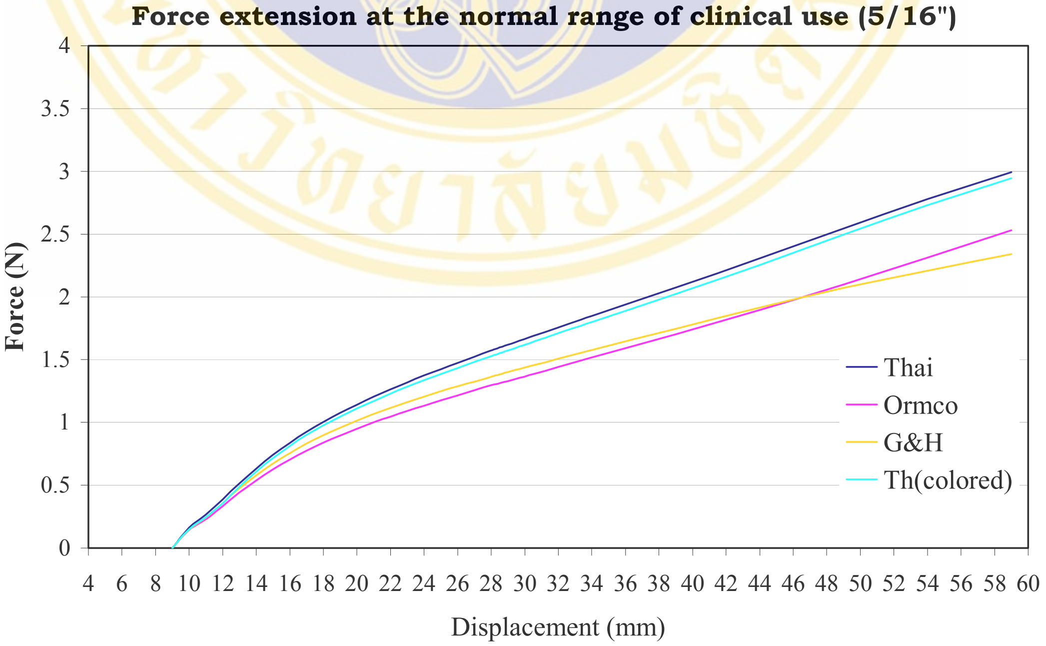


Figure 17. Graph of force extension characteristic at the normal range of clinical use of 5/16" elastics

Table 4. Mean forces at different extensions for the clinical range of 1/4" elastics

Extension (mm)	Force extension of 1/4" elastics (g)			
	Thai	**Ormco**	**G&H**	**Thai (colored)**
	Mean (SD)	Mean (SD)	Mean (SD)	Mean (SD)
13 (2xID)	89.44 (6.10)	76.09* (6.24)	90.98* (5.83)	85.40* (5.30)
16	114.58 (6.97)	97.28 (7.44)	115.69 (6.96)	109.08 (6.56)
19 (3xID)	135.18 (8.12)	113.65* (8.88)	134.57* (7.92)	127.98 (7.62)
22	153.72 (9.46)	127.58 (9.54)	150.28 (8.67)	144.51 (8.63)
27	180.12 (10.39)	147.27 (10.91)	174.43 (10.13)	170.33 (10.31)
37	237.04 (14.58)	186.96 (13.41)	219.83 (12.10)	223.34 (13.56)
47	292.73 (18.44)	223.70 (16.99)	259.74 (14.45)	275.75 (16.29)
57	381.09 (31.32)	281.71 (32.11)	351.68 (17.91)	358.70 (21.86)

* Significantly difference from manufacturer's value (127.5 g) at P < 0.05

(ID = internal diameter)

Table 5. Mean force at different extensions for the clinical range of 5/16”elastics

Extension (mm)	Thai	Ormco	G&H	Thai (colored)
	Mean (SD)	Mean (SD)	Mean (SD)	Mean (SD)
16 (2xID)	85.40* (6.02)	71.88* (7.63)	77.06* (5.44)	82.83* (4.20)
19	109.69 (7.19)	91.35 (9.41)	97.74 (6.84)	106.68 (5.26)
22	128.89 (8.44)	106.73 (10.90)	113.77 (8.07)	125.31 (6.13)
24 (3xID)	138.40* (10.90)	115.60* (11.66)	122.94 (8.74)	136.30* (6.75)
27	155.26 (10.37)	128.01 (12.94)	135.08 (9.74)	151.10 (7.50)
29	165.26 (11.40)	135.60 (13.56)	142.86 (10.42)	160.45 (7.96)
39	211.50 (15.10)	173.68 (17.86)	177.90 (12.98)	206.27 (9.99)
49	259.55 (19.67)	213.93 (21.43)	211.17 (15.39)	254.68 (12.65)
59	305.40 (23.65)	258.00 (26.17)	238.70 (17.22)	300.30 (15.25)
69	374.82 (32.25)	313.61 (32.65)	296.08 (22.35)	363.12 (16.12)

Force extension of 5/16” elastics (g)

* Significantly difference from manufacturer’s value (127.5 g) at $P < 0.05$
(ID = internal diameter)

Table 6. Comparison of mean forces of 1/4” elastics at different extensions

Extension (mm)	1/4” elastic		
	Sequence (high to low)	Homogenous subset	Sig.($P < 0.05$)
13	3, 1, 4, 2	3 = 4 = 1	(3, 4, 1) > 2
16	3, 1, 4, 2	3 = 4 = 1	(3, 4, 1) > 2
19	1, 3, 4, 2	1 = 3 = 4	(1, 3, 4) > 2
22	1, 3, 4, 2	1 = 3 = 4	(1, 3, 4) > 2
27	1, 3, 4, 2	1 = 3 = 4	(1, 3, 4) > 2
37	1, 4, 3, 2	1 = 4, 4 = 3	1 > 3 > 2, (1, 4) > 2
47	1, 4, 3, 2	1 = 4, 4 = 3	1 > 3 > 2, (1, 4) > 2
57	1, 4, 3, 2	1 = 4, 4 = 3	1 > 3 > 2, (1, 4) > 2

1 = Thai elastics; 2 = Ormco elastics; 3 = G&H elastics; 4 = Thai (colored) elastics

Sig. = Significant difference

Table 7. Comparison of mean forces of 5/16”elastics at different extensions

Extension (mm)	5/16” elastic		
	Sequence (high to low)	Homogenous subset	Sig.(P < 0.05)
16	1, 4, 3, 2	1 = 4, 4 = 3 , 3 = 2	1 > (3, 2), 4 > 2
19	1, 4, 3, 2	1 = 4, 3 = 2	(1, 4) > (3, 2)
22	1, 4, 3, 2	1 = 4, 3 = 2	(1, 4) > (3, 2)
24	1, 4, 3, 2	1 = 4, 3 = 2	(1, 4) > (3, 2)
27	1, 4, 3, 2	1 = 4, 3 = 2	(1, 4) > (3, 2)
29	1, 4, 3, 2	1 = 4, 3 = 2	(1, 4) > (3, 2)
39	1, 4, 3, 2	1 = 4, 3 = 2	(1, 4) > (3, 2)
49	1, 4, 2, 3	1 = 4, 2 = 3	(1, 4) > (2, 3)
59	1, 4, 2, 3	1 = 4, 2 = 3	(1, 4) > (2, 3)
69	1, 4, 2, 3	1 = 4, 2 = 3	(1, 4) > (2, 3)

1 = Thai elastic; 2 = Ormco elastics; 3 = G&H elastics; 4 = Thai (colored) elastics

Sig. = Significant difference

Table 8. Means of breaking forces, maximum displacements, cross-sectional areas, and internal diameters of 1/4" elastics

1/4" elastics	Breaking force (N)		Maximum displacement (mm)		Cross-sectional area (mm^2)		Internal diameter (mm)	
	Mean	(SD)	Mean	(SD)	Mean	(SD)	Mean	(SD)
Thai	26.62	(2.44)	88.60*	(2.10)	1.144*	(0.067)	6.22	(0.068)
Ormco	26.86	(3.02)	95.37	(2.24)	0.997	(0.040)	6.34*	(0.075)
G&H	32.61*	(2.91)	93.20	(1.59)	1.039	(0.033)	6.24	(0.066)
Th color	26.00	(3.37)	89.25*	(1.75)	1.043	(0.062)	6.21	(0.083)

* Significant difference at $P < 0.05$

Table 9. Means of breaking forces, maximum displacements, cross-sectional areas, and internal diameters of 5/16" elastics

5/16" elastics	Breaking force (N)		Maximum displacement (mm)		Cross-sectional area (mm^2)		Internal diameter (mm)	
	Mean	(SD)	Mean	(SD)	Mean	(SD)	Mean	(SD)
Thai	33.19	(3.38)	112.84	(3.74)	0.964	(0.088)	7.755*	(0.084)
Ormco	26.19*	(2.82)	113.19	(2.44)	1.016	(0.082)	7.963	(0.100)
G&H	32.05	(3.33)	117.08*	(3.22)	0.995	(0.041)	7.904	(0.092)
Th color	30.57	(2.05)	111.64	(1.43)	0.986	(0.047)	7.836	(0.106)

* Significant difference at $P < 0.05$

Part II : Static Force Relaxation Characteristics

To evaluate static force relaxation, the elastics were stretched at 3x internal diameter (19 mm for 1/4” elastic and 24 mm for 5/16” elastic) in 37 ^{o}C water over 24 hours. Because of the wide range of initial forces, the decay in force levels over time was compared by percentages of initial force remaining as shown in Tables 10-11 and Figures 18-19. However, the data of mean force over time is included in Appendix B.

Statistical comparisons were shown in Table 12. For the 1/4” elastics, there were significant differences of percentages of initial force from 15 minutes to 24 hours among all elastic groups ($P < 0.05$). At 15 minutes, the Ormco and G&H elastics had percentages of initial force significantly more than those of the Thai and Thai (colored) elastics. At 4 hours, the percentages of initial force among all elastic groups were not significantly different. After that, the G&H elastics began to lose more force and had percentage of force remaining from 8 to 24 hours significantly less than other groups. At 24 hours, the 1/4” elastics maintained the initial force ranking from high to low as follows: the Thai elastics maintained 77.98%, the Thai (colored) elastics maintained 76.69%, the Ormco elastics maintained 76.64% and the G&H elastics maintained 74.87% of initial force, respectively.

For 5/16” elastics, the significant difference was seen from 2 to 24 hours of testing. The Thai and Thai (colored) elastics had percentage of initial force significantly higher than those of the G&H and Ormco elastics. There were no significant differences between Thai and Thai (colored) elastics and between Ormco and G&H elastics. At 24 hours, the Thai elastics maintained 79.71%, the Thai (colored) elastics maintained 79.51%, the G&H maintained 75.18% and the Ormco maintained 75.16% of initial force, respectively.

Table 10. Mean percentage of initial force over time of 1/4” elastics for static testing

Time (Hours)	% of force remained over time of 1/4” elastics in static testing			
	Thai	**Ormco**	**G&H**	**Thai (colored)**
	Mean (SD)	Mean (SD)	Mean (SD)	Mean (SD)
0	100.00 (0.00)	100.00 (0.00)	100.00 (0.00)	100.00 (0.00)
0.25	85.35 (1.93)	88.60 (1.12)	88.00 (1.46)	84.78 (1.02)
0.5	84.14 (2.23)	86.40 (1.45)	85.85 (1.91)	83.20 (1.09)
0.75	83.48 (2.61)	85.64 (1.71)	84.66 (2.03)	82.30 (1.10)
1	82.69 (2.16)	84.57 (1.75)	83.89 (2.23)	81.65 (1.20)
1.5	82.20 (1.92)	83.33 (1.42)	82.44 (1.89)	80.86 (0.98)
2	81.51 (1.93)	82.40 (1.31)	81.35 (1.72)	80.42 (0.86)
4	80.64 (2.06)	80.33 (1.04)	79.23 (1.39)	79.57 (0.88)
8	80.17 (1.93)	79.14 (0.93)	77.65 (1.25)	79.20 (0.94)
12	79.89 (1.73)	78.58 (1.09)	76.78 (1.69)	78.87 (1.35)
24	77.98 (2.06)	76.64 (1.01)	74.87 (1.02)	76.69 (1.51)

Table 11. Mean percentage of initial force over time of 5/16” elastics for static testing

% of force remained over time of 5/16” elastics in static testing				
Time (Hours)	**Thai**	**Ormco**	**G&H**	**Thai (colored)**
	Mean (SD)	Mean (SD)	Mean (SD)	Mean (SD)
0	100.00 (0.00)	100.00 (0.00)	100.00 (0.00)	100.00 (0.00)
0.25	86.79 (1.25)	86.88 (2.58)	88.39 (3.07)	87.08 (1.69)
0.5	85.84 (1.28)	85.34 (2.70)	87.00 (3.67)	86.25 (1.94)
0.75	85.20 (1.63)	84.61 (3.06)	86.01 (3.85)	85.51 (1.69)
1	84.95 (1.49)	83.93 (3.01)	85.40 (3.83)	85.08 (2.09)
1.5	84.04 (1.42)	82.56 (2.62)	83.58 (3.29)	84.26 (2.13)
2	83.31 (1.31)	81.70 (2.14)	81.99 (2.46)	83.49 (1.64)
4	82.51 (1.44)	79.77 (1.66)	80.24 (2.26)	82.77 (1.88)
8	81.60 (1.35)	78.07 (1.84)	78.22 (2.12)	81.79 (1.65)
12	81.28 (1.26)	77.91 (1.77)	77.84 (2.14)	81.51 (1.54)
24	79.71 (1.73)	75.16 (0.94)	75.18 (1.51)	79.51 (2.19)

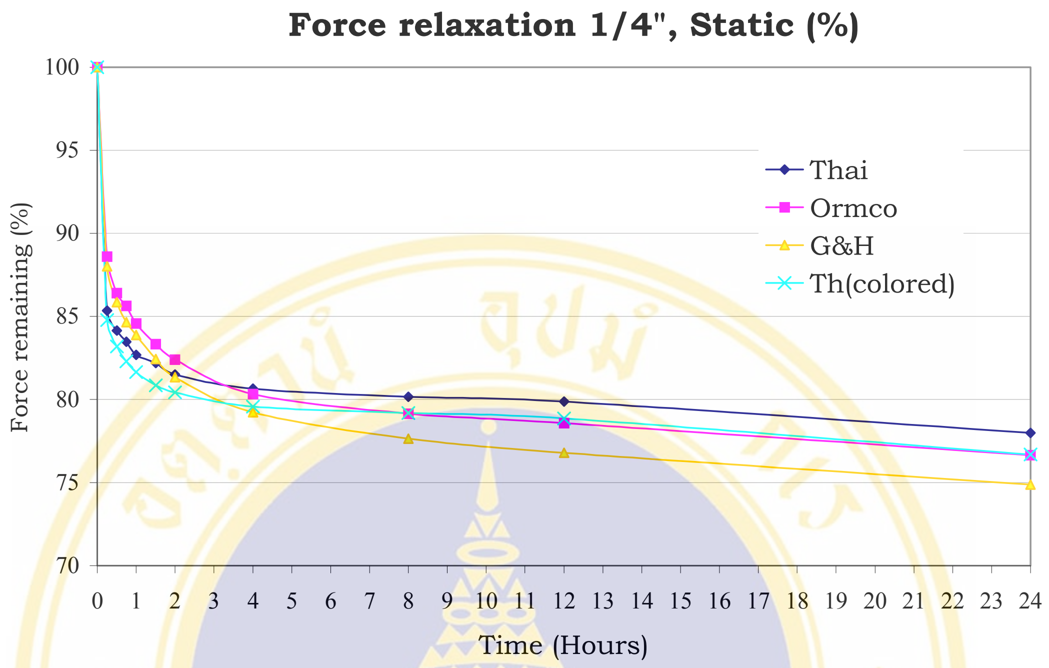


Figure 18. Graph of mean percentage of initial force over time of 1/4" elastics during static testing

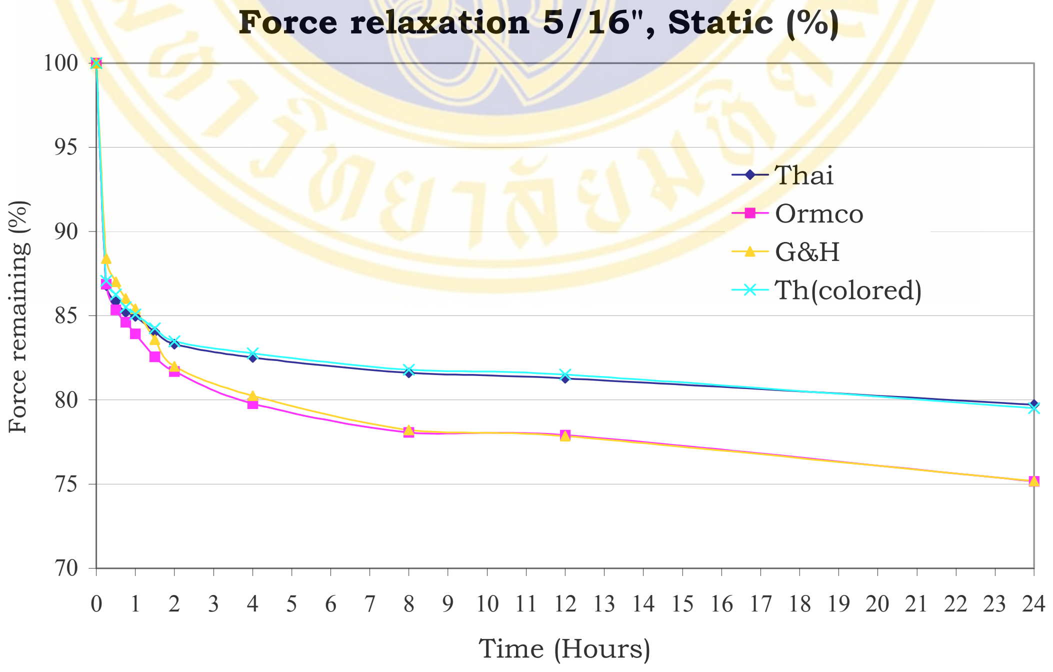


Figure 19. Graph of mean percentage of initial force over time of 5/16" elastics during static testing

Table 12. Comparisons of percent initial force over time during static testing

Time (Hours)	1/4” elastic			5/16” elastic		
	Sequence (high to low)	Homogenous subset	Sig.(P<0.05)	Sequence (high to low)	Homogenous subset	Sig.(P<0.05)
0	–	–	–	–	–	–
0.25	2 ,3, 1, 4	2 = 3, 1 = 4	(2, 3) > (1, 4)	3, 4, 1, 2	3 = 4 = 1 = 2	NS
0.5	2, 3, 1, 4	2 = 3, 3 = 1, 1 = 4	2 > (1, 4), 3 > 4	3, 4, 1, 2	3 = 4 = 1 = 2	NS
0.75	2, 3, 1, 4	2 = 3, 3 = 1, 1 = 4	2 > (1, 4), 3 > 4	3, 1, 4, 2	3 = 1 = 4 = 2	NS
1	2, 3, 1, 4	2 = 3 = 1, 1 = 4	(2, 3) > 4	1, 4, 3, 2	1 = 4 = 3, 4 = 3 = 2	NS
1.5	2, 3, 1, 4	2 = 3 = 1, 3 = 1 = 4	2 > 4	1, 4, 3, 2	1 = 4 = 3 = 2	NS
2	2, 1, 3, 4	2 = 1 = 3, 1 = 3 = 4	2 > 4	1, 4, 3, 2	1 = 4, 4 = 3, 3 = 2	1 > 3, 4 > 2, (1, 4) > 2
4	1, 2, 4, 3	1 = 2 = 4 = 3	NS	1, 4, 3, 2	1 = 4, 3 = 2	(1, 4) > (3,2)
8	1, 4, 2, 3	1 = 4 = 2	(1, 4, 2) > 3	1, 4, 3, 2	1 = 4, 3 = 2	(1,4) > (3,2)
12	1, 4, 2, 3	1 = 4 = 2	(1, 4, 2) > 3	1, 4, 3, 2	1 = 4, 3 = 2	(1,4) > (3,2)
24	1, 4, 2, 3	1 = 4 = 2	(1, 4, 2) > 3	1, 4, 2, 3	1 = 4, 2 = 3	(1,4) > (2,3)

1 = Thai elastics; 2 = Ormco elastics; 3= G&H elastics; 4= Thai (colored) elastics.
Sig. = Significant difference

NS = Not significant difference

Mean cross-sectional area and internal diameter measurements of the different elastics are shown in Tables 13-14. Statistic comparison (ANOVA) indicated significant differences in mean cross-sectional areas of 1/4" elastics among all groups. The Thai (colored) elastics had significantly smaller cross-sectional areas than did the Ormco and G&H elastics. There were no significant differences in cross-sectional areas between Thai and Thai (colored) elastics and among Thai, Ormco and G&H elastics. For 5/16" elastics, there were no significant differences in mean cross-sectional areas among all elastic groups. The internal diameters of all types of elastics were not significantly different among groups.

Table 13. Means cross-sectional area and internal diameter of 1/4"elastics during static testing

1/4" static	Cross-sectional area		Internal diameter	
	Mean	(SD)	Mean	(SD)
Thai	0.939	(0.040)	6.330	(0.079)
Ormco	0.980	(0.033)	6.290	(0.098)
G&H	0.986	(0.055)	6.282	(0.090)
Th color	0.912*	(0.053)	6.288	(0.077)

* Significant differences from Ormco and G&H at $P < 0.05$

Table 14. Means cross-sectional area and internal diameter of 5/16"elastics during static testing.

5/16" static	Cross-sectional area		Internal diameter	
	Mean	(SD)	Mean	(SD
Thai	1.026	(0.064)	7.835	(0.075)
Ormco	1.020	(0.048)	7.938	(0.162)
G&H	0.996	(0.038)	7.817	(0.110)
Th color	1.014	(0.066)	7.978	(0.280)

Part III: Dynamic Force Relaxation Characteristics

To evaluate dynamic force relaxation, all elastics were repeated stretching from 24-32 mm in 37 ^{o}C water over 24 hours. Because of the wide range of initial forces, decreases of force over time were compared by percentages of initial force remaining as shown in Tables 15-16 and Figures 20-21. However, the data of mean force over time can be seen in Appendix B.

For 1/4” elastics, statistical comparisons (Table 17) indicated significant differences among groups, from 45 minutes to 24 hours ($P < 0.05$). At 45 minutes and 2 hours the G&H elastics had significantly less percentage of initial force than the Thai and Ormco elastics. The Thai, Ormco, and Thai (colored) elastics were not significantly different from each other. Then at 12 to 24 hours, the Thai and Thai (colored) elastics had percentage of initial force significantly higher than the Ormco and G&H elastics. The G&H elastics had percentage of initial force significantly lower than other groups.

For 5/16” elastics, the significant differences were seen from 1 to 24 hours. At 1 hour, the Thai elastic had percentage of initial force higher than the Ormco elastic but was not significantly different from the Thai (colored) and G&H elastics. From 4 - 24 hours, the Thai and Thai (colored) elastics retained significantly greater percentage of initial force than the G&H and Ormco elastics.

At 24 hours, the 1/4” elastics maintained the initial force from high to low as follows: the Thai elastics maintained 77.80%, the Thai (colored) elastics maintained 77.18%, the Ormco elastics maintained 76.01% and the G&H elastics maintained 73.14% of initial force, respectively. For 5/16” elastics, the Thai elastics maintained 78.90%, the Thai (colored) elastics maintained 78.54%, the Ormco elastics maintained 75.17% and G&H elastics maintained 74.99% of initial force, respectively.

Table 15. Mean percentage of initial force over time of 1/4” elastics for dynamic testing

	% of force remained over time of 1/4” elastics in dynamic testing			
Time (Hours)	**Thai**	**Ormco**	**G&H**	**Thai (colored)**
	Mean (SD)	Mean (SD)	Mean (SD)	Mean (SD)
0	100.00 (0.00)	100.00 (0.00)	100.00 (0.00)	100.00 (0.00)
0.25	83.86 (1.37)	84.65 (1.21)	83.70 (1.11)	83.14 (1.54)
0.5	82.77 (1.22)	82.87 (0.96)	81.56 (1.24)	81.91 (1.55)
0.75	82.27 (1.56)	81.93 (1.06)	80.34 (1.13)	81.28 (1.64)
1	81.54 (1.45)	81.06 (1.24)	79.75 (1.46)	80.63 (1.68)
1.5	81.14 (1.50)	80.30 (0.96)	78.65 (1.06)	80.36 (1.58)
2	80.56 (1.63)	79.24 (1.16)	77.66 (1.63)	79.98 (1.69)
4	79.86 (1.57)	78.32 (1.27)	76.24 (1.61)	79.12 (1.66)
8	79.00 (1.33)	77.13 (1.06)	74.81 (0.92)	78.35 (1.43)
12	78.67 (1.35)	77.00 (1.11)	74.50 (0.95)	78.07 (1.51)
24	77.80 (1.57)	76.01 (1.06)	73.14 (1.03)	77.18 (1.36)

Table 16. Mean percentage of initial force over time of 5/16” elastics for dynamic testing

% of force remained over time of 5/16” elastics in dynamic testing				
Time (Hours)	**Thai**	**Ormco**	**G&H**	**Thai (colored)**
	Mean (SD)	Mean (SD)	Mean (SD)	Mean (SD)
0	100.00 (0.00)	100.00 (0.00)	100.00 (0.00)	100.00 (0.00)
0.25	84.26 (2.64)	84.07 (0.94)	85.15 (1.29)	84.38 (0.94)
0.5	83.30 (2.49)	82.27 (1.02)	83.53 (1.20)	83.34 (1.02)
0.75	82.35 (2.15)	81.09 (0.99)	82.38 (1.31)	82.00 (0.99)
1	82.12 (2.44)	80.31 (0.89)	81.97 (1.21)	81.97 (0.89)
1.5	81.51 (2.42)	79.89 (1.92)	80.56 (1.26)	81.45 (1.92)
2	81.20 (2.10)	78.93 (0.89)	79.65 (1.19)	80.99 (0.89)
4	80.54 (2.16)	77.70 (0.78)	78.36 (1.27)	80.19 (0.78)
8	80.08 (2.16)	76.71 (0.81)	76.86 (1.13)	79.72 (0.81)
12	79.50 (2.25)	76.13 (0.74)	76.57 (1.12)	79.47 (0.74)
24	78.90 (2.26)	75.17 (0.99)	74.99 (1.33)	78.54 (0.99)

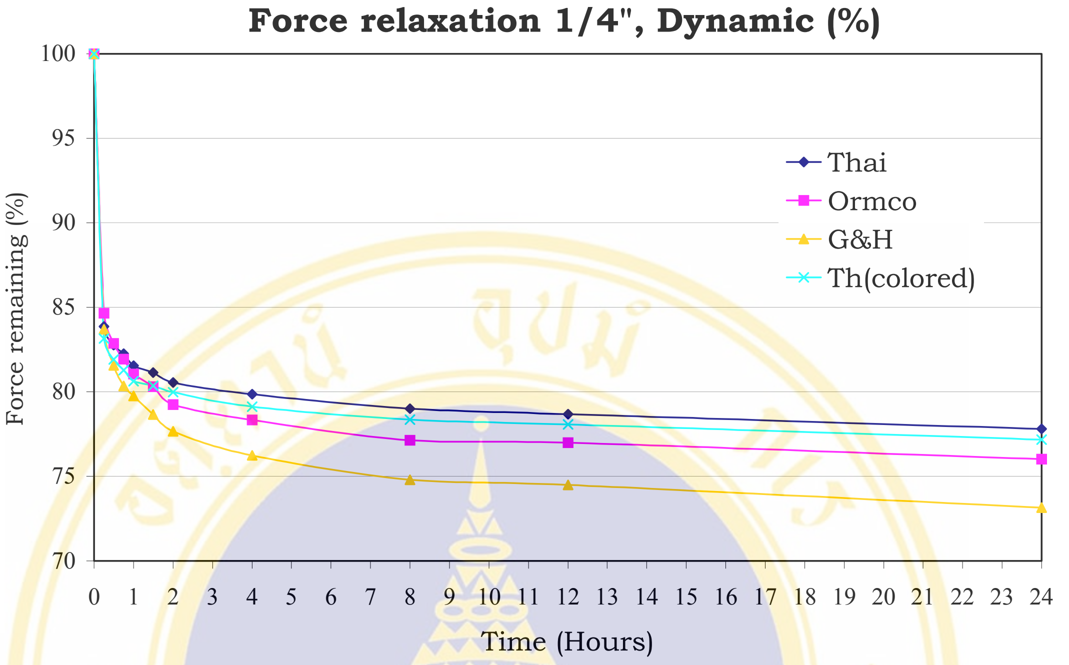


Figure 20. Graph of mean percentage of initial force over time of 1/4” elastics during dynamic testing

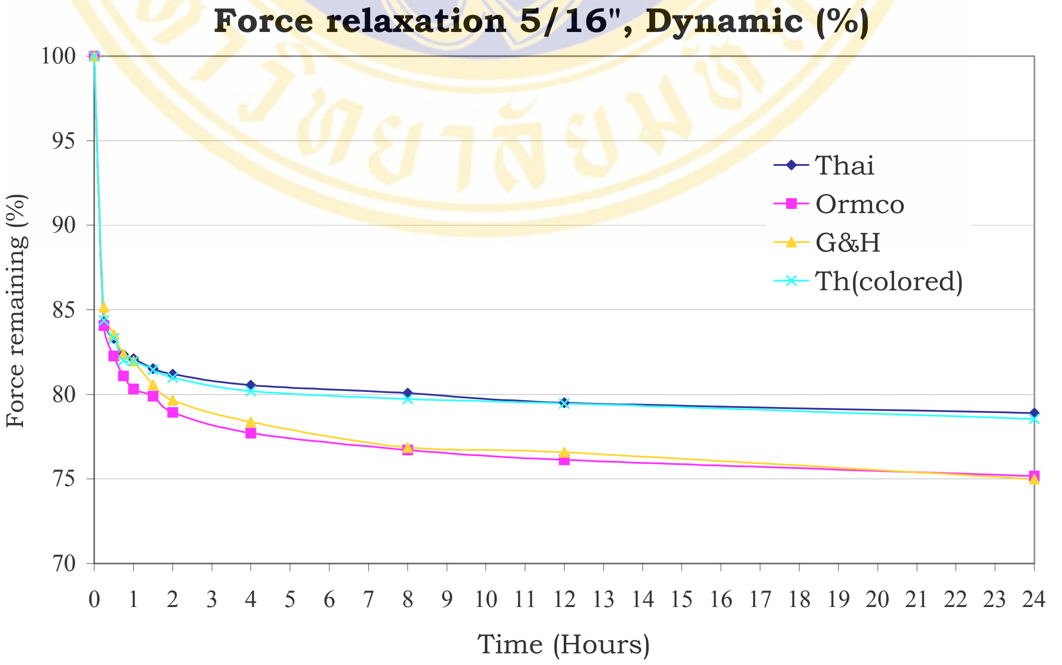


Figure 21. Graph of mean percentage of initial force over time of 5/16” elastics during dynamic testing

Table 17. Comparisons of percent initial force over time during dynamic testing

Time (Hours)	1/4” elastic			5/16” elastic		
	Sequence (high to low)	Homogenous subset	Sig. (p<0.05)	Sequence (high to low)	Homogenous subset	Sig. (P<0.05)
0	–	–	–	–	–	–
0.25	2 ,1, 3, 4	2 = 1 = 3, 1 = 3 = 4	2 > 4	3, 4, 2, 1	3 = 4 = 2 = 1	NS
0.5	2, 1, 4, 3	2 = 1 = 4 = 3	NS	3, 4, 1, 2	3 = 4 = 1 = 2	NS
0.75	1, 2, 4, 3	1 = 2 = 4, 4 = 3	(1, 2) > 3	3, 4, 1, 2	3 = 4 = 1 = 2	NS
1	1, 2, 4, 3	1 = 2 = 4, 2 = 4 = 3	1 > 3	3, 4, 1, 2	3 = 4 = 1 = 2	NS
1.5	1, 4, 2, 3	1 = 4 = 2	(1, 4, 2) > 3	4, 1, 3, 2	4 = 1 = 3 = 2	NS
2	1, 4, 2, 3	1 = 4 = 2, 2 = 3	(1, 4) > 3	4, 1, 3, 2	4 = 1 = 3 = 2	NS
4	1, 4, 2, 3	1 = 4 = 2	(1, 4, 2) > 3	4, 1, 3, 2	4 = 1, 3 = 2	(4, 1) > (3, 2)
8	1, 4, 2, 3	1 = 4, 4 = 2	1 > 2, (1, 4, 2) > 3	4, 1, 2 ,3	4 = 1, 2 = 3	(4, 1) > (2, 3)
12	1, 4, 2, 3	1 = 4, 4 = 2	1 > 2, (1, 4, 2) > 3	4, 1, 2 ,3	4 = 1, 2 = 3	(4, 1) > (2, 3)
24	1, 4, 2, 3	1 = 4, 4 = 2	1 > 2, (1, 4, 2) > 3	4, 1, 3, 2	4 = 1, 3 = 2	(4, 1) > (3, 2)

1 = Thai elastics; 2 = Ormco elastics; 3 = G&H elastics; 4 = Thai (colored) elastics.
Sig. = Significant difference
NS = Not significant difference

Means of cross-sectional areas and internal diameters of the different elastics are shown in Tables 18-19. Statistic comparison (ANOVA) indicated significant differences in mean internal diameters among all groups of 1/4” elastics. Multiple comparisons revealed that the G&H elastics had significant smaller internal diameter than the Ormco and Thai elastics and there were no significant differences between the G&H and Thai (colored) and among the Thai, Ormco and Th (colored) elastics. There was no significant difference in mean cross-sectional areas among all groups of 1/4” elastics. For 5/16” elastics, there were no significant differences in mean cross-sectional areas and internal diameter among all elastic groups.

Table 18. Means cross-sectional area and internal diameter of 1/4”elastics during dynamic testing

1/4” dynamic	**Cross-sectional area**		**Internal diameter**	
	Mean	(SD)	Mean	(SD)
Thai	0.942	(0.074)	6.292	(0.093)
Ormco	0.979	(0.046)	6.318	(0.096)
G&H	0.971	(0.043)	6.174	(0.084)
Thai (colored)	0.938	(0.069)	6.248	(0.058)

Table 19. Means cross-sectional area and internal diameter of 5/16”elastics during dynamic testing

5/16” dynamic	**Cross-sectional area**		**Internal diameter**	
	Mean	(SD)	Mean	(SD)
Thai	1.028	(0.050)	7.804	(0.092)
Ormco	1.036	(0.036)	7.817	(0.237)
G&H	1.003	(0.037)	7.871	(0.176)
Thai (colored)	1.000	(0.045)	7.878	(0.091)

CHAPTER 6

DISCUSSION

This study was conducted to test mechanical properties of elastics that related to their clinical use. Although testing in vitro is unable to represent the actual clinical use, this would give some clinical guidelines by simulating the clinical performance of intra-arch and inter-arch use of orthodontic elastics.

The elastics in this study were all homogenous with respect to indicated force on packages. They were all reported to be of medium weight which the indicated force exertion of 4.5 Oz or 127.5 g. Manufacturers specify elastics according to the standard index; at the extension approximately 3 times the internal diameter, elastic would deliver the force indicated on package.

There are many companies providing orthodontic elastics nowadays. The elastics are categorized into; light weight, medium weight and heavy weight, respectively. Furthermore, along with light, medium and heavy weight, there are various internal diameters of elastics such as 1/8", 3/16", 1/4", and 5/16". The force provided by elastics is related to the amount of extension between 2 attachment points. This extension varies from patient to patient, depending on the particular propose and on the amount of jaw movement. In addition, the same size and weight of elastic from different suppliers may indicate forces on packages differently, such as the 1/4" medium weight elastic of the Ormco has indicated forces of 3.5 and 4.5 Oz, while Masel elastics has indicated force of 4 Oz, and Unitek elastics has indicated force of 3.5 Oz. Because of various types and sizes of elastics, orthodontists must be able to choose the elastic with the force that is suitable for the required tooth movement. This means that orthodontists using elastics must know:

1. The amount of force for the particular tooth movement.
2. The forces applied to teeth at a given elastic extension.
3. The amount of force relaxation of elastic over time.

The 1/4” and 5/16” elastics were chosen to be tested in this experiment. The reason for choosing the 1/4” elastic was because it is an intermediate size and is frequently used by orthodontists as intermaxillary traction. Many authors investigated the mechanical properties of this elastic size (14, 16, 17, 27, 29, 30). However, they investigated on various brands and force exertions. Although the 5/16” elastic is less frequently used than the 1/4” elastic, but the result from the earlier pilot study conducted at Orthodontics clinic, Faculty of Dentistry, Mahidol University showed that the mean extension of elastic from the hook of the upper canine bracket to the hook of the lower first molar tube at mouth closing was 24 mm. The 3 times internal diameter of 5/16” elastics (23.8 mm) is therefore closer to this length of extension than that of the 1/4” elastics (19.05 mm). The 5/16” elastic then would rather be the size of choice for the intermaxillary traction.

The investigation of force extension of elastics in this study was performed in dry test. The author wanted to focus only on the forces generated by elastics at various displacements. An effect of humidity on elastics could not be determined. Even though the extension of elastics from the original diameter to tearing exceeded the normal clinical use. Nevertheless, it enabled to show overall characteristics of force extension curves of elastics. Furthermore, the suitable range of elastic displacement could be displayed.

It has been suggested that the characteristic of force decay of elastics depended on the environment in which the elastics were tested (31). Ash and Nikolai (32) suggested that greater force relaxation was observed in water at 37 ^{o}C compared with air at the same temperature. According to Kapila (33), the oxygen concentration and pH changes have no obvious significant effect on force degradation of elastomeric chains, whilst pre-stretching and temperature are significantly affected. Bishara & Adreasen (29) found no statistically significant difference between testing at room temperature and testing at 37 ^{o}C in water. The testing in the present study was conducted in 37 ^{o}C tap water over 24 hours to reproduce the clinical situation, which elastics were stretched in the mouth at body temperature for 24 hours. However, the results from this study might differ from those of testing in saliva because the composition and pH of tap water are different from saliva. Moreover, the saliva is composed of various enzymes that might affect to physical and mechanical properties of elastics.

In order to test force relaxation of elastics, this study was designed to divide the test into 2 situations. Firstly, the static testing which can simulate intramaxillary traction of elastics, the elastic was held between 2 constant hooks. Secondly, the dynamic testing which can simulate intermaxillary traction of elastic, the elastic was subjected to repeat stretching over time. These study designs covered the performance of elastics in the oral cavity.

In order to simulate the intermaxillary traction of elastics, the extensions between 24-32 mm were chosen. These distances represented the range of elastic extension in common clinical use based on the pilot study conducted at Orthodontic clinic, Faculty of Dentistry, Mahidol University. These extensions were in accordance with the normal range of clinical use as suggested by Bertran (1931) cited by Bales et al.(14) that intermaxillary elastics are used mainly over distances of 20-40 mm. On the other hand, Kersey et al.(16, 27) used the distances from 19.05-43.75 mm which he claimed that this length corresponded to the distances from the upper right canine to the lower right first molar between closing and maximal opening of the mouth. Barries (23) used the initial stretch ranging from 15.3-32 mm of different sizes of elastics and additional cyclic extension of 10 mm to perform dynamic state. Liu et al. (28) tested the distance from 20-50 mm. Russel et al. (17) tested the extension from original internal diameter to three times internal diameter. In comparison to previous studies, the present study used shorter extension than studies of Liu (28) and Kersey (16, 27). However, this extension corresponded to the actual stretch of intermaxillary traction of elastic during patient rest and talks.

The period of 24 hours in force relaxation test reproduced the common period of wearing elastics in clinical use. Elastics were not recommended to place in mouth over the 24 hours period due to hygienic purpose and their force might decay until they might not be sufficient to initiate tooth movement. Furthermore, their appearances were changed after being in the mouth or in humidity condition for a period of time. Some previous studies investigated elastics over the longer period such as 48 hours (23), 72 hours (15, 26) and 3 weeks (29). Most of these studies reported trend of force degradation after 24 hours to be small and almost negligible. Therefore, the period of

24 hours should be sufficient to demonstrate the force relaxation characteristic of elastics.

The mean maximum displacement of elastics could represent its abilities to withstand extension. In this experiment, for the1/4" internal diameter, the Thai and Thai (colored) elastics withstood extension less than the Ormco and G&H elastics. For the 5/16" diameter, the G&H elastics were able to withstand the longest extension. As stated by Russell et al. (17), there are no international standards for latex orthodontic elastics. Nonetheless, there are Australian Standards for latex orthodontic elastics which state that the extensions at which failure occur must be at least 750% of the resting internal diameter. All of the elastics in this present study met this specification for breaking extension. However, this breaking point is much higher than the range of clinical use.

The force extension characteristic curves of elastics in the present study were characterized by the small concave downward portion followed by the straight line, finally the concave upward curve. As suggested by Ware (13), the force within the straight portion was appropriate for tooth movement because the force is reasonably light and constant. The displacements within the straight portion of force extension curve of the 1/4" elastic were approximately 20-50 mm. and that of the 5/16"elastic were approximately 20-65 mm. These extensions were approximately 3-8 times their internal diameters. This could be assumed that for the same weight elastics, the larger internal diameter would have the larger range of use because the elastics with larger internal diameter have a longer straight portion of graph. At the straight portion of the graph, it is interesting to measure the stiffness of the elastics. The stiffness was calculated directly as the slope of the straight portion of force/displacement graph. Figure 22 demonstrated that the Thai and Thai (colored) elastics were stiffer than the Ormco and G&H elastics. In addition, it seems that the 1/4" elastics were stiffer than the 5/16" elastics. Statistical comparison indicated that there were significant differences among groups of elastics ($P < 0.01$). For the 1/4" elastics, each elastic group was significantly different from each other, the stiffness was ranging from high to low as follows: the Thai elastic, the Thai (colored) elastic, the G&H elastic, and the Ormco elastic, respectively. For the 5/16" elastics, the Thai and Thai (colored) was not significantly different and they both were significantly stiffer than the G&H and

Ormco elastics (P < 0.01). When compared between the elastic size, the stiffness of the 1/4” elastics was significantly greater than that of the 5/16” elastics (P < 0.01) except the Ormco elastics that showed the similar stiffness. Force generated by low stiffness elastic could be more predictable because with the large extension there was minimal force changed. However, this difference might not affect the clinical use.

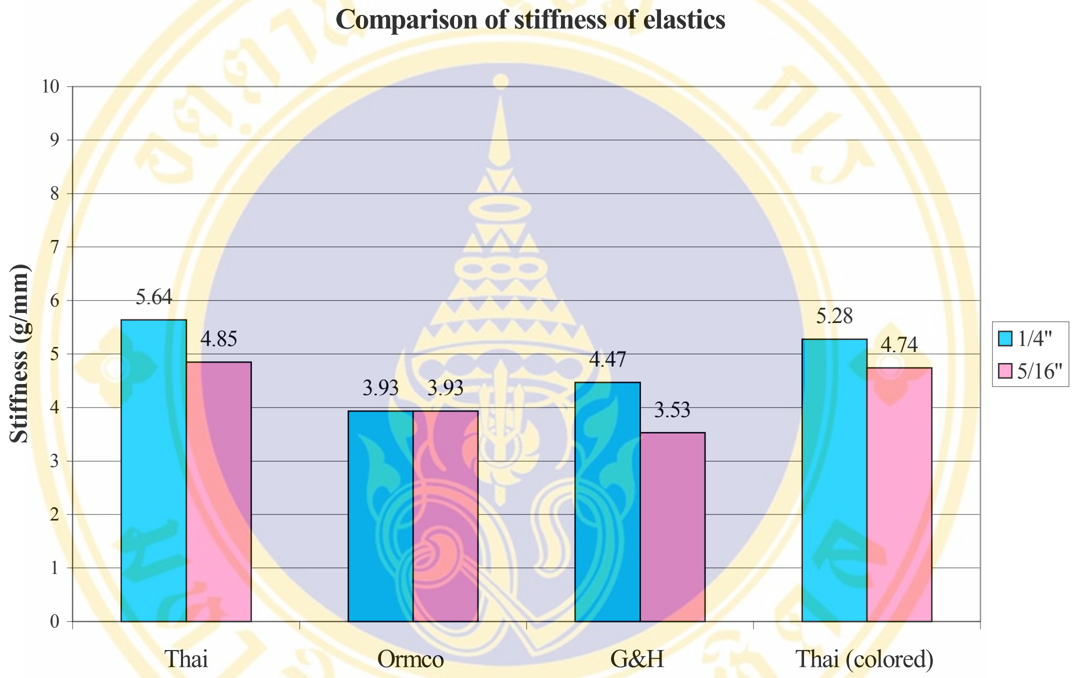


Figure 22. Bar chart of stiffness of elastics

From clinical point of view, both elastic sizes are appropriate to use as intermaxillary traction. Nevertheless, the 1/4” elastic should be used at caution in case of the extension of elastic exceeds 50 mm or is beyond the straight portion of force extension graph because the elastic would generate more or unpredictable force as a result of over stretching it exceeding its elastic limit.

The results from this study revealed that the Thai and Thai (colored) elastics generated more force in comparison to the Ormco and G&H elastics. This may be attributed to the differernces in their cross-sectional areas and internal diameters. A statistical correlation was observed between the cross-sectional area of the 1/4” elastics and their forces at 3x internal diameter (correlation coefficient = 0.635). The correlation was significant at the 0.01 level (2-tailed). The correlation between internal diameter of the 1/4” elastics and their forces at 3x internal diameter was significant at the 0.01 level (2-tailed), (correlation coefficient = -0.621). Although, the mean cross-sectional area of the 1/4” Ormco elastics was not statistically significant differrent from the G&H and Thai (colored), their mean internal diameter was significantly larger than other groups. Therefore, they might generate the least force. Similarly, for the 5/16” elastics, the Thai elastics generated more force, which may result from their smaller internal diameter. Interestingly, there was no significant correlation between cross-sectional area of 5/16” elastics and their forces. However, the correlation between internal diameter of 5/16” elastics and their forces was significant at the 0.01 level (2-tailed), (correlation coefficient = –0.370). The differences in force generated might be the result of other effects such as the differences in composition of latex rubber, that were kept secret by manufacturers, and the length of time from manufacturing date to testing date that could not be determined in this study.

Many studies investigated on an accuracy of standard force extension index, which has been set at three times internal diameter extensions. The results from previous studies (14, 15)showed higher force than the index at three times internal diameter. Conversely, Kersey (16) tested non-latex elastics and found the different results that some elastic brands generated less force than the index. The difference of forces exerted may come from the different elastic brands and the testing methods which were different in some details. The results from the present study showed that most elastics did not perform according to specifications, except the 1/4” Thai (colored) and the 5/16” G&H elastics which generated forces that were not significantly different from the index. The observation from a force-extension curve showed that the position of the standard index (3x internal diameter) was on the beginning of straight the portion. From the clinical point of view, elastics are used mainly over wide range of extensions and frequently extended over three times the internal diameter. Therefore, it is recommended that the suppliers should indicate the range of forces which elastics would actually generate within the straight portion of force extension curve besides the force index. However, this observation was able to compare only the initial force generated by elastics. The force throughout 24 hours period, which is actually generated by elastics has to be determined from the force relaxation characteristic of elastic. The amount of force relaxation should be incorporated in considering the use of elastic in order to obtain the desired force values.

The term “initial force” was given definition by Bishara and Andeasen (29) that the force values recorded during the first stretch of the material when taken from the manufacturer’s envelopes, i.e., the material was not manipulated before being stretched.

The force relaxation characteristics of elastics in the present study were all in similar pattern. In static test, the greatest percentage of force reduction occurred within 15 minutes approximately 13.0-15.0% for Thai elastics (both no-color and color-added) and approximately 11.0 -13.0% for imported elastics (Ormco and G&H). The force reduction of all elastics continue to reduce to 17.0-19.0% at 2 hours then the force remained relatively constant and percentage of force reduction at 24 hours was approximately 20.0-23.0% for Thai elastics (no-color and color-added) and approximately 23.4-25.0% for imported elastics. The percentage of force reduction in dynamic test, in comparison to static test, was slightly higher. At 15 minutes the average force reduced approximately 15.5-16.5% for Thai elastics (no-color and color-added) and 15.4-16.0% for imported elastics. The force reduced to approximately 19.0-22.0% at 2 hours for all elastics groups then the force kept reducing gradually throughout 24 hours. The percentages of force reduction at 24 hours were approximately 21.3-22.5% for Thai elastics (no-color and color-added) and approximately 24.0-26.8% for imported elastics (Ormco and G&H). The results in the present study agree with the previous studies (15, 29) that found the rate of force decay was greater in the first few hours. The drop of force with time continued for the rest of the period at a much slower rate. However, the present study demomstrated lower amount of the percentage of force loss. This finding supported the finding of Kersey et al (27) that cyclic testing caused more force loss than static testing. However, at the end of testing (24 hours) the difference between static and dynamic testing was not significant.

During the static test, the 1/4” elastics of Thai and Thai (colored) had the percentage of force remained over 24 hours not significant difference from the Ormco elastics and had higher percentage of force remained than the G&H elastics. At 24 hours, the Thai elastics maintained 77.98%, the Thai (colored) elastics maintained 76.69%, the Ormco elastics maintained 76.64% and the G&H elastics maintained 74.87% of initial force, respectively. For the 5/16” elastics, the Thai and Thai (colored) elastics had the percentage of force remained over 24 hours significant difference from the G&H and Ormco elastics. At 24 hours, the Thai elastics maintained 79.71%, the Thai (colored) elastics maintained 79.51%, the G&H elastics maintained 75.18% and the Ormco elastics maintained 75.16% of initial force, respectively.

During the dynamic test, for the 1/4” elastics, the Thai and Thai (colored) elastics had significantly higher percentage of initial force than the Ormco and G&H elastics. At 24 hours, the Thai elastics maintained 77.80%, the Thai (colored) elastics maintained 77.18%, the Ormco elastics maintained 76.01% and the G&H elastics maintained 73.14% of initial force, respectively. For the 5/16” elastics, the Thai and Thai (colored) elastics had significantly higher percentage of initial force than the Ormco and G&H elastics. At 24 hours, the Thai elastics maintained 78.90%, the Thai (colored) elastics maintained 78.54%, the Ormco elastics maintained 75.17% and the G&H elastics maintained 74.99% of initial force, respectively.

On balance, the Thai elastics both no color-added and color-added showed lower amount of percentage of force loss over 24 hours than the Ormco and G&H elastics. This finding was obvious with 5/16” elastics. When considering the stiffness of elastics, the Thai and Thai (colored) elastics were significant stiffer than the Ormco and G&H elastics. Therefore, this finding might indicate that stiffer elastics represented lesser force relaxation. Mostly, statistical correlation between the cross-sectional area of elastics and percent of force relaxation was not significant. Except, at 15 minutes, the correlation between cross-sectional area and percent of force relaxation of 1/4” elastics was significant at the 0.01 level (2-tailed), (correlation coefficient = -0.258). At 24 hours, this correlation of the 5/16” elastics was significant at the 0.05 level (2-tailed), (correlation coefficient = – 0.192). It could not be strongly indicated that the elastics with larger cross-sectional area could present lesser force relaxation. However, this trend was observed and there could be other factors affected the force relaxation of elastic such as the composition, the internal diameter and the stiffness of elastic.

The present study supported the finding of Yogosawa et al (26) that the longer elongation, the greater the force degradation. When comparing the rate of force decay, elastics with 1/4” internal diameter demonstrated more percentage of force loss than elastics with 5/16” internal diameter.

There was no previous study investigated the effect of color on mechanical properties of orthodontic elastics. The result from this study did not find the difference in force extension, force relaxation and breaking force between no color-added and color-added elastics. They both all acted in similar way.

Factors that may affect the mechanical properties of elastics are:

1. The cross sectional area.
2. The internal diameter.
3. The stiffness.
4. The composition of latex rubber.
5. The extension of elastic in clinical use.
6. Temperature.
7. Storage.
8. Age of elastics.

By the end of the present study, elastics underwent some changes in their appearance; the no-color elastics changed their color from yellowish straw color to a rather white color, and the color-added elastics changed from transparent greenish blue color to a milky green color. Furthermore, they all had swollen appearance with enlarged internal diameter.

In clinical use, repeat stretching elastics before inserting them on teeth to reduce their initial force might be required to create more consistent force delivery. And orthodontists should select the elastic with force greater than design about 20-25% to compensate for further force reduction.

The limitation of time caused the author unable to determine elastics on many sizes along with different forces level. The further investigation should be performed with various sizes, various force levels and testing in saliva or artificial saliva. In addition, further study should also be performed for testing the biocompatibility of the elastics.

CHAPTER 7

CONCLUSION

The conclusion of this study were:

1. The general graph pattern of force extension of natural latex rubber orthodontic elastics was characterized by an elongated S-curve. There were statistical significant differences in force-extension characteristics among all types of elastics. The 1/4" Ormco elastics generated significantly less force ($P < 0.05$) than the Thai, Thai (colored) and G&H elastics. The 5/16" elastics of both Thai and Thai (colored) generated significantly greater force than the Ormco and G&H elastics.

2. The standard force-extension index that was suggested by manufacturers (127.5 g) could not be applied accurately to all elastic groups, only the 1/4" Thai (colored) and the 5/16" G&H elastics met this standard index. Both the 1/4" and 5/16" Ormco elastics generated significantly less force than the index force level. All Thai elastics both non-color and colored except 1/4" colored elastic generated significantly greater force than the standard index.

3. There were statistically significant differences in breaking force and maximum extension among groups of elastics. For the 1/4" elastics, breaking forces of the Thai, Thai (colored), and Ormco elastics were not significant differences. The G&H elastics had greater breaking force than other groups. While the maximum extension of the Thai and Thai (colored) were significantly less than the Ormco and G&H elastics. For the 5/16" elastics, the breaking forces of the Thai, Thai (colored), and G&H elastics were not significant differences. The Ormco elastics had lower breaking force than other groups. While the maximum extension of the Thai, Thai (colored) and Ormco elastics were not significant differences. However, from the clinical point of view, these differences could be neglected because the breaking point of elastics exceeds the normal range of clinical use. Additionally, all elastics met the specifications of Australian Standards for latex orthodontic elastics.

4. During static testing on force relaxation characteristics the percentage of initial force was immediately reduced after initial elongation (15 minutes) and then

kept gradually decreasing throughout 24 hours period. There were significant differences among all groups of elastics in force relaxation characteristics. For the 1/4" elastics, the G&H elastics had significantly less percentage of initial force over 24 hours than other elastic groups. At 24 hours, the Thai elastics maintained 77.98%, the Thai (colored) elastics maintained 76.69%, the Ormco elastics maintained 76.64% and the G&H elastics maintained 74.87% of initial force, respectively. For the 5/16" elastics, the Thai and Thai (colored) elastics had significantly higher percentage of initial force than the Ormco and G&H elastics. At 24 hours, the Thai elastics maintained 79.71%, the Thai (colored) elastics maintained 79.51%, the G&H elastics maintained 75.18% and the Ormco elastics maintained 75.16% of initial force, respectively.

5. During dynamic testing, the pattern of force relaxation of elastics was similar to the static testing. There were significant differences in force-relaxation characteristics among all groups of elastics ($P<0.05$). For the 1/4" elastics, the Thai and Thai (colored) elastics had significantly higher percentage of initial force after 24 hours than the Ormco and G&H elastics. Furthermore, the G&H elastics had significantly lesser percentage of initial force than other groups. At 24 hours, the Thai elastic maintained 77.80%, the Thai (colored) elastics maintained 77.18%, the Ormco elastics maintained 76.01% and the G&H elastics maintained 73.14% of initial force, respectively. For the 5/16" elastics, the Thai and Thai (colored) elastics had significantly higher percentage of initial force after 24 hours than the Ormco and G&H elastics. At 24 hours, the Thai elastics maintained 78.90%, the Thai (colored) elastics maintained 78.54%, the Ormco elastics maintained 75.17% and the G&H elastics maintained 74.99% of initial force, respectively.

6. Color adding did not affect mechanical properties of Thai elastics because there was no statistically significant difference between Thai and Thai (colored) elastics in force extension, breaking force, maximum displacement and force relaxation characteristics both during static and dynamic tests.

REFFERNCES

1. Wong AK. Orthodontic elastic materials. Angle Orthod 1976;46(2):196-205.
2. Smith WF. Polymeric materials. In: Materials Science and Engineering. 2nd ed. New york: McGraw-Hill; 1993. p. 275-372.
3. Varner AM. Rubber. In: Young JF, editor. Materials and Processes. 2 ed. New York: John Wiley & Sons.; 1954. p. 535-547.
4. Sperling L. In: Introduction to Physical Polymer Science. Singapore.: John Wiley & Sons; 1993. p. 1-554.
5. Barlow FW. Elastomers : Natural rubber. In: Rubber Compounding, Principle, Materials and techniques. 2 ed. New York: Mercel Dekker; 1993. p. 9-27.
6. PechSiam Technotrade Ltd. Rubber varieties.
7. Gazeley KF. Technological processing of natural rubber latex. In: Roberts AD, editor. Natural Rubber Science and Technology. New York: Oxford University Press, New York; 1988. p. 99-105.
8. Schwarz AM. Tissue changes incidental to orthodontic tooth movement. Inter J Orthod. 1932;18:331-352.
9. Nikolai RJ. On optimum orthodontic force theory as applied to canine retraction. Am J Orthod 1975;68(3):290-302.
10. Storey E, Smith R. Forces of orthodontics and its relation to tooth movement. Aus J Dent. 1952;56:11-18.
11. Lee BW. Relationship between tooth-movement rate and estimated pressure applied. J Dent Res 1965;44:1053.
12. Quinn RS, Yoshikawa DK. A reassessment of force magnitude in orthodontics. Am J Orthod 1985;88:252-260.
13. Ware AL. A survey of elastics for control of tooth movement. 1. General properties. Aust Orthod J 1970;2(3):99-108.
14. Bales TR, Chaconas SJ, Caputo AA. Force-extension characteristics of orthodontic elastics. Am J Orthod 1977;72(3):296-302.

15. Kanchana P, Godfrey K. Calibration of force extension and force degradation characteristics of orthodontic latex elastics. Am J Orthod Dentofacial Orthop 2000;118(3):280-7.

16. Kersey ML, Glover K, Heo G, Raboud D, Major PW. An in vitro comparison of 4 brands of nonlatex orthodontic elastics. Am J Orthod Dentofacial Orthop 2003;123(4):401-7.

17. Russell KA, Milne AD, Khanna RA, Lee JM. In vitro assessment of the mechanical properties of latex and non-latex orthodontic elastics. Am J Orthod Dentofacial Orthop 2001;120(1):36-44.

18. Australian standard specification:. orthodontic latex elastic brands, AS 1240. In: Standard Association of Australia; 1973.

19. Newman GV, Orange W. Biophysical properties of orthodontic rubber elastics. J New Jersey State Dent Soc 1963;35:95-103.

20. Bell WR. A study of applied force as related to the use of elastics and coiled springs. Angle Orthod 1951;21:151-154.

21. Paulson RC, Speidel TM, Isaacson RJ. A laminagraphic study of cuspid retraction versus molar anchorage loss. Angle Orthod 1970;40(1):20-7.

22. Andreasen GF, Bishara S, Bishara SE. Comparison of alastik chains of elastics involved with intra-arch molar-to-molar forces. Am J Orthod 1971;60 (2):200-1.

23. Barrie WJ, Spence JA. Elastics--their properties and clinical applications in orthodontic fixed appliance therapy. Br J Orthod 1974;1(4):167-71.

24. Oliver WK. The effect of environtent on loss of tension in orthodontic elastics, rubber and plastic, Thesis. St.louis, Mo.: Washinton University School of dentistry; 1968.

25. Bertl WH, Droschl H. Forces produced by orthodontic elastics as a function of time and distance extended. Eur J Orthod 1986;8(3):198-201.

26. Yogosawa F, Nishimaki H, Ono E. Degradation of orthodontic elastics. J Japan Orthod Soc 1967;26:49-55.

27. Kersey ML, Glover KE, Heo G, Raboud D, Major PW. A comparison of dynamic and static testing of latex and nonlatex orthodontic elastics. Angle Orthod 2003;73(2):181-6.

28. Liu CC, Wataha JC, Craig RG. The effect of repeated stretching on the force decay and compliance of vulcanized cis-polyisoprene orthodontic elastics. Dent Mater 1993;9(1):37-40.
29. Bishara SE, Andreasen GF. A comparison of time related forces between plastic alastiks and latex elastics. Angle Orthod 1970;40(4):319-28.
30. Hwang CJ, Cha JY. Mechanical and biological comparison of latex and silicone rubber bands. Am J Orthod Dentofacial Orthop 2003;124(4):379-86.
31. Paulich F. Measuring of orthodontic forces. Am J Orthod. 1939;25:817-849.
32. Ash JL, Nikolai RJ. Relaxation of orthodontic elastomeric chains and modules in vitro and in vivo. J Dent Res 1978;57:685-690.
33. Kapila S. Commentary: Characteristics of elastomeric chains. Angle Orthod 1994;64:465-466.

Appendix A

(Raw data)

Table 20. Intermaxillary distances between the hook of upper canine bracket and the hook of lower first molar tube

Patient	Occluded teeth		Half open mouth		Maximal open mouth	
	Left	Right	Left	Right	Left	Right
1	25	25	35	35	43	43
2	25	25	33	33	44	44
3	25	27	30	32	44	47
4	23	27	32	35	42	44
5	23	25	30	32	42	41
6	23	25	34	35	44	45
7	23	23	33	33	45	45
8	22	25	31	33	42	43
9	25	25	35	34	45	45
10	22	21	28	28	43	43
11	27	25	33	35	50	51
12	21	21	29	29	55	55
13	25	26	33	35	45	45
14	22	22	30	30	42	42
15	23	23	31	31	43	43
16	25	25	32	32	42	42
17	23	23	29	29	45	45
18	25	22	32	28	45	43
19	27	25	33	31	47	46
20	20	17	30	27	47	44
Mean (Lt & Rt)	23.775		31.75		44.775	

Table 21. Raw data of force (N) at different extensions of elastics

Elastics	Displacement (mm)																
(1/4”)	6	9	13	16	19	22	27	37	47	57	67	77	87	89.5	92	93	95
Thai	0	0.327	0.82	1.075	1.273	1.424	1.679	2.184	2.693	3.313	5.365	10.56	20.39	24.68			
Thai	0	0.312	0.824	1.115	1.342	1.534	1.757	2.394	2.94	3.815	6.354	12.61	23.58				
Thai	0	0.399	0.891	1.145	1.352	1.545	1.799	2.359	2.913	3.756	6.34	12.53	23.87				
Thai	0	0.358	0.809	1.038	1.222	1.399	1.65	2.15	2.65	3.37	5.73	11.35	21.73	25.2			
Thai	0	0.365	0.82	1.054	1.239	1.414	1.65	2.16	2.66	3.5	6.05	12.3	23.5				
Thai	0	0.439	0.92	1.171	1.375	1.55	1.83	2.42	2.975	3.95	7	14	26.2				
Thai	0	0.429	0.923	1.183	1.394	1.58	1.864	2.453	3.032	4.029	7.198	14.49	27.46				
Thai	0	0.4	0.887	1.142	1.346	1.58	1.798	2.348	2.888	3.662	6.292	12.68	24.45	27.96			
Thai	0	0.461	0.949	1.21	1.42	1.62	1.845	2.47	3.062	4.077	6.965	13.71	25.8				
Thai	0	0.399	0.873	1.116	1.309	1.48	1.74	2.28	2.8	3.6	6.2	12.42	23.75				
Thai	0	0.48	1.01	1.28	1.51	1.71	2.027	2.66	3.31	4.45	7.96	16.14	26.48				
Thai	0	0.42	0.882	1.12	1.315	1.49	1.76	2.32	2.87	3.9	7.06	14.3	25				
Thai	0	0.353	0.81	1.047	1.24	1.4	1.68	2.2	2.77	3.6	6.1	12.3	23				
Thai	0	0.391	0.868	1.113	1.314	1.485	1.76	2.3	2.83	3.62	6.2	12.5	23.5				
Thai	0	0.367	0.813	1.045	1.233	1.399	1.655	2.167	2.664	3.412	5.718	11.28	21.51				
Mean	0	0.393	0.873	1.124	1.326	1.507	1.766	2.324	2.87	3.737	6.435	12.88	24.01	27.5			

Ormco	0	0.252	0.657	0.847	0.991	1.114	1.297	1.655	1.978	2.368	3.765	7.287	14.56	17.04	19.8		
Ormco	0	0.283	0.703	0.896	1.042	1.164	1.353	1.711	2.041	2.586	4.299	8.387	16.16	18.76	21.63		
Ormco	0	0.275	0.704	0.908	1.061	1.149	1.353	1.755	2.096	2.582	4.139	7.937	15.4	17.91	20.71		
Ormco	0	0.327	0.772	0.979	1.138	1.273	1.474	1.869	2.226	2.787	4.668	9.098	17.64	20.49	23.64		
Ormco	0	0.281	0.708	0.911	1.064	1.202	1.394	1.768	2.115	2.638	4.335	8.381	16.23	18.85	21.64		
Ormco	0	0.259	0.688	0.897	1.053	1.293	1.384	1.752	2.1	2.527	3.922	7.317	14.16	16.52	19.13		
Ormco	0	0.303	0.74	0.945	1.102	1.23	1.427	1.811	2.163	2.664	4.371	8.433	16.33	19.01	21.95		
Ormco	0	0.422	0.872	1.104	1.284	1.436	1.671	2.122	2.592	3.687	6.277	11.9	22.23	25.64	28		
Ormco	0	0.344	0.824	1.053	1.266	1.381	1.601	2.028	2.428	3.017	4.946	9.584	18.5	21.47	24.71		
Ormco	0	0.317	0.741	0.941	1.097	1.237	1.433	1.81	2.16	2.77	4.67	9.21	17.8	20.7	23.6		
Ormco	0	0.279	0.7	0.901	1.052	1.18	1.37	1.74	2.085	2.57	4.16	7.9	15.35	17.6	20.5		
Ormco	0	0.311	0.748	0.954	1.111	1.24	1.43	1.83	2.18	2.79	4.55	8.95	17	19.95	23		
Ormco	0	0.348	0.832	1.056	1.224	1.37	1.585	2	2.39	3.05	5.18	10	19.5	22.85	26		
Ormco	0	0.292	0.708	0.903	1.053	1.177	1.364	1.729	2.06	2.56	4.182	7.999	15.53	18.06	20.87		
Ormco	0	0.329	0.795	1.013	1.178	1.319	1.525	1.92	2.29	2.84	4.64	8.99	17.5	20.5	23.95		
Mean	0	0.308	0.746	0.954	1.114	1.251	1.444	1.833	2.194	2.762	4.54	8.758	16.93	19.69	22.61		

Table 21. Raw data of force (N) at different extensions of elastics (cont.)

Elastics (1/4”)	Displacement (mm)															
	6	9	13	16	19	22	27	37	47	57	67	77	87	89.5	92	93	95
G&H	0	0.378	0.853	1.09	1.27	1.42	1.66	2.1	2.49	3.4	6.24	12.5	23.5	27.5			
G&H	0	0.386	0.851	1.079	1.254	1.4	1.62	2.04	2.44	3.47	6.49	13	23.5	26.5			
G&H	0	0.432	0.887	1.108	1.277	1.42	1.63	2.04	2.37	3.18	5.93	11.75	22.65	25			
G&H	0	0.458	0.965	1.218	1.41	1.55	1.85	2.27	2.67	3.5	6.2	12.5	23.6	27.2			
G&H	0	0.492	1.01	1.27	1.47	1.64	1.88	2.36	2.77	3.68	6.57	13	24.4	28.17			
G&H	0	0.388	0.9	1.143	1.327	1.47	1.71	2.16	2.55	3.47	6.2	12.4	23.3	30.5			
G&H	0	0.359	0.875	1.13	1.321	1.48	1.73	2.2	2.59	3.39	5.95	11.95	22.8	26			
G&H	0	0.379	0.887	1.136	1.327	1.495	1.72	2.19	2.6	3.45	6.35	12.86	24	27			
G&H	0	0.335	0.807	1.04	1.218	1.36	1.59	2.02	2.35	3.1	5.6	11.2	20.9	23.5			
G&H	0	0.351	0.806	1.035	1.21	1.36	1.58	2	2.38	3.3	6.13	12.2	22.4	25.5			
G&H	0	0.39	0.918	1.168	1.355	1.52	1.75	2.2	2.58	3.46	6.11	11.95	22.4	25.8			
G&H	0	0.422	0.93	1.18	1.38	1.54	1.79	2.26	2.73	3.8	6.94	13.8	25.45	30			
G&H	0	0.4	0.93	1.19	1.39	1.56	1.81	2.29	2.7	3.55	6.34	12.75	24.15	27.8			
G&H	0	0.417	0.929	1.178	1.367	1.53	1.767	2.225	2.624	3.578	6.54	13	24.41	28.07			
G&H	0	0.378	0.834	1.051	1.217	1.36	1.57	1.98	2.36	3.4	6.39	12.73	23.59	27			
Mean	0	0.399	0.895	1.138	1.323	1.478	1.714	2.16	2.551	3.452	6.267	12.51	23.4	27			

Th(colored)	0	0.34	0.817	1.05	1.23	1.39	1.635	2.14	2.66	3.41	5.68	11.03	20.82	24			
Th(colored)	0	0.378	0.825	1.05	1.231	1.39	1.639	2.15	2.63	3.46	6.18	12.54	23.87	27			
Th(colored	0	0.349	0.759	0.965	1.131	1.27	1.5	1.96	2.4	3.18	5.69	11.5	21.85	25			
Th(colored)	0	0.422	0.914	1.16	1.36	1.54	1.81	2.37	2.92	3.8	6.79	13.8	26.29	29.3			
Th(colored)	0	0.374	0.845	1.083	1.27	1.43	1.69	2.21	2.73	3.56	6.24	12.63	24.2	26			
Th(colored	0	0.338	0.798	1.028	1.208	1.37	1.6	2.12	2.63	3.37	5.66	11	20.65	23.5			
Th(colored)	0	0.388	0.86	1.1	1.292	1.46	1.73	2.27	2.81	3.66	6.44	13	24.8	28.4			
Th(colored)	0	0.348	0.816	1.05	1.24	1.39	1.66	2.19	2.73	3.5	5.88	11.57	21.85	25			
Th(colored	0	0.34	0.89	1.136	1.33	1.5	1.77	2.32	2.88	3.7	6.09	11.95	22.7	26.5			
Th(colored)	0	0.33	0.76	0.975	1.146	1.31	1.53	2	2.5	3.2	5.32	10.38	19.7	25			
Th(colored)	0	0.426	0.905	1.153	1.35	1.53	1.8	2.36	2.9	3.8	6.79	13.8	26.45	30			
Th(colored	0	0.373	0.826	1.052	1.233	1.39	1.64	2.14	2.65	3.41	5.71	11.2	21.4	25			
Th(colored)	0	0.353	0.788	1.01	1.18	1.33	1.57	2.06	2.55	3.37	5.79	11.3	23				
Th(colored)	0	0.389	0.838	1.06	1.25	1.406	1.65	2.16	2.64	3.45	6.19	12.64	24.27	27.5			
Th(colored)	0	0.425	0.92	1.172	1.373	1.55	1.83	2.4	2.93	3.89	6.85	14.1	26.1				
Mean	0	0.372	0.837	1.07	1.255	1.417	1.67	2.19	2.704	3.517	6.087	12.16	23.21	26.32			

Table 21. Raw data of force (N) at different extensions of elastics (cont.)

Elastics (5/16”)	Displacement (mm)																	
	9	13	16	19	21	24	27	29	39	49	59	69	79	89	99	109	113	117
Thai	0	0.479	0.765	0.974	1.09	1.24	1.37	1.45	1.84	2.25	2.63	3.12	4.44	7.46	13.3	22.5	28.5	
Thai	0	0.504	0.793	1.004	1.12	1.27	1.4	1.49	1.89	2.31	2.68	3.19	4.57	7.82	14	23.9	30.5	
Thai	0	0.558	0.916	1.18	1.33	1.52	1.7	1.81	2.34	2.88	3.4	4.17	6.32	11.3	20.3	33.7		
Thai	0	0.49	0.806	1.04	1.16	1.33	1.47	1.57	2.01	2.4	2.9	3.83	5.92	10.2	18			
Thai	0	0.533	0.868	1.109	1.24	1.41	1.56	1.67	2.15	2.67	3.13	3.82	5.73	10.1	18.6	31.3		
Thai	0	0.567	0.924	1.18	1.32	1.5	1.66	1.77	2.26	2.78	3.28	4.03	6.1	10.8	19.5	32.5	36	
Thai	0	0.543	0.88	1.13	1.26	1.44	1.59	1.7	2.16	2.64	3.1	3.67	5.1	8.6	15.3	26	33.1	
Thai	0	0.502	0.818	1.053	1.18	1.35	1.5	1.59	2.03	2.5	2.94	3.63	5.4	9.38	16.6	27.6		
Thai	0	0.408	0.73	0.978	1.11	1.27	1.42	1.51	1.95	2.39	2.82	3.46	4.86	8.04	14.6	23.4	29.5	
Thai	0	0.539	0.874	1.116	1.25	1.14	1.57	1.66	2.13	2.63	3.1	3.81	5.85	10.4	18.5	30.8		
Thai	0	0.561	0.912	1.16	1.3	1.5	1.66	1.77	2.27	2.81	3.31	4.08	6.04	10.7	19.6			
Thai	0	0.474	0.77	0.992	1.11	1.3	1.41	1.49	1.91	2.34	2.75	3.33	4.91	8.41	14.9	25	31.4	
Thai	0	0.508	0.82	1.05	1.17	1.33	1.47	1.56	1.99	2.43	2.84	3.44	4.94	8.3	14.7	24.7	30.9	
Thai	0	0.506	0.828	1.068	1.2	1.36	1.51	1.62	2.06	2.54	2.98	3.68	5.64	10	18.1	30.1		
Thai	0	0.529	0.857	1.1	1.23	1.4	1.55	1.65	2.12	2.61	3.07	3.87	5.89	10.4	18.5	30.2		
Mean	0	0.513	0.837	1.076	1.2	1.36	1.52	1.62	2.07	2.55	3	3.68	5.45	9.46	17	27.8	33.5	
Ormco	0	0.42	0.671	0.856	0.95	1.08	1.19	1.27	1.61	1.98	2.37	2.83	3.95	6.63	11.7	19.7	24.9	
Ormco	0	0.475	0.747	0.939	1.05	1.18	1.31	1.35	1.78	2.19	2.64	3.23	4.76	8.26	14.5	24.2		
Ormco	0	0.407	0.66	0.843	0.94	1.07	1.19	1.26	1.62	1.99	2.4	2.93	4.18	7.01	12.3	20.5		
Ormco	0	0.467	0.745	0.951	1.06	1.21	1.34	1.42	1.82	2.25	2.71	3.26	4.62	7.85	13.9	23.3	29.3	
Ormco	0	0.422	0.674	0.859	0.96	1.09	1.2	1.28	1.63	2.02	2.43	2.97	4.33	7.48	13.2	21.9	27	
Ormco	0	0.484	0.784	1	1.12	1.27	1.41	1.49	1.91	2.35	2.84	3.43	4.8	7.98	14	23.4		
Ormco	0	0.373	0.607	0.773	0.86	0.98	1.09	1.16	1.48	1.83	2.21	2.67	3.82	6.52	11.5	19.2	24.2	
Ormco	0	0.45	0.726	0.921	1.03	1.17	1.29	1.37	1.75	2.16	2.6	3.16	4.47	7.5	13.2	22.1		
Ormco	0	0.451	0.72	0.914	1.02	1.15	1.28	1.35	1.73	2.13	2.57	3.12	4.47	7.64	13.5	22.5	28.5	
Ormco	0	0.391	0.63	0.804	0.9	1.02	1.13	1.2	1.53	1.88	2.26	2.74	3.9	6.57	11.4	19	23.6	
Ormco	0	0.399	0.638	0.811	0.91	1.03	1.14	1.21	1.55	1.91	2.31	2.85	4.11	6.92	12.1	20.1		
Ormco	0	0.403	0.651	0.829	0.93	1.05	1.17	1.24	1.58	1.96	2.37	2.88	4.1	6.95	12.2	20.3		
Ormco	0	0.519	0.812	1.022	1.14	1.28	1.42	1.5	1.91	2.35	2.84	3.47	4.97	8.36	14.6	24.4		
Ormco	0	0.559	0.866	1.095	1.22	1.38	1.53	1.63	2.1	2.56	3.1	3.81	5.51	9.28	16	26.7		
Ormco	0	0.383	0.642	0.819	0.91	1.04	1.15	1.22	1.55	1.91	2.3	2.78	3.88	6.5	11.4	19.1	24	
Mean	0	0.44	0.705	0.896	1	1.13	1.26	1.33	1.7	2.1	2.53	3.08	4.39	7.43	13	21.7	26.5	

Table 21. Raw data of force (N) at different extensions of elastics (cont.)

Elastics (5/16")	Displacement (mm)																	
	9	13	16	19	21	24	27	29	39	49	59	69	79	89	99	109	113	117
G&H	0	0.432	0.691	0.876	0.97	1.1	1.21	1.27	1.58	1.88	2.11	2.63	4.08	7.15	12.5	20.7	25.9	31.9
G&H	0	0.455	0.725	0.919	1.02	1.15	1.26	1.34	1.66	1.97	2.22	2.75	4.24	7.41	12.9	21.4	26.7	32.7
G&H	0	0.43	0.708	0.905	1.01	1.15	1.26	1.33	1.66	1.98	2.22	2.63	3.91	6.77	11.9	19.9	25.2	31.2
G&H	0	0.458	0.725	0.919	1.02	1.16	1.28	1.35	1.7	2	2.33	3.05	4.92	8.76	15.2	24.8	30	
G&H	0	0.446	0.71	0.904	1.01	1.14	1.25	1.32	1.65	1.97	2.24	2.85	4.55	8.03	14	23	28.5	
G&H	0	0.425	0.677	0.858	0.95	1.08	1.18	1.25	1.55	1.84	2.06	2.52	3.87	6.81	12	19.9	24.9	
G&H	0	0.484	0.758	0.958	1.07	1.2	1.32	1.39	1.73	2.05	2.32	2.85	4.4	7.73	13.5	22.4	28	
G&H	0	0.466	0.73	0.92	1.03	1.16	1.27	1.35	1.68	1.98	2.27	2.89	4.54	7.95	13.7	22.5		
G&H	0	0.533	0.844	1.07	1.2	1.35	1.49	1.57	1.96	2.33	2.63	3.25	5.02	8.84	15.5	25.7		
G&H	0	0.505	0.82	1.049	1.17	1.33	1.46	1.55	1.94	2.3	2.58	3.16	4.82	8.44	14.8	24.5	30.7	
G&H	0	0.44	0.73	0.934	1.04	1.18	1.3	1.37	1.7	2.02	2.27	2.72	4.06	7.05	12.4	20.6	25.9	
G&H	0	0.51	0.82	1.04	1.16	1.32	1.45	1.54	1.91	2.27	2.56	3.1	4.72	8.27	14.5	24	30.2	
G&H	0	0.5	0.79	0.995	1.1	1.25	1.37	1.45	1.8	2.14	2.43	3.08	4.85	8.53	14.9	24.4	30.3	
G&H	0	0.51	0.803	1.02	1.13	1.28	1.41	1.49	1.85	2.2	2.47	3.06	4.77	8.44	14.8	24.4	30.6	
G&H	0	0.52	0.804	1.01	1.12	1.25	1.37	1.45	1.8	2.13	2.4	3.01	4.73	8.35	14.6	24.2	30.2	
Mean	0	0.474	0.756	0.958	1.07	1.21	1.32	1.4	1.74	2.07	2.34	2.9	4.5	7.9	13.8	22.8	28	32.1

Th (colored)	0	0.514	0.851	1.09	1.22	1.39	1.54	1.64	2.1	2.59	3.05	3.66	5.39	9.5	17.27	29.3		
Th (colored)	0	0.534	0.883	1.132	1.26	1.44	1.59	1.69	2.17	2.68	3.16	3.82	5.55	9.76	17.63	30		
Th (colored)	0	0.485	0.838	1.092	1.23	1.4	1.56	1.65	2.12	2.62	3.1	3.66	5.11	8.7	15.74	26.91		
Th (colored)	0	0.47	0.775	1	1.12	1.28	1.42	1.5	1.94	2.39	2.82	3.49	5.14	8.81	15.7	26.6		
Th (colored)	0	0.486	0.804	1.032	1.15	1.315	1.46	1.55	1.99	2.46	2.89	3.47	5.12	9.03	16.42	27.68		
Th (colored)	0	0.517	0.857	1.1	1.23	1.4	1.56	1.65	2.12	2.62	3.07	3.69	5.32	9.24	16.87	28.66	35.91	
Th (colored)	0	0.477	0.82	1.07	1.2	1.38	1.53	1.63	2.1	2.6	3.08	3.68	5.14	8.7	15.63	26.7	33.92	
Th (colored)	0	0.445	0.756	0.99	1.11	1.27	1.41	1.5	1.93	2.38	2.8	3.39	4.9	8.29	14.75	24.92		
Th (colored)	0	0.476	0.796	1.03	1.16	1.32	1.47	1.56	2.01	2.48	2.95	3.73	5.53	9.24	16.05	26.9		
Th (colored)	0	0.49	0.807	1.03	1.16	1.32	1.465	1.56	2.01	2.47	2.91	3.48	5.14	9.07	16.6	28	34.7	
Th (colored)	0	0.524	0.857	1.096	1.226	1.4	1.54	1.64	2.1	2.6	3.07	3.65	5.29	9.29	16.87	28.6		
Th (colored)	0	0.457	0.754	0.968	1.082	1.23	1.36	1.44	1.86	2.29	2.68	3.26	4.95	8.83	16.1	27.2		
Th (colored)	0	0.476	0.794	1.02	1.14	1.3	1.44	1.53	1.96	2.43	2.87	3.45	5.02	8.73	15.86	26.9		
Th (colored)	0	0.5	0.836	1.075	1.2	1.37	1.52	1.61	2.07	2.56	3.02	3.62	5.21	9.1	16.53	28.1		
Th (colored)	0	0.46	0.755	0.967	1.082	1.23	1.36	1.45	1.86	2.29	2.7	3.36	5.1	8.9	15.9	26.9		
Mean	0	0.487	0.812	1.046	1.171	1.336	1.482	1.573	2.023	2.497	2.945	3.561	5.194	9.013	16.26	27.56	33.9	

Table 22. Raw data of width, thickness, internal diameter, maximum force and maximum displacement

	Thai 1/4"elastics				
Number	**Width**	**Thickness**	**Internal diameter**	**Maximum force**	**Maximum displacement**
1	1.31	0.92	6.24	26.137	90.167
2	1.22	0.95	6.16	23.856	86.333
3	1.25	0.95	6.24	25.924	88.333
4	1.12	0.90	6.25	29.110	92.500
5	1.20	0.92	6.24	25.203	88.333
6	1.14	0.94	6.17	26.96	87.667
7	1.25	0.94	6.17	30.738	89.167
8	1.27	0.94	6.24	27.964	89.500
9	1.29	0.95	6.29	27.954	88.333
10	1.24	0.89	6.25	31.373	92.333
11	1.31	0.94	6.11	26.479	84.833
12	1.26	0.92	6.15	24.331	85.833
13	1.19	0.88	6.33	23.546	87.833
14	1.27	0.93	6.15	26.008	88.500
15	1.19	0.93	6.33	23.669	89.333
Mean	1.23	0.93	6.22	26.620	88.600
(SD)	(0.057)	(0.02)	(0.068)	(2.443)	(2.103)

	Ormco ¼"elastics				
Number	**Width**	**Thickness**	**Internal diameter**	**Maximum force**	**Maximum displacement**
1	1.19	0.83	6.42	26.623	97.500
2	1.16	0.85	6.41	29.708	98.333
3	1.11	0.88	6.42	25.012	95.667
4	1.16	0.82	6.29	30.397	97.000
5	1.23	0.82	6.43	22.041	92.500
6	1.11	0.86	6.46	23.695	96.330
7	1.13	0.88	6.31	25.005	94.500
8	1.28	0.82	6.23	27.678	90.833
9	1.25	0.87	6.28	27.459	94.167
10	1.14	0.85	6.36	24.531	92.667
11	1.17	0.83	6.35	24.004	95.167
12	1.16	0.82	6.26	26.224	94.667
13	1.23	0.85	6.27	30.576	95.333
14	1.23	0.83	6.36	27.003	97.000
15	1.22	0.82	6.25	33.005	98.833
Mean	1.185	0.842	6.34	26.864	95.366
(SD)	(0.053)	(0.022)	(0.075)	(3.016)	(2.244)

Table 22. Raw data of width, thickness, internal diameter, maximum force and maximum displacement (cont.)

Number	G&H ¼”elastics				
	Width	**Thickness**	**Internal diameter**	**Maximum force**	**Maximum displacement**
1	1.21	0.88	6.20	31.331	92.167
2	1.18	0.84	6.27	35.667	95.500
3	1.20	0.82	6.19	28.413	91.667
4	1.20	0.86	6.22	35.841	95.167
5	1.20	0.88	6.34	33.537	92.833
6	1.22	0.88	6.18	34.535	94.833
7	1.24	0.88	6.30	35.063	95.500
8	1.24	0.87	6.21	30.759	91.833
9	1.21	0.84	6.25	30.837	94.500
10	1.18	0.88	6.35	26.109	90.333
11	1.19	0.87	6.29	32.132	93.833
12	1.19	0.84	6.13	36.902	92.667
13	1.22	0.88	6.29	32.772	92.000
14	1.20	0.86	6.21	31.791	92.167
15	1.18	0.86	6.15	33.433	93.000
Mean (SD)	1.204 (0.02)	0.862 (0.019)	6.24 (0.066)	32.608 (2.909)	93.200 (1.596)

Number	Thai (colored) 1/4”elastics				
	Width	**Thickness**	**Diameter**	**Maximum force**	**Maximum displace**
1	1.17	0.83	6.30	23.178	89.000
2	1.19	0.88	6.12	26.846	89.333
3	1.16	0.85	6.13	23.573	88.333
4	1.20	0.91	6.11	28.820	88.667
5	1.23	0.92	6.19	25.803	88.167
6	1.16	0.85	6.33	23.719	89.833
7	1.27	0.92	6.18	29.483	90.333
8	1.18	0.85	6.32	25.503	90.000
9	1.12	0.87	6.27	30.526	92.500
10	1.22	0.86	6.30	20.704	88.167
11	1.11	0.92	6.14	30.233	89.667
12	1.25	0.82	6.21	28.995	92.667
13	1.21	0.84	6.29	19.477	86.000
14	1.21	0.86	6.11	27.134	89.000
15	1.21	0.94	6.16	26.111	87.167
Mean (SD)	1.193 (0.044)	0.875 (0.038)	6.211 (0.083)	26.007 (3.374)	89.256 (1.754)

Table 22. Raw data of width, thickness, internal diameter, maximum force and maximum displacement (cont.)

Number	Thai 5/16” elastics				
	Width	**Thickness**	**Diameter**	**Maximum force**	**Maximum displace**
1	1.06	0.89	7.69	31.266	116.17
2	1.24	0.78	7.70	35.130	117.50
3	1.31	0.84	7.72	37.571	111.67
4	1.02	0.83	7.84	25.764	106.50
5	1.08	0.81	7.84	32.117	109.83
6	1.14	0.84	7.86	38.506	113.50
7	1.35	0.87	7.63	38.447	117.67
8	1.14	0.79	7.79	32.175	112.67
9	1.20	0.86	7.64	34.423	117.00
10	1.17	0.83	7.67	31.863	110.17
11	1.07	0.90	7.89	31.391	108.50
12	1.05	0.82	7.76	34.195	116.17
13	1.16	0.86	7.69	33.550	116.17
14	1.16	0.82	7.77	31.350	110.50
15	1.14	0.81	7.83	30.173	108.67
Mean	1.153	0.84	7.755	33.195	112.84
(SD)	(0.093)	(0.03)	(0.084)	(3.381)	(3.737)

Number	Ormco 5/16” elastics				
	Width	**Thickness**	**Diameter**	**Maximum force**	**Maximum displace**
1	1.21	0.85	8.06	26.503	115.33
2	1.23	0.85	8.06	24.515	109.67
3	1.16	0.82	8.02	22.956	111.33
4	1.23	0.84	8.03	31.407	115.50
5	1.18	0.83	7.94	26.450	113.33
6	1.30	0.85	7.97	25.630	110.83
7	1.11	0.84	7.98	27.251	117.00
8	1.20	0.86	7.97	24.129	110.83
9	1.27	0.80	7.83	32.085	117.00
10	1.08	0.81	7.86	23.805	114.50
11	1.22	0.82	7.72	23.169	112.17
12	1.16	0.80	8.08	23.389	112.33
13	1.30	0.85	8.04	28.418	112.50
14	1.45	0.83	7.90	27.572	110.17
15	1.25	0.80	7.98	25.536	115.33
Mean	1.223	0.83	7.963	26.188	113.19
(SD)	(0.089)	(0.021)	(0.099)	(2.816)	(2.444)

Table 22. Raw data of width, thickness, internal diameter, maximum force and maximum displacement (cont.)

Number	G&H 5/16" elastics				
	Width	**Thickness**	**Diameter**	**Maximum force**	**Maximum displace**
1	1.24	0.78	7.94	34.574	121.33
2	1.19	0.83	7.93	34.914	121.00
3	1.27	0.83	7.90	37.411	123.50
4	1.24	0.81	7.93	30.112	113.83
5	1.19	0.83	7.88	31.386	117.33
6	1.17	0.80	7.83	27.495	117.33
7	1.19	0.80	7.94	30.153	115.67
8	1.14	0.83	7.92	24.960	111.33
9	1.18	0.86	7.94	29.689	112.33
10	1.20	0.88	7.95	35.106	117.83
11	1.20	0.83	8.02	29.905	117.50
12	1.18	0.83	8.00	33.924	116.83
13	1.19	0.80	7.82	32.666	115.83
14	1.19	0.86	7.93	34.167	117.17
15	1.21	0.88	7.63	34.346	117.33
Mean (SD)	1.199 (0.031)	0.83 (0.03)	7.904 (0.092)	32.054 (3.330)	117.08 (3.222)

Number	Thai (colored) 5/16" elastics				
	Width	**Thickness**	**Diameter**	**Maximum force**	**Maximum displace**
1	1.32	0.76	8.01	31.006	114.00
2	1.28	0.80	7.67	33.032	111.67
3	1.30	0.79	7.75	34.028	112.00
4	1.28	0.81	7.97	30.649	111.83
5	1.24	0.77	7.80	29.321	111.00
6	1.25	0.80	7.73	32.292	112.50
7	1.23	0.81	7.90	38.599	115.83
8	1.35	0.84	7.87	38.618	117.33
9	1.32	0.77	7.92	29.499	113.00
10	1.20	0.82	7.71	30.204	111.50
11	1.22	0.83	7.73	34.650	113.83
12	1.26	0.82	7.85	31.674	111.17
13	1.17	0.78	7.74	32.630	113.33
14	1.16	0.78	7.89	28.703	110.17
15	1.23	0.82	7.89	30.829	110.83
Mean (SD)	1.254 (0.055)	0.8 (0.024)	7.829 (0.103)	32.382 (3.043)	112.67 (1.958)

Table 23. Raw data of force values over time of the 1/4” elastics during static testing

Time (Hours) Force(N)	0	0.25	0.5	0.75	1	1.5	2	4	8	12	24
Thai	1.147	0.958	0.941	0.939	0.927	0.927	0.921	0.904	0.896	0.899	0.856
Thai	1.247	1.071	1.056	1.050	1.050	1.036	1.024	1.017	1.000	1.005	0.954
Thai	1.066	0.954	0.935	0.933	0.927	0.923	0.912	0.903	0.894	0.886	0.847
Thai	1.344	1.102	1.089	1.081	1.072	1.065	1.049	1.027	1.020	1.017	0.982
Thai	1.114	0.963	0.943	0.936	0.927	0.93	0.908	0.908	0.906	0.903	0.861
Thai	1.148	0.984	0.976	0.962	0.962	0.959	0.95	0.93	0.913	0.916	0.876
Thai	1.132	0.996	0.984	0.970	0.970	0.957	0.951	0.931	0.924	0.919	0.897
Thai	1.135	0.983	1.005	1.021	0.964	0.945	0.94	0.935	0.934	0.920	0.899
Thai	1.142	0.958	0.940	0.930	0.921	0.927	0.916	0.913	0.908	0.902	0.903
Thai	1.173	0.994	0.972	0.962	0.953	0.952	0.945	0.936	0.938	0.933	0.928
Thai	1.134	0.949	0.932	0.922	0.910	0.909	0.903	0.888	0.893	0.885	0.883
Thai	1.096	0.942	0.925	0.920	0.912	0.903	0.907	0.889	0.891	0.890	0.877
Thai	1.141	0.974	0.965	0.944	0.943	0.936	0.937	0.930	0.930	0.916	0.912
Thai	1.061	0.883	0.871	0.859	0.855	0.853	0.845	0.832	0.836	0.844	0.832
Thai	1.168	1.001	0.971	0.962	0.962	0.948	0.942	0.957	0.933	0.933	0.930
Mean	1.1498	0.9808	0.967	0.9594	0.9503	0.9446	0.9366	0.9266	0.9210	0.9178	0.8958

Time (Hours) Force(N)	0	0.25	0.5	0.75	1	1.5	2	4	8	12	24
Ormco	1.109	1.000	0.986	0.968	0.966	0.951	0.943	0.908	0.883	0.889	0.853
Ormco	1.135	0.984	0.965	0.949	0.940	0.925	0.917	0.900	0.885	0.869	0.856
Ormco	1.218	1.104	1.064	1.056	1.054	1.039	1.014	0.983	0.970	0.961	0.929
Ormco	1.078	0.947	0.929	0.925	0.913	0.895	0.883	0.863	0.841	0.837	0.809
Ormco	1.171	1.037	1.013	1.010	0.998	0.971	0.976	0.940	0.920	0.911	0.887
Ormco	1.116	0.983	0.960	0.968	0.946	0.940	0.919	0.902	0.883	0.873	0.858
Ormco	1.170	1.056	1.045	1.025	1.030	1.002	0.981	0.967	0.945	0.939	0.903
Ormco	1.142	1.006	0.994	1.020	0.981	0.952	0.943	0.909	0.889	0.892	0.862
Ormco	1.044	0.923	0.897	0.882	0.871	0.862	0.851	0.832	0.825	0.819	0.805
Ormco	1.139	1.002	0.962	0.953	0.944	0.941	0.921	0.900	0.896	0.886	0.868
Ormco	1.050	0.932	0.901	0.883	0.872	0.862	0.862	0.840	0.830	0.831	0.809
Ormco	1.058	0.923	0.896	0.888	0.877	0.863	0.859	0.841	0.833	0.828	0.814
Ormco	1.117	0.996	0.963	0.944	0.938	0.931	0.922	0.901	0.897	0.886	0.867
Ormco	1.130	0.993	0.959	0.953	0.929	0.924	0.911	0.897	0.893	0.878	0.866
Ormco	1.134	1.012	0.994	0.978	0.965	0.955	0.953	0.924	0.916	0.911	0.897
Mean	1.121	0.993	0.969	0.960	0.948	0.934	0.924	0.900	0.887	0.881	0.859

Table 23. Raw data of force values over time of the 1/4” elastics during static testing (cont.)

Time (hours) Force(N)	0	0.25	0.5	0.75	1	1.5	2	4	8	12	24
G&H	1.204	1.078	1.067	1.049	1.039	1.026	1.010	0.983	0.950	0.95	0.912
G&H	1.189	1.071	1.054	1.044	1.037	1.015	1.000	0.969	0.953	0.944	0.903
G&H	1.086	0.966	0.942	0.938	0.944	0.910	0.906	0.874	0.857	0.853	0.813
G&H	1.206	1.079	1.069	1.055	1.044	1.029	1.005	0.974	0.950	0.945	0.906
G&H	1.213	1.069	1.062	1.027	1.024	1.011	0.983	0.954	0.936	0.925	0.895
G&H	1.065	0.931	0.911	0.905	0.897	0.868	0.854	0.833	0.818	0.811	0.774
G&H	1.206	1.068	1.043	1.042	1.020	1.003	0.985	0.957	0.930	0.931	0.897
G&H	1.235	1.073	1.034	1.020	1.007	0.998	0.986	0.962	0.949	0.945	0.925
G&H	1.289	1.155	1.109	1.090	1.098	1.054	1.051	1.029	1.007	1.003	0.984
G&H	1.127	1.002	0.970	0.960	0.944	0.937	0.927	0.901	0.890	0.820	0.861
G&H	1.102	0.941	0.919	0.905	0.900	0.879	0.868	0.861	0.839	0.833	0.812
G&H	1.054	0.910	0.883	0.868	0.858	0.855	0.842	0.818	0.800	0.792	0.783
G&H	1.250	1.100	1.053	1.031	1.018	1.016	1.005	0.976	0.961	0.950	0.936
G&H	1.197	1.036	1.009	0.996	0.980	0.968	0.963	0.944	0.929	0.919	0.902
G&H	1.244	1.073	1.044	1.027	1.011	0.997	0.988	0.964	0.951	0.949	0.930
Mean	1.178	1.037	1.011	0.997	0.988	0.971	0.958	0.933	0.915	0.905	0.882

Time (Hours) Force(N)	0	0.25	0.5	0.75	1	1.5	2	4	8	12	24
Th(colored)	1.117	0.956	0.940	0.932	0.925	0.917	0.91	0.893	0.889	0.886	0.846
Th(colored)	1.180	0.998	0.983	0.978	0.968	0.963	0.951	0.94	0.928	0.92	0.887
Th(colored)	1.102	0.925	0.919	0.916	0.903	0.893	0.89	0.871	0.867	0.854	0.823
Th(colored)	1.091	0.926	0.908	0.901	0.882	0.876	0.87	0.857	0.845	0.846	0.818
Th(colored)	1.147	0.977	0.959	0.950	0.949	0.935	0.925	0.908	0.906	0.904	0.867
Th(colored)	1.085	0.927	0.918	0.906	0.911	0.888	0.885	0.879	0.863	0.893	0.828
Th(colored)	1.197	1.040	1.010	1.000	0.990	0.979	0.966	0.964	0.952	0.955	0.898
Th(colored)	1.104	0.945	0.935	0.915	0.902	0.896	0.89	0.887	0.888	0.863	0.842
Th(colored)	1.123	0.961	0.942	0.932	0.922	0.92	0.918	0.909	0.914	0.909	0.893
Th(colored)	1.075	0.903	0.884	0.870	0.864	0.858	0.858	0.854	0.841	0.844	0.832
Th(colored)	1.292	1.085	1.065	1.049	1.042	1.032	1.029	1.025	1.015	1.014	1.002
Th(colored)	1.181	0.989	0.965	0.962	0.951	0.941	0.938	0.932	0.933	0.926	0.924
Th(colored)	1.252	1.068	1.042	1.025	1.03	1.017	1.008	0.999	1.000	0.997	0.987
Th(colored)	1.133	0.953	0.930	0.922	0.913	0.906	0.912	0.895	0.892	0.886	0.876
Th(colored)	1.125	0.932	0.912	0.899	0.894	0.890	0.884	0.876	0.892	0.872	0.874
Mean	1.147	0.972	0.954	0.944	0.936	0.927	0.922	0.913	0.908	0.905	0.880

Table 24. Raw data of force values over time of the 5/16” elastics during static testing.

Time (Hours) Force(N)	0	0.25	0.5	0.75	1	1.5	2	4	8	12	24
Thai	1.213	1.068	1.060	1.053	1.053	1.042	1.028	1.012	1.000	0.992	0.967
Thai	1.286	1.137	1.135	1.123	1.121	1.105	1.089	1.083	1.071	1.072	1.032
Thai	1.334	1.152	1.138	1.136	1.128	1.114	1.105	1.086	1.076	1.076	1.031
Thai	1.285	1.124	1.110	1.107	1.103	1.087	1.063	1.052	1.041	1.035	1.000
Thai	1.245	1.085	1.066	1.059	1.050	1.044	1.029	1.018	1.015	1.011	0.961
Thai	1.341	1.150	1.148	1.145	1.123	1.106	1.098	1.086	1.065	1.069	1.045
Thai	1.198	1.063	1.050	1.049	1.045	1.027	1.012	1.012	0.998	0.995	0.965
Thai	1.204	1.030	1.011	1.001	1.008	1.000	0.988	0.981	0.975	0.959	0.952
Thai	1.243	1.070	1.066	1.050	1.059	1.040	1.037	1.024	1.013	1.014	1.005
Thai	1.258	1.069	1.058	1.028	1.038	1.023	1.016	1.003	0.998	1.000	0.985
Thai	1.152	0.997	0.983	0.980	0.969	0.963	0.963	0.948	0.938	0.939	0.939
Thai	1.172	1.005	0.999	0.986	0.991	0.984	0.979	0.974	0.958	0.948	0.947
Thai	1.177	1.002	0.991	0.983	0.974	0.969	0.968	0.963	0.949	0.946	0.940
Thai	1.293	1.132	1.113	1.107	1.107	1.102	1.095	1.087	1.073	1.067	1.055
Thai	1.131	0.999	0.981	0.982	0.974	0.967	0.966	0.958	0.947	0.938	0.938
Mean	1.235	1.072	1.061	1.053	1.049	1.038	1.029	1.019	1.008	1.004	0.984

Time (hours) Force(N)	0	0.25	0.5	0.75	1	1.5	2	4	8	12	24
Ormco	1.186	1.079	1.046	1.043	1.043	1.015	0.993	0.970	0.941	0.938	0.890
Ormco	1.160	1.043	1.023	1.020	1.004	1.001	0.963	0.940	0.914	0.913	0.872
Ormco	1.226	1.097	1.097	1.096	1.083	1.056	1.003	0.991	0.988	0.980	0.910
Ormco	1.247	1.121	1.111	1.114	1.105	1.075	1.056	1.031	1.018	0.999	0.950
Ormco	1.148	1.005	0.979	0.974	0.966	0.949	0.929	0.904	0.891	0.897	0.843
Ormco	1.165	1.037	1.018	1.014	1.003	0.986	0.965	0.955	0.923	0.927	0.893
Ormco	1.128	0.998	0.989	0.967	0.964	0.943	0.911	0.900	0.891	0.898	0.855
Ormco	1.230	1.046	1.024	1.014	1.010	0.995	0.990	0.983	0.957	0.961	0.931
Ormco	1.185	1.010	0.991	0.978	0.970	0.958	0.952	0.938	0.929	0.917	0.895
Ormco	1.176	0.980	0.971	0.952	0.942	0.932	0.925	0.912	0.903	0.896	0.883
Ormco	1.245	1.072	1.052	1.040	1.036	1.015	1.022	1.001	0.978	0.984	0.951
Ormco	1.182	1.014	0.987	0.982	0.970	0.955	0.946	0.934	0.906	0.909	0.886
Ormco	1.205	1.019	0.997	0.988	0.981	0.963	0.962	0.943	0.910	0.913	0.904
Ormco	1.133	0.946	0.925	0.913	0.908	0.898	0.981	0.875	0.849	0.845	0.833
Ormco	1.176	0.992	0.976	0.963	0.952	0.950	0.937	0.920	0.897	0.887	0.879
Mean	1.186	1.030	1.012	1.004	0.996	0.979	0.969	0.946	0.926	0.924	0.892

Table 24. Raw data of force values over time of the 5/16” elastics during static testing (cont.)

Time (Hours) Force(N)	0	0.25	0.5	0.75	1	1.5	2	4	8	12	24
G&H	1.103	1.004	0.988	1.009	1.000	0.961	0.942	0.904	0.878	0.875	0.824
G&H	1.168	1.062	1.064	1.041	1.035	1.030	0.993	0.968	0.939	0.940	0.891
G&H	1.075	0.987	0.986	0.972	0.968	0.930	0.900	0.878	0.851	0.843	0.806
G&H	1.079	0.983	0.981	0.968	0.960	0.927	0.902	0.879	0.861	0.853	0.804
G&H	1.066	0.975	0.950	0.963	0.949	0.925	0.893	0.871	0.850	0.842	0.800
G&H	1.148	1.055	1.042	1.008	1.003	0.985	0.964	0.940	0.914	0.918	0.875
G&H	1.063	0.956	0.953	0.939	0.937	0.917	0.874	0.869	0.852	0.843	0.816
G&H	1.023	0.912	0.891	0.883	0.876	0.860	0.856	0.843	0.822	0.813	0.799
G&H	1.034	0.918	0.902	0.887	0.881	0.864	0.859	0.849	0.825	0.828	0.802
G&H	1.068	0.903	0.876	0.868	0.861	0.853	0.847	0.835	0.805	0.807	0.793
G&H	1.062	0.894	0.885	0.870	0.876	0.849	0.839	0.826	0.814	0.808	0.790
G&H	1.098	0.947	0.928	0.911	0.902	0.889	0.880	0.861	0.841	0.833	0.809
G&H	1.145	0.963	0.940	0.930	0.921	0.909	0.904	0.878	0.857	0.850	0.831
G&H	1.034	0.880	0.853	0.846	0.835	0.826	0.813	0.797	0.780	0.783	0.770
G&H	1.049	0.897	0.875	0.857	0.848	0.834	0.832	0.815	0.795	0.787	0.778
Mean	1.081	0.956	0.941	0.930	0.923	0.904	0.886	0.867	0.846	0.842	0.813

Time (Hours) Force(N)	0	0.25	0.5	0.75	1	1.5	2	4	8	12	24
Th(colored)	1.317	1.155	1.133	1.132	1.130	1.127	1.108	1.078	1.070	1.066	1.022
Th(colored)	1.294	1.152	1.150	1.121	1.117	1.117	1.087	1.078	1.080	1.060	1.006
Th(colored)	1.245	1.112	1.106	1.100	1.106	1.091	1.063	1.057	1.037	1.042	0.986
Th(colored)	1.068	0.920	0.901	0.898	0.886	0.866	0.860	0.848	0.850	0.849	0.796
Th(colored)	1.192	1.036	1.024	1.029	1.013	1.004	1.007	0.995	0.977	0.981	0.942
Th(colored)	1.119	0.990	0.991	0.964	0.982	0.952	0.922	0.924	0.909	0.913	0.887
Th(colored)	1.269	1.116	1.107	1.093	1.092	1.076	1.076	1.062	1.053	1.052	1.038
Th(colored)	1.252	1.093	1.085	1.077	1.071	1.074	1.058	1.064	1.041	1.036	1.031
Th(colored)	1.225	1.023	1.010	1.002	0.991	0.984	0.994	0.979	0.970	0.974	0.951
Th(colored)	1.293	1.122	1.110	1.098	1.099	1.083	1.086	1.072	1.062	1.036	1.045
Th(colored)	1.177	1.041	1.023	1.024	1.012	1.011	1.002	1.005	0.988	0.987	0.966
Th(colored)	1.237	1.083	1.069	1.066	1.058	1.045	1.043	1.035	1.020	1.016	1.003
Th(colored)	1.268	1.113	1.115	1.096	1.085	1.082	1.074	1.066	1.054	1.036	1.035
Th(colored)	1.232	1.050	1.037	1.028	1.022	1.016	1.010	0.999	0.989	0.998	0.986
Th(colored)	1.142	0.961	0.955	0.951	0.937	0.926	0.923	0.918	0.901	0.899	0.889
Mean	1.222	1.065	1.054	1.045	1.040	1.030	1.021	1.012	1.000	0.996	0.972

Table 25. Raw data of dimension of ¼” elastics in static testing

Number	Thai ¼” elastics in static testing			
	Width (mm)	Thickness (mm)	Cross-sectional area (mm^2)	Internal diameter (mm)
1	1.175	0.824	0.97	6.327
2	1.110	0.886	0.98	6.186
3	1.100	0.850	0.94	6.329
4	1.219	0.830	1.01	6.272
5	1.105	0.828	0.91	6.351
6	1.176	0.764	0.90	6.299
7	1.105	0.888	0.98	6.255
8	1.152	0.806	0.93	6.288
9	1.125	0.823	0.93	6.327
10	1.200	0.827	0.99	6.422
11	1.104	0.824	0.91	6.416
12	1.187	0.770	0.91	6.221
13	1.185	0.772	0.91	6.436
14	1.125	0.776	0.87	6.441
15	1.226	0.765	0.94	6.386
Mean	1.153	0.816	0.939	6.330

Number	Ormco ¼” elastics in static testing			
	Width (mm)	Thickness (mm)	Cross-sectional area (mm^2)	Internal diameter (mm)
1	1.197	0.802	0.96	6.308
2	1.095	0.866	0.95	6.254
3	1.270	0.827	1.05	6.245
4	1.133	0.820	0.93	6.237
5	1.251	0.819	1.02	6.298
6	1.172	0.819	0.96	6.455
7	1.196	0.857	1.02	6.131
8	1.163	0.848	0.99	6.423
9	1.105	0.861	0.95	6.356
10	1.126	0.866	0.98	6.439
11	1.122	0.874	0.98	6.312
12	1.116	0.855	0.95	6.231
13	1.151	0.868	1.00	6.206
14	1.190	0.820	0.98	6.310
15	1.142	0.857	0.98	6.148
Mean	1.162	0.844	0.98	6.290

Table 25. Raw data of dimension of ¼” elastics in static testing (cont.)

Number	G&H ¼” elastics in static testing			
	Width (mm)	Thickness (mm)	Cross-sectional area (mm^2)	Internal diameter (mm)
1	1.191	0.909	1.08	6.213
2	1.160	0.904	1.05	6.282
3	1.169	0.816	0.95	6.460
4	1.144	0.878	1.00	6.146
5	1.102	0.880	0.97	6.314
6	1.178	0.782	0.92	6.399
7	1.049	0.917	0.96	6.170
8	1.145	0.858	0.98	6.280
9	1.162	0.892	1.04	6.213
10	1.050	0.879	0.92	6.262
11	1.183	0.834	0.99	6.240
12	1.162	0.763	0.89	6.422
13	1.194	0.894	1.07	6.239
14	1.127	0.863	0.97	6.339
15	1.064	0.931	0.99	6.248
Mean	1.139	0.867	0.985	6.282

Number	Thai (colored) ¼” elastics in static testing			
	Width (mm)	Thickness (mm)	Cross-sectional area (mm^2)	Internal diameter (mm)
1	1.098	0.788	0.87	6.259
2	1.119	0.820	0.92	6.405
3	1.162	0.764	0.89	6.190
4	1.050	0.779	0.82	6.349
5	1.130	0.810	0.91	6.259
6	1.154	0.773	0.89	6.350
7	1.245	0.810	1.01	6.415
8	1.108	0.805	0.89	6.287
9	1.064	0.805	0.86	6.250
10	1.098	0.837	0.92	6.275
11	1.201	0.810	0.97	6.182
12	1.226	0.741	0.91	6.389
13	1.145	0.889	1.02	6.190
14	1.143	0.795	0.91	6.245
15	1.103	0.823	0.91	6.283
Mean	1.136	0.803	0.913	6.289

Table 26. Raw data of dimension of 5/16” elastics in static testing

Number	Thai 5/16” elastics in static testing			
	Width (mm)	Thickness (mm)	Cross-sectional area (mm^2)	Internal diameter (mm)
1	1.187	0.807	0.96	7.845
2	1.342	0.810	1.09	7.861
3	1.203	0.817	0.98	7.830
4	1.270	0.856	1.09	7.917
5	1.159	0.815	0.94	7.865
6	1.250	0.811	1.01	7.927
7	1.187	0.832	0.99	7.762
8	1.128	0.848	0.96	7.821
9	1.281	0.852	1.09	7.963
10	1.386	0.748	1.04	7.824
11	1.318	0.796	1.05	7.812
12	1.271	0.789	1.00	7.705
13	1.275	0.795	1.01	7.846
14	1.316	0.899	1.18	7.860
15	1.263	0.798	1.01	7.688
Mean	1.256	0.818	1.027	7.835

Number	Ormco 5/16” elastics in static testing			
	Width (mm)	Thickness (mm)	Cross-sectional area (mm^2)	Internal diameter (mm)
1	1.173	0.842	0.99	7.789
2	1.158	0.863	1.00	8.026
3	1.258	0.840	1.06	8.162
4	1.231	0.846	1.04	8.034
5	1.274	0.782	1.00	7.806
6	1.188	0.822	0.98	7.953
7	1.195	0.826	0.99	7.517
8	1.260	0.883	1.11	7.971
9	1.169	0.873	1.02	7.750
10	1.233	0.773	0.95	8.035
11	1.280	0.867	1.11	7.995
12	1.183	0.881	1.04	7.981
13	1.220	0.860	1.05	8.099
14	1.087	0.888	0.96	7.936
15	1.252	0.804	1.01	8.019
Mean	1.211	0.843	1.021	7.938

Table 26. Raw data of dimension of 5/16” elastics in static testing (cont.)

Number	G&H 5/16” elastics in static testing			
	Width (mm)	Thickness (mm)	Cross-sectional area (mm^2)	Internal diameter (mm)
1	1.228	0.832	1.02	7.961
2	1.143	0.954	1.09	7.796
3	1.165	0.848	0.99	7.637
4	1.120	0.854	0.96	7.853
5	1.158	0.851	0.99	7.900
6	1.179	0.855	1.01	7.791
7	1.150	0.821	0.94	7.899
8	1.222	0.819	1.00	7.905
9	1.175	0.826	0.97	7.956
10	1.200	0.869	1.04	7.687
11	1.166	0.832	0.97	7.681
12	1.211	0.839	1.02	7.685
13	1.156	0.847	0.98	7.773
14	1.136	0.893	1.01	7.785
15	1.160	0.829	0.96	7.952
Mean	1.171	0.851	0.997	7.817

Number	Thai (colored) 5/16” elastics in static testing			
	Width (mm)	Thickness (mm)	Cross-sectional area (mm^2)	Internal diameter (mm)
1	1.332	0.796	1.06	7.834
2	1.337	0.791	1.06	8.127
3	1.276	0.877	1.12	8.904
4	1.123	0.802	0.90	7.929
5	1.226	0.778	0.95	7.936
6	1.188	0.769	0.91	7.883
7	1.305	0.759	0.99	8.081
8	1.339	0.822	1.10	7.740
9	1.198	0.839	1.01	8.005
10	1.306	0.782	1.02	7.767
11	1.257	0.794	1.00	7.793
12	1.284	0.788	1.01	8.000
13	1.328	0.806	1.07	7.953
14	1.198	0.889	1.06	7.911
15	1.107	0.856	0.95	7.805
Mean	1.254	0.81	1.01	7.978

Table 27. Raw data of force values over time of the 1/4” elastics during dynamic testing

Time (Hours) Force(N)	0	0.25	0.5	0.75	1	1.5	2	4	8	12	24
Thai	1.305	1.10	1.079	1.07	1.067	1.064	1.054	1.048	1.036	1.025	1.013
Thai	1.347	1.12	1.111	1.10	1.097	1.089	1.077	1.069	1.05	1.042	1.032
Thai	1.315	1.09	1.083	1.07	1.058	1.056	1.051	1.043	1.027	1.018	1.004
Thai	1.226	1.03	1.017	1.03	1.002	0.994	0.99	0.984	0.969	0.963	0.947
Thai	1.434	1.18	1.172	1.16	1.155	1.157	1.143	1.142	1.127	1.118	1.109
Thai	1.120	0.95	0.937	0.93	0.927	0.922	0.927	0.918	0.898	0.900	0.890
Thai	1.433	1.20	1.187	1.19	1.170	1.163	1.165	1.151	1.134	1.134	1.132
Thai	1.310	1.14	1.119	1.12	1.109	1.101	1.104	1.100	1.076	1.075	1.069
Thai	1.449	1.21	1.199	1.19	1.164	1.149	1.139	1.137	1.119	1.117	1.103
Thai	1.479	1.21	1.196	1.18	1.171	1.166	1.153	1.150	1.146	1.139	1.121
Thai	1.302	1.07	1.057	1.05	1.036	1.033	1.032	1.022	1.015	1.014	0.991
Thai	1.458	1.26	1.240	1.23	1.217	1.220	1.193	1.152	1.150	1.152	1.141
Thai	1.486	1.24	1.222	1.21	1.211	1.199	1.182	1.173	1.170	1.176	1.164
Thai	1.340	1.12	1.105	1.10	1.090	1.082	1.073	1.058	1.060	1.059	1.047
Thai	1.366	1.15	1.133	1.13	1.129	1.127	1.115	1.108	1.108	1.087	1.080
Mean	1.358	1.14	1.124	1.12	1.107	1.101	1.093	1.084	1.072	1.068	1.056

Time (Hours) Force(N)	0	0.25	0.5	0.75	1	1.5	2	4	8	12	24
Ormco	1.350	1.145	1.124	1.098	1.103	1.084	1.071	1.055	1.035	1.028	1.020
Ormco	1.401	1.184	1.169	1.158	1.146	1.134	1.127	1.115	1.090	1.090	1.065
Ormco	1.316	1.097	1.077	1.071	1.057	1.045	1.037	1.027	1.000	0.994	0.986
Ormco	1.261	1.048	1.038	1.021	1.005	0.995	0.992	0.980	0.951	0.953	0.937
Ormco	1.261	1.080	1.059	1.044	1.037	1.029	1.020	1.014	0.990	0.988	0.976
Ormco	1.259	1.070	1.046	1.034	1.028	1.021	1.003	0.992	0.971	0.972	0.966
Ormco	1.369	1.193	1.155	1.146	1.142	1.113	1.102	1.084	1.066	1.068	1.049
Ormco	1.229	1.055	1.032	1.017	1.007	0.999	0.989	0.981	0.968	0.968	0.950
Ormco	1.362	1.157	1.138	1.140	1.115	1.109	1.097	1.085	1.066	1.060	1.038
Ormco	1.273	1.088	1.048	1.032	1.011	1.007	0.995	0.993	0.976	0.983	0.962
Ormco	1.264	1.053	1.033	1.017	1.009	1.005	0.994	0.980	0.974	0.964	0.949
Ormco	1.354	1.158	1.128	1.119	1.112	1.094	1.076	1.060	1.058	1.056	1.053
Ormco	1.304	1.082	1.061	1.052	1.038	1.033	1.009	0.992	0.989	0.986	0.979
Ormco	1.295	1.096	1.074	1.057	1.042	1.038	1.014	1.003	0.997	0.997	0.994
Ormco	1.355	1.131	1.105	1.098	1.081	1.076	1.049	1.032	1.028	1.026	1.014
Mean	1.310	1.109	1.086	1.074	1.062	1.052	1.038	1.026	1.011	1.009	0.996

Table 27. Raw data of force values over time of the 1/4” elastics during dynamic testing (cont.)

Time (hours) Force(N)	0	0.25	0.5	0.75	1	1.5	2	4	8	12	24
G&H	1.410	1.197	1.184	1.150	1.140	1.128	1.115	1.095	1.065	1.06	1.041
G&H	1.276	1.054	1.036	1.018	1.017	0.993	0.984	0.964	0.946	0.935	0.921
G&H	1.433	1.208	1.185	1.176	1.184	1.143	1.150	1.127	1.087	1.088	1.062
G&H	1.224	1.027	1.013	0.990	0.993	0.979	0.970	0.956	0.924	0.924	0.901
G&H	1.385	1.178	1.127	1.098	1.119	1.086	1.087	1.073	1.031	1.022	1.020
G&H	1.288	1.095	1.069	1.055	1.045	1.026	1.021	0.999	0.973	0.981	0.964
G&H	1.319	1.109	1.075	1.061	1.047	1.037	1.032	1.011	0.982	0.98	0.967
G&H	1.369	1.152	1.120	1.107	1.091	1.08	1.071	1.056	1.039	1.029	1.011
G&H	1.359	1.154	1.124	1.110	1.089	1.085	1.077	1.049	1.03	1.019	0.996
G&H	1.392	1.139	1.121	1.088	1.064	1.060	1.047	1.036	1.012	1.024	0.984
G&H	1.301	1.066	1.036	1.037	1.028	1.020	1.000	0.992	0.976	0.958	0.935
G&H	1.378	1.147	1.114	1.099	1.089	1.079	1.051	1.026	1.027	1.031	1.006
G&H	1.330	1.095	1.068	1.055	1.047	1.036	1.005	0.983	0.98	0.977	0.961
G&H	1.259	1.048	1.019	1.005	0.995	0.984	0.958	0.937	0.943	0.93	0.924
G&H	1.426	1.198	1.143	1.139	1.120	1.111	1.080	1.058	1.057	1.054	1.045
Mean	1.343	1.124	1.096	1.079	1.071	1.057	1.043	1.024	1.005	1.001	0.983

Time (Hours) Force(N)	0	0.25	0.5	0.75	1	1.5	2	4	8	12	24
Th(colored)	1.413	1.23	1.210	1.20	1.185	1.180	1.175	1.163	1.152	1.153	1.128
Th(colored)	1.348	1.11	1.095	1.09	1.082	1.073	1.095	1.077	1.042	1.042	1.031
Th(colored)	1.327	1.12	1.107	1.10	1.096	1.082	1.084	1.072	1.046	1.044	1.027
Th(colored)	1.298	1.09	1.071	1.07	1.055	1.051	1.056	1.037	1.021	1.013	1.000
Th(colored)	1.432	1.21	1.186	1.18	1.169	1.171	1.157	1.155	1.133	1.128	1.121
Th(colored)	1.339	1.11	1.093	1.09	1.079	1.067	1.076	1.066	1.044	1.046	1.034
Th(colored)	1.368	1.13	1.101	1.09	1.081	1.078	1.076	1.071	1.045	1.050	1.039
Th(colored)	1.233	1.04	1.021	1.02	1.009	1.001	1.001	0.986	0.986	0.979	0.962
Th(colored)	1.337	1.11	1.086	1.08	1.067	1.062	1.062	1.045	1.049	1.032	1.024
Th(colored)	1.435	1.17	1.147	1.14	1.121	1.126	1.112	1.106	1.103	1.097	1.085
Th(colored)	1.302	1.05	1.041	1.02	1.015	1.016	1.008	0.996	0.991	0.988	0.971
Th(colored)	1.224	1.02	1.007	1.00	0.990	0.991	0.976	0.969	0.968	0.967	0.958
Th(colored)	1.428	1.19	1.179	1.17	1.155	1.166	1.142	1.119	1.121	1.125	1.111
Th(colored)	1.367	1.11	1.092	1.09	1.076	1.071	1.058	1.044	1.056	1.04	1.038
Th(colored)	1.303	1.08	1.072	1.07	1.068	1.062	1.041	1.039	1.033	1.03	1.025
Mean	1.344	1.12	1.101	1.09	1.083	1.08	1.075	1.063	1.053	1.049	1.037

Table 28. Raw data of force values over time of the 5/16” elastics during dynamic testing.

Time (Hours) Force(N)	0	0.25	0.5	0.75	1	1.5	2	4	8	12	24
Thai	1.193	1.048	1.038	1.013	1.013	1.005	1.005	0.993	0.988	0.974	0.976
Thai	1.297	1.158	1.144	1.124	1.134	1.139	1.114	1.105	1.091	1.095	1.094
Thai	1.343	1.129	1.106	1.111	1.099	1.093	1.090	1.068	1.058	1.068	1.064
Thai	1.263	1.058	1.044	1.034	1.033	1.028	1.022	1.025	1.013	0.999	0.982
Thai	1.395	1.145	1.125	1.122	1.112	1.107	1.105	1.098	1.095	1.081	1.066
Thai	1.373	1.158	1.146	1.135	1.139	1.120	1.116	1.105	1.108	1.108	1.078
Thai	1.250	1.050	1.035	1.026	1.018	1.009	1.023	1.010	1.000	0.991	0.980
Thai	1.345	1.074	1.064	1.048	1.046	1.043	1.047	1.036	1.024	1.017	1.015
Thai	1.223	1.059	1.048	1.019	1.019	1.000	1.006	1.005	0.990	0.982	0.978
Thai	1.200	1.051	1.029	1.012	1.014	0.999	0.992	0.984	0.994	0.986	0.973
Thai	1.263	1.048	1.022	1.017	1.011	1.011	0.997	0.990	0.987	0.988	0.985
Thai	1.266	1.019	1.025	1.010	1.003	0.995	0.998	0.982	0.980	0.964	0.966
Thai	1.353	1.136	1.126	1.114	1.119	1.104	1.099	1.089	1.084	1.074	1.065
Thai	1.303	1.101	1.091	1.086	1.079	1.066	1.060	1.061	1.059	1.037	1.030
Thai	1.311	1.083	1.088	1.080	1.066	1.070	1.054	1.048	1.038	1.035	1.029
Mean	1.292	1.088	1.075	1.063	1.060	1.053	1.049	1.04	1.034	1.027	1.019

Time (hours) Force(N)	0	0.25	0.5	0.75	1	1.5	2	4	8	12	24
Ormco	1.187	0.997	0.985	0.970	0.963	0.943	0.939	0.919	0.905	0.900	0.905
Ormco	1.150	0.953	0.941	0.929	0.924	0.991	0.903	0.894	0.884	0.887	0.879
Ormco	1.246	1.049	1.019	1.020	1.006	0.987	0.984	0.971	0.953	0.945	0.941
Ormco	1.152	0.971	0.941	0.926	0.919	0.924	0.916	0.890	0.876	0.863	0.847
Ormco	1.228	1.037	1.009	0.990	0.983	0.974	0.967	0.953	0.943	0.934	0.916
Ormco	1.150	0.970	0.944	0.936	0.923	0.913	0.910	0.896	0.884	0.879	0.853
Ormco	1.267	1.067	1.042	1.030	1.026	1.010	1.007	1.001	0.981	0.964	0.935
Ormco	1.246	1.043	1.016	0.998	0.986	0.979	0.974	0.952	0.946	0.944	0.938
Ormco	1.262	1.053	1.032	1.023	1.010	0.999	0.990	0.976	0.977	0.964	0.953
Ormco	1.192	0.991	0.965	0.955	0.945	0.934	0.925	0.925	0.904	0.900	0.892
Ormco	1.253	1.040	1.016	0.994	0.988	0.982	0.970	0.961	0.948	0.945	0.934
Ormco	1.222	1.061	1.036	1.017	1.004	0.994	0.984	0.966	0.959	0.950	0.937
Ormco	1.262	1.060	1.044	1.028	1.015	1.002	0.996	0.975	0.966	0.957	0.950
Ormco	1.216	1.030	1.021	1.003	0.990	0.982	0.980	0.960	0.947	0.938	0.930
Ormco	1.225	1.028	1.010	0.987	0.981	0.967	0.965	0.948	0.933	0.930	0.915
Mean	1.217	1.023	1.001	0.987	0.978	0.972	0.961	0.946	0.934	0.927	0.915

Table 28. Raw data of force values over time of the 5/16" elastics during dynamic testing (cont.)

Time (Hours) Force(N)	0	0.25	0.5	0.75	1	1.5	2	4	8	12	24
G&H	1.104	0.956	0.925	0.923	0.919	0.897	0.886	0.871	0.850	0.849	0.840
G&H	1.092	0.916	0.894	0.881	0.876	0.861	0.856	0.842	0.824	0.824	0.814
G&H	1.131	0.989	0.974	0.954	0.947	0.935	0.924	0.915	0.885	0.891	0.878
G&H	1.189	1.036	1.006	0.999	0.990	0.965	0.959	0.950	0.923	0.921	0.906
G&H	1.081	0.916	0.894	0.873	0.872	0.858	0.849	0.841	0.824	0.818	0.793
G&H	1.088	0.936	0.910	0.883	0.891	0.867	0.852	0.845	0.827	0.821	0.796
G&H	1.203	1.024	1.018	1.003	0.990	0.982	0.948	0.938	0.925	0.914	0.892
G&H	1.094	0.921	0.904	0.891	0.876	0.870	0.859	0.841	0.830	0.824	0.819
G&H	1.113	0.949	0.937	0.922	0.909	0.908	0.893	0.883	0.875	0.861	0.847
G&H	1.111	0.934	0.918	0.911	0.905	0.889	0.885	0.865	0.851	0.859	0.828
G&H	1.091	0.927	0.902	0.892	0.890	0.875	0.867	0.855	0.840	0.844	0.812
G&H	1.159	0.995	0.980	0.966	0.954	0.945	0.940	0.920	0.904	0.894	0.883
G&H	1.214	1.036	1.020	1.014	1.014	0.996	0.987	0.958	0.952	0.942	0.920
G&H	1.147	0.960	0.954	0.946	0.951	0.924	0.914	0.900	0.873	0.870	0.859
G&H	1.191	0.988	0.973	0.957	0.961	0.933	0.93	0.904	0.892	0.892	0.868
Mean	1.134	0.966	0.947	0.934	0.930	0.914	0.903	0.889	0.872	0.868	0.850

Time (Hours) Force(N)	0	0.25	0.5	0.75	1	1.5	2	4	8	12	24
Th(colored)	1.213	1.035	1.030	1.014	1.022	1.005	0.995	0.990	0.980	0.983	0.974
Th(colored)	1.18	0.987	0.975	0.964	0.968	0.956	0.953	0.943	0.932	0.936	0.929
Th(colored)	1.185	1.014	0.976	0.964	0.964	0.964	0.952	0.945	0.950	0.951	0.941
Th(colored)	1.296	1.098	1.094	1.071	1.066	1.061	1.055	1.042	1.038	1.028	1.001
Th(colored)	1.18	1.021	1.005	0.992	0.989	0.979	0.985	0.969	0.963	0.953	0.930
Th(colored)	1.268	1.047	1.031	1.019	1.012	1.020	1.003	0.994	0.987	0.983	0.967
Th(colored)	1.347	1.132	1.117	1.103	1.099	1.087	1.087	1.083	1.077	1.072	1.049
Th(colored)	1.307	1.087	1.073	1.058	1.055	1.051	1.045	1.034	1.036	1.029	1.024
Th(colored)	1.2	1.012	1.004	0.988	0.993	0.979	0.991	0.970	0.972	0.962	0.954
Th(colored)	1.178	1.009	0.983	0.977	0.977	0.966	0.963	0.950	0.947	0.949	0.939
Th(colored)	1.196	0.989	0.978	0.967	0.963	0.957	0.956	0.952	0.945	0.944	0.942
Th(colored)	1.234	1.039	1.029	1.008	1.001	0.997	1.002	0.989	0.980	0.974	0.960
Th(colored)	1.273	1.093	1.094	1.070	1.067	1.060	1.052	1.045	1.034	1.030	1.022
Th(colored)	1.185	1.008	1.011	0.977	0.975	0.961	0.952	0.942	0.933	0.933	0.934
Th(colored)	1.258	1.035	1.015	0.996	1.011	1.024	0.990	0.985	0.973	0.972	0.960
Mean	1.233	1.04	1.028	1.011	1.011	1.005	0.999	0.989	0.983	0.98	0.968

Table 29. Raw data of dimension of ¼” elastics in dynamic testing

Number	Thai ¼” elastics in dynamic testing			
	Width (mm)	Thickness (mm)	Cross-sectional area (mm^2)	Internal diameter (mm)
1	1.191	0.768	0.91	6.276
2	1.127	0.832	0.94	6.347
3	1.344	0.764	1.03	6.436
4	1.074	0.784	0.84	6.400
5	1.161	0.880	1.02	6.145
6	1.035	0.767	0.79	6.227
7	1.248	0.810	1.01	6.265
8	1.022	0.873	0.89	6.258
9	1.064	0.877	0.93	6.176
10	1.245	0.845	1.05	6.287
11	1.130	0.775	0.88	6.420
12	1.147	0.869	1.00	6.257
13	1.155	0.836	0.97	6.282
14	1.108	0.812	0.90	6.188
15	1.136	0.862	0.98	6.419
Mean	1.146	0.824	0.943	6.292

Number	Ormco ¼” elastics in dynamic testing			
	Width (mm)	Thickness (mm)	Cross-sectional area (mm^2)	Internal diameter (mm)
1	1.232	0.811	1.00	6.309
2	1.224	0.843	1.03	6.287
3	1.182	0.816	0.96	6.410
4	1.150	0.824	0.95	6.281
5	1.121	0.858	0.96	6.399
6	1.143	0.825	0.94	6.310
7	1.227	0.873	1.07	6.436
8	1.091	0.833	0.91	6.424
9	1.167	0.894	1.04	6.401
10	1.119	0.823	0.92	6.248
11	1.075	0.878	0.94	6.390
12	1.183	0.853	1.01	6.090
13	1.116	0.873	0.97	6.227
14	1.160	0.844	0.98	6.223
15	1.211	0.816	0.99	6.338
Mean	1.160	0.844	0.978	6.318

Table 29. Raw data of dimension of elastics in dynamic testing (cont.)

Number	G&H ¼" elastics in dynamic testing			
	Width (mm)	Thickness (mm)	Cross-sectional area (mm^2)	Internal diameter (mm)
1	1.160	0.873	1.01	6.115
2	1.140	0.815	0.93	6.106
3	1.181	0.895	1.06	6.136
4	1.178	0.794	0.93	6.127
5	1.174	0.825	0.97	6.153
6	1.074	0.849	0.91	6.073
7	1.159	0.815	0.94	6.190
8	1.120	0.874	0.98	6.320
9	1.109	0.903	1.00	6.140
10	1.144	0.822	0.94	6.060
11	1.068	0.877	0.94	6.312
12	1.123	0.878	0.99	6.252
13	1.147	0.889	1.02	6.147
14	1.104	0.845	0.93	6.184
15	1.171	0.869	1.02	6.296
Mean	1.137	0.855	0.971	6.174

Number	Thai (colored) ¼" elastics in dynamic testing			
	Width (mm)	Thickness (mm)	Cross-sectional area (mm^2)	Internal diameter (mm)
1	1.118	0.915	1.02	6.152
2	1.231	0.763	0.94	6.294
3	1.201	0.757	0.91	6.208
4	1.050	0.780	0.82	6.191
5	1.214	0.806	0.98	6.149
6	1.127	0.885	1.00	6.251
7	1.218	0.819	1.00	6.300
8	1.141	0.758	0.86	6.303
9	1.230	0.843	1.04	6.311
10	1.231	0.810	1.00	6.320
11	1.118	0.752	0.84	6.281
12	1.082	0.800	0.87	6.264
13	1.190	0.823	0.98	6.251
14	1.144	0.792	0.91	6.270
15	1.259	0.732	0.92	6.176
Mean	1.170	0.802	0.939	6.248

Table 30. Raw data of dimension of 5/16” elastics in dynamic testing

Number	Thai 5/16” elastics in dynamic testing			
	Width (mm)	Thickness (mm)	Cross-sectional area (mm^2)	Internal diameter (mm)
1	1.209	0.815	0.99	7.882
2	1.220	0.900	1.10	7.867
3	1.291	0.864	1.12	7.769
4	1.153	0.840	0.97	7.858
5	1.176	0.844	0.99	7.761
6	1.268	0.844	1.07	7.956
7	1.252	0.816	1.02	7.770
8	1.232	0.845	1.04	7.957
9	1.123	0.838	0.94	7.635
10	1.187	0.854	1.01	7.723
11	1.285	0.806	1.04	7.800
12	1.282	0.779	1.00	7.873
13	1.249	0.843	1.05	7.721
14	1.141	0.881	1.00	7.735
15	1.352	0.805	1.09	7.751
Mean	1.228	0.838	1.029	7.804

Number	Ormco 5/16” elastics in dynamic testing			
	Width (mm)	Thickness (mm)	Cross-sectional area (mm^2)	Internal diameter (mm)
1	1.246	0.804	1.00	7.676
2	1.286	0.745	0.96	7.823
3	1.216	0.857	1.04	7.946
4	1.098	0.905	0.99	8.028
5	1.176	0.890	1.05	7.843
6	1.170	0.860	1.01	8.005
7	1.214	0.879	1.07	7.900
8	1.216	0.877	1.07	7.851
9	1.234	0.864	1.07	7.841
10	1.174	0.852	1.00	7.789
11	1.252	0.857	1.07	7.859
12	1.170	0.907	1.06	7.018
13	1.211	0.867	1.05	7.864
14	1.265	0.844	1.07	7.953
15	1.224	0.861	1.05	7.854
Mean	1.21	0.858	1.037	7.817

Table 30. Raw data of dimension of 5/16” elastics in dynamic testing (cont.)

Number	**G&H 5/16” elastics in dynamic testing**			
	Width (mm)	Thickness (mm)	Cross-sectional area (mm^2)	Internal diameter (mm)
1	1.178	0.856	1.01	7.871
2	1.132	0.838	0.95	7.957
3	1.189	0.843	1.00	8.160
4	1.140	0.937	1.07	8.072
5	1.125	0.824	0.93	7.545
6	1.151	0.842	0.97	7.906
7	1.133	0.883	1.00	7.657
8	1.194	0.848	1.01	7.971
9	1.176	0.855	1.00	7.702
10	1.173	0.860	1.01	7.981
11	1.179	0.855	1.01	7.949
12	1.180	0.898	1.06	7.680
13	1.142	0.905	1.03	7.874
14	1.202	0.841	1.01	7.708
15	1.175	0.838	0.98	8.037
Mean	1.165	0.862	1.003	7.871

Number	**Thai (colored) 5/16” elastics in dynamic testing**			
	Width (mm)	Thickness (mm)	Cross-sectional area (mm^2)	Internal diameter (mm)
1	1.325	0.735	0.97	7.863
2	1.321	0.750	0.99	7.947
3	1.206	0.771	0.93	7.909
4	1.279	0.835	1.07	7.972
5	1.169	0.881	1.03	7.800
6	1.201	0.821	0.99	7.863
7	1.350	0.781	1.05	7.984
8	1.301	0.799	1.04	7.804
9	1.269	0.801	1.02	7.790
10	1.253	0.780	0.98	7.919
11	1.137	0.823	0.94	7.778
12	1.147	0.854	0.98	7.784
13	1.334	0.808	1.08	8.000
14	1.321	0.737	0.97	8.013
15	1.217	0.799	0.97	7.746
Mean	1.255	0.798	1.001	7.878

Appendix B

Table 31. Mean force over time of ¼” elastics during static testing

1/4” elastics during static testing

Time (Hours) Force (N)		0	0.25	0.50	0.75	1	1.5	2	4	8	12	24
Thai	Mean (SD)	1.149 (0.07)	0.981 (0.052)	0.967 (0.053)	0.959 (0.055)	0.950 (0.053)	0.944 (0.051)	0.936 (0.049)	0.926 (0.048)	0.921 (0.044)	0.918 (0.044)	0.896 (0.041)
Ormco	Mean (SD)	1.120 (0.048)	0.993 (0.049)	0.968 (0.050)	0.960 (0.052)	0.948 (0.054)	0.934 (0.050)	0.923 (0.047)	0.900 (0.044)	0.887 (0.042)	0.880 (0.040)	0.859 (0.037)
G&H	Mean (SD)	1.177 (0.073)	1.036 (0.071)	1.011 (0.069)	0.997 (0.066)	0.988 (0.066)	0.971 (0.065)	0.958 (0.063)	0.933 (0.061)	0.915 (0.059)	0.905 (0.064)	0.882 (0.061)
Th color	Mean (SD)	1.146 (0.062)	0.972 (0.054)	0.954 (0.051)	0.944 (0.050)	0.936 (0.052)	0.927 (0.051)	0.922 (0.041)	0.913 (0.050)	0.908 (0.051)	0.905 (0.051)	0.808 (0.056)

Table 32. Mean force over time of 5/16” elastics in static state

5/16” elastics during static testing

Time (Hours) Force (N)		0	0.25	0.50	0.75	1	1.5	2	4	8	12	24
Thai	Mean (SD)	1.235 (0.064)	1.072 (0.057)	1.060 (0.058)	1.053 (0.059)	1.049 (0.057)	1.038 (0.054)	1.029 (0.051)	1.019 (0.049)	1.008 (0.049)	1.004 (0.051)	0.984 (0.041)
Ormco	Mean (SD)	1.186 (0.038)	1.031 (0.047)	1.012 (0.049)	1.004 (0.053)	0.996 (0.053)	0.979 (0.047)	0.969 (0.039)	0.946 (0.042)	0.926 (0.044)	0.924 (0.041)	0.892 (0.034)
G&H	Mean (SD)	1.081 (0.044)	0.956 (0.056)	0.941 (0.062)	0.930 (0.061)	0.923 (0.061)	0.904 (0.058)	0.886 (0.050)	0.867 (0.045)	0.845 (0.042)	0.841 (0.043)	0.812 (0.033)
Th color	Mean (SD)	1.222 (0.070)	1.064 (0.069)	1.054 (0.071)	1.045 (0.068)	1.040 (0.070)	1.030 (0.074)	1.021 (0.072)	1.012 (0.070)	1.000 (0.069)	0.996 (0.064)	0.972 (0.070)

Table 33. Mean force over time of ¼” elastics during dynamic testing

1/4” elastics during dynamic testing												
Time (Hours) Force (N)		**0**	**0.25**	**0.50**	**0.75**	**1**	**1.5**	**2**	**4**	**8**	**12**	**24**
Thai	Mean (SD)	1.358 (0.102)	1.138 (0.083)	1.124 (0.083)	1.117 (.081)	1.107 (0.080)	1.101 (0.08)	1.093 (0.075)	1.084 (0.073)	1.072 (0.075)	1.068 (0.076)	1.056 (0.077)
Ormco	Mean (SD)	1.310 (0.052)	1.109 (0.048)	1.086 (0.047)	1.074 (.049)	1.062 (0.050)	1.052 (0.046)	1.038 (0.046)	1.026 (0.044)	1.011 (0.043)	1.009 (0.043)	0.996 (0.042)
G&H	Mean (SD)	1.343 (0.064)	1.124 (0.059)	1.096 (0.055)	1.079 (.054)	1.071 (0.055)	1.056 (0.051)	1.043 (0.055)	1.024 (0.054)	1.005 (0.048)	1.001 (0.05)	0.983 (0.049)
Th color	Mean (SD)	1.344 (0.066)	1.117 (0.060)	1.101 (0.059)	1.092 (.058)	1.083 (0.056)	1.08 (0.058)	1.075 (0.057)	1.063 (0.057)	1.053 (0.054)	1.049 (0.055)	1.037 (0.054)

Table 34. Mean force over time of 5/16” elastics in dynamic state

5/16” elastics during dynamic testing												
Time (Hours) Force (N)		**0**	**0.25**	**0.50**	**0.75**	**1**	**1.5**	**2**	**4**	**8**	**12**	**24**
Thai	Mean (SD)	1.292 (0.062)	1.088 (0.046)	1.075 (0.045)	1.063 (0.048)	1.06 (0.049)	1.053 (0.05)	1.049 (0.046)	1.04 (0.046)	1.034 (0.045)	1.027 (0.048)	1.019 (0.045)
Ormco	Mean (SD)	1.217 (0.042)	1.023 (0.037)	1.001 (0.037)	0.987 (0.036)	0.978 (0.035)	0.972 (0.03)	0.961 (0.033)	0.946 (0.034)	0.934 (0.035)	0.927 (0.032)	0.915 (0.034)
G&H	Mean (SD)	1.134 (0.046)	966 (0.043)	0.947 (0.045)	0.934 (0.047)	0.930 (0.046)	0.914 (0.045)	0.903 (0.044)	0.889 (0.041)	0.872 (0.041)	0.868 (0.039)	0.850 (0.04)
Th color	Mean (SD)	1.233 (0.055)	1.04 (0.043)	1.028 (0.046)	1.011 (0.044)	1.011 (0.043)	1.004 (0.044)	0.999 (0.043)	0.989 (0.044)	0.983 (0.044)	0.980 (0.041)	0.968 (0.038)

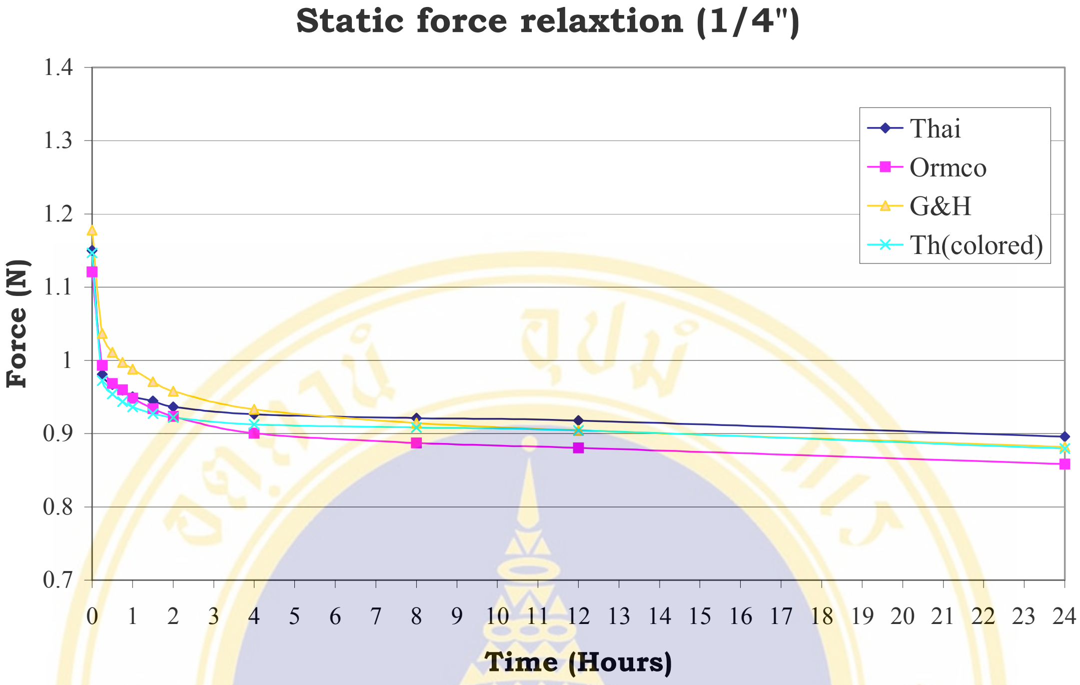


Figure 23. Graph of force relaxation of ¼” elastics during static testing

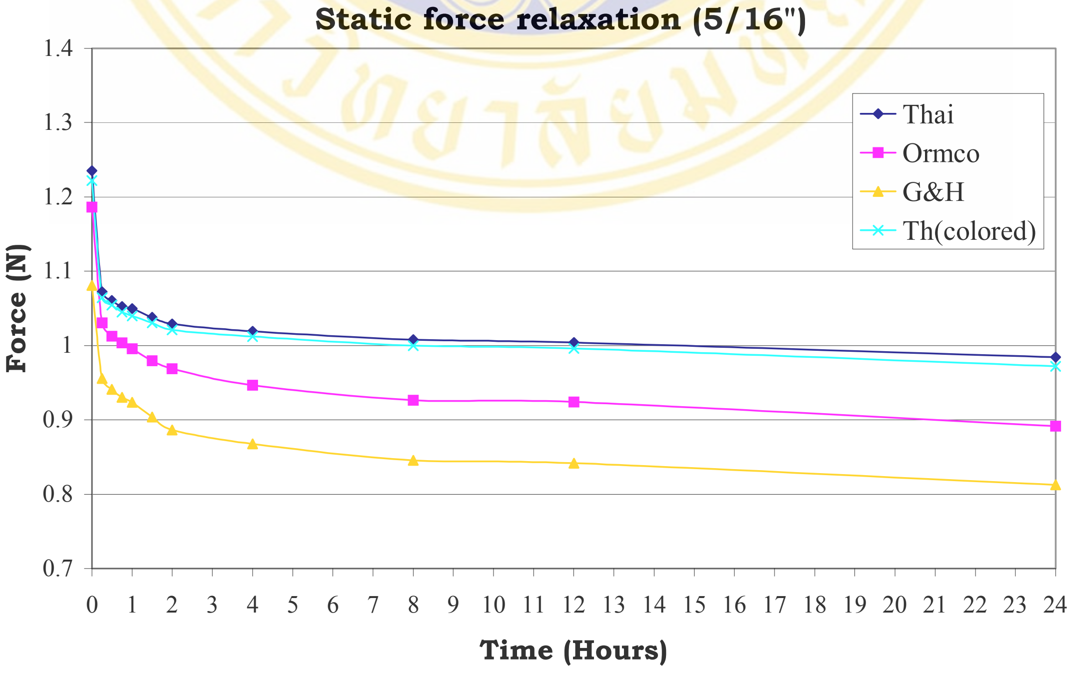


Figure 24. Graph of force relaxation of 5/16” elastics during static testing

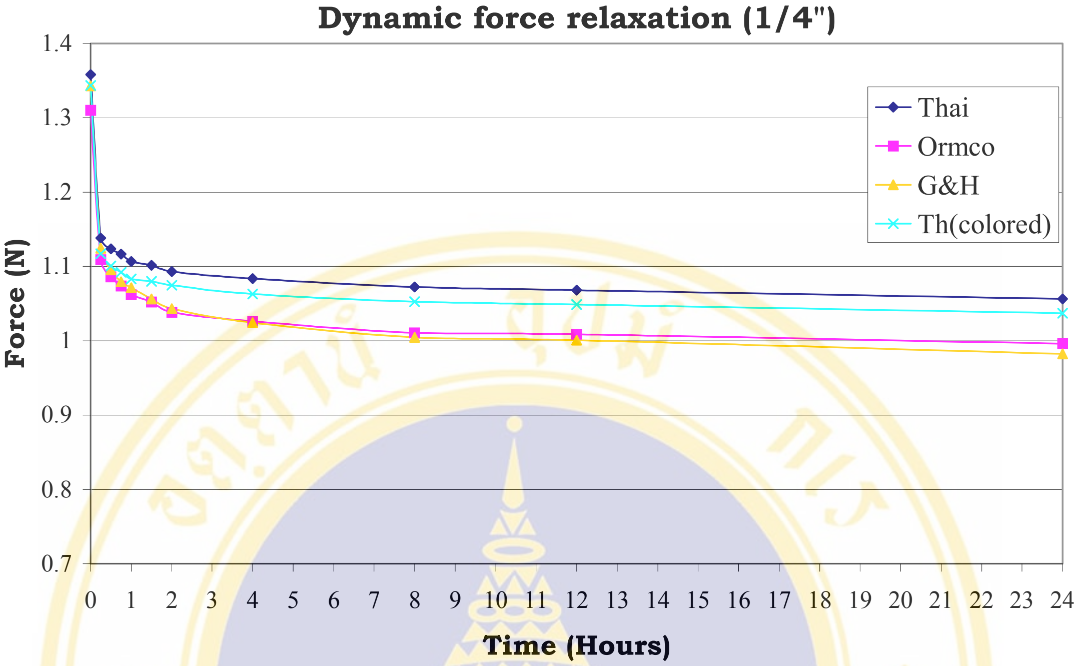


Figure 25. Graph of force relaxation of ¼” elastics during dynamic testing

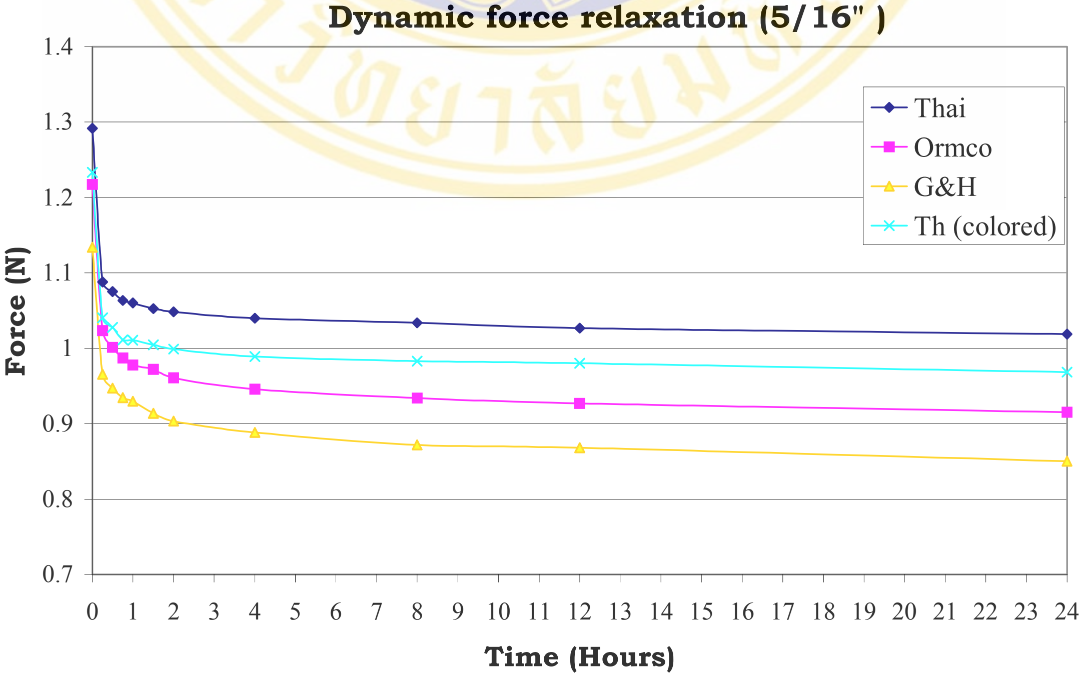


Figure 26. Graph of force relaxation of 5/16” elastics during dynamic testing

Appendix C

(Statistic analysis)

Table 35. ANOVA of force at different extensions of the 1/4" elastics

Extension (mm)	Sum of Squares	df	Mean Square	F	P-value
13	1967.402	3	655.8007	19.024	0
16	2760.518	3	920.1727	20.763	0
19	4509.866	3	1503.289	22.634	0
22	6058.621	3	2019.540	24.462	0
27	9355.791	3	3118.597	28.622	0
37	20274.52	3	6758.174	37.409	0
47	39021.39	3	13007.13	47.171	0
57	82934.84	3	27644.95	39.346	0

Table 36. ANOVA of force at different extensions of the 5/16" elastics

Extension (mm)	Sum of Squares	df	Mean Square	F	P-value
16	1644.9124	3	548.3041	15.488	0
19	2643.4648	3	881.1549	18.481	0
21	4178.2365	3	1392.745	21.028	0
24	5342.6143	3	1780.871	18.920	0
27	7527.7527	3	2509.251	23.550	0
29	8941.5527	3	2980.518	24.537	0
39	16768.78	3	5589.593	27.416	0
49	30021.535	3	10007.18	32.208	0
59	47559.903	3	15853.30	35.764	0
69	65012.196	3	21670.73	30.252	0

Table 37. Multiple comparison of force extension of 1/4” elastics

Scheffe

Displacement (mm)	Elastic (1= Thai, 2= Ormco, 3= G&H, 4= Thai(colored)			P-value
		Force (g)		
13	Thai	89.06	2*	0
			3	0.848
			4	0.413
	Ormco*	76.09	1*	0
			3*	0
			4*	0
	G&H	90.98	1	0.848
			2*	0
			4	0.091
	Thai (colored)	85.4	1	0.413
			2*	0
			3	0.091
16	Thai	114.58	2*	0
			3	0.98
			4	0.21
	Ormco*	97.28	1*	0
			3*	0
			4*	0
	G&H	115.69	1	0.98
			2*	0
			4	0.09
	Th (colored)	109.08	1	0.21
			2*	0
			3	0.09
19	Thai	135.18	2*	0
			3	0.998
			4	0.131
	Ormco*	113.65	1*	0
			3*	0
			4*	0
	G&H	134.57	1	0.998
			2*	0
			4	0.192
	Thai (colored)	127.98	1	0.131
			2*	0
			3	0.192

* The mean difference is significant at the 0.05 level.

Table 37. Multiple comparison of force extension of 1/4" elastics (cont.)

Scheffe				
Displacement (mm)	Elastic (1= Thai, 2= Ormco, 3= G&H, 4= Thai(colored)			P-value
		Force (g)		
22	Thai	153.72	2*	0
			3	0.784
			4	0.064
	Ormco*	127.58	1*	0
			3*	0
			4*	0
	G&H	150.28	1	0.784
			2*	0
			4	0.396
	Th (colored)	144.51	1	0.064
			2*	0
			3	0.396
27	Thai	180.12	2*	0
			3	0.531
			4	0.098
	Ormco*	147.27	1*	0
			3*	0
			4*	0
	G&H	174.43	1	0.531
			2*	0
			4	0.764
	Thai (colored)	170.33	1	0.098
			2*	0
			3	0.764
37	Thai	237.04	2*	0
			3*	0.011
			4	0.061
	Ormco*	186.96	1*	0
			3*	0
			4*	0
	G&H	219.83	1*	0.011
			2*	0
			4	0.916
	Th (colored)	223.34	1	0.061
			2*	0
			3	0.916

* The mean difference is significant at the 0.05 level.

Table 37. Multiple comparison of force extension of 1/4” elastics (cont.)

Scheffe

Displacement (mm)	Elastic (1= Thai, 2= Ormco, 3= G&H, 4= Thai(colored)			P-value
		Force (g)		
47	Thai	292.73	2*	0
			3	0
			4	0.06
	Ormco*	223.7	1*	0
			3*	0
			4*	0
	G&H	259.74	1	0
			2*	0
			4	0.085
	Thai (colored)	275.75	1	0.06
			2*	0
			3	0.085
57	Thai	381.09	2*	0
			3*	0.035
			4	0.161
	Ormco*	281.71	1*	0
			3*	0
			4*	0
	G&H	351.68	1*	0.035
			2*	0
			4	0.913
	Th (colored)	358.7	1	0.161
			2*	0
			3	0.913

* The mean difference is significant at the 0.05 level.

Table 38. Multiple comparison of force extension of 5/16”elastics

Scheffe				
Displacement (mm)	Elastic (1= Thai, 2= Ormco, 3= G&H, 4= Thai(colored))			P-value
		Force (g)		
16	Thai*	85.4	2*	0
			3*	0.004
			4	0.707
	Ormco*	71.88	1*	0
			3	0.141
			4*	0
	G&H	77.06	1*	0.004
			2	0.141
			4	0.082
	Thai (colored)	82.83	1	0.707
			2*	0
			3	0.082
19	Thai*	109.69	2*	0
			3*	0
			4	0.74
	Ormco*	91.35	1*	0
			3	0.14
			4*	0
	G&H*	97.74	1*	0
			2	0.14
			4*	0.02
	Th* (colored)	106.68	1	0.74
			2*	0
			3*	0.02
21	Thai*	122.86	2*	0
			3*	0
			4	0.727
	Ormco*	101.93	1*	0
			3	0.158
			4*	0
	G&H*	108.83	1*	0
			2	0.158
			4*	0.009
	Thai* (colored)	119.45	1	0.727
			2*	0
			3*	0.009

*The mean difference is significant at the 0.05 level.

Table 38. Multiple comparison of force extension of 5/16” elastics (cont.)

Scheffe				
Displacement (mm)	Elastic (1= Thai, 2= Ormco, 3= G&H, 4= Thai(colored)			P-value
		Force (g)		
24	Thai*	138.42	2*	0
			3*	0
			4	0.947
	Ormco*	115.6	1*	0
			3	0.243
			4*	0
	G&H*	122.94	1*	0
			2	0.243
			4*	0.005
	Th* (colored)	136.28	1	0.947
			2*	0
			3*	0.005
27	Thai*	155.26	2*	0
			3*	0
			4	0.749
	Ormco*	128.01	1*	0
			3	0.327
			4*	0
	G&H*	135.08	1*	0
			2	0.327
			4*	0.001
	Thai* (colored)	151.1	1	0.749
			2*	0
			3*	0.001
29	Thai*	165.26	2*	0
			3*	0
			4	0.7
	Ormco*	135.6	1*	0
			3	0.363
			4*	0
	G&H*	142.86	1*	0
			2	0.363
			4*	0
	Th* (colored)	160.45	1	0.7
			2*	0
			3*	0

* The mean difference is significant at the 0.05 level.

Table 38. Multiple comparison of force extension of 5/16” elastics (cont.)

Scheffe				
Displacement (mm)	Elastic (1= Thai, 2= Ormco, 3= G&H, 4= Thai(colored)			P-value
		Force (g)		
39	Thai*	211.5	2*	0
			3*	0
			4	0.8
	Ormco*	173.68	1*	0
			3	0.883
			4*	0
	G&H*	177.9	1*	0
			2	0.883
			4*	0
	Thai* (colored)	206.27	1	0.8
			2*	0
			3*	0
49	Thai*	259.55	2*	0
			3*	0
			4	0.902
	Ormco*	213.93	1*	0
			3	0.98
			4*	0
	G&H*	211.17	1*	0
			2	0.98
			4*	0
	Th* (colored)	254.68	1	0.902
			2*	0
			3*	0
59	Thai*	305.44	2*	0
			3*	0
			4	0.93
	Ormco*	258.02	1*	0
			3	0.11
			4*	0
	G&H*	238.7	1*	0
			2	0.11
			4*	0
	Thai* (colored)	300.3	1	0.93
			2*	0
			3*	0

*The mean difference is significant at the 0.05 level.

Table 38. Multiple comparison of force extension of 5/16” elastics (cont.)

Scheffe				
Displacement (mm)	Elastic (1= Thai, 2= Ormco, 3= G&H, 4= Thai(colored)			P-value
		Force (g)		
69	Thai*	374.82	2*	0
			3*	0
			4	0.699
	Ormco*	313.61	1*	0
			3	0.368
			4*	0
	G&H*	296.08	1*	0
			2	0.368
			4*	0
	Th* (colored)	363.12	1	0.699
			2*	0
			3*	0

* The mean difference is significant at the 0.05 level.

Table 39. One-sample T-Test of standard force index

One-Sample Test of ¼" elastics at 2x internal diameter (Test Value = 127.5)

Elastics	Mean	t	df	Sig. (2-tailed)
Thai*	89.06	-24.21934	14	0
Ormco*	76.09	-31.60294	14	0
G&H*	90.98	-23.92344	14	0
Thai (colored)*	85.40	-30.37265	14	0

One-sample Test of ¼" elastics at 3x internal diameter (Test Value = 127.5)

Elastics	Mean	t	df	Sig. (2-tailed)
Thai*	135.2	3.9020558	14	0.002
Ormco*	113.6	-5.824832	14	0
G&H*	134.6	3.6997086	14	0.002
Thai (colored)	128.0	0.4969613	14	0.627

One-sample Test of 5/16 elastics at 2x internal diameter (Test Value = 127.5)

Elastics	Mean	t	df	Sig. (2-tailed)
Thai*	85.40	-26.77129	14	0
Ormco*	71.88	-27.97481	14	0
G&H*	77.06	-35.58401	14	0
Thai (colored)*	82.83	-40.75999	14	0

One-sample Test of 5/16" elastics at 3x internal diameter (Test Value = 127)

Elastics	Mean	t	df	Sig. (2-tailed)
Thai*	138.4	4.0611572	14	0.001
Ormco*	115.6	-3.78724	14	0.002
G&H	122.9	-1.799259	14	0.094
Thai (colored)*	136.3	5.3247072	14	0

* Significant difference at 0.05 level (2-tailed)

Table 40. Multiple comparison of percentage of force relaxation of 1/4” elastics in static testing

Scheffe

Time (Hrs)	Elastic (1= Thai, 2= Ormco, 3= G&H, 4= Thai(colored))			P-value
	% of force relaxation			
0.25	Thai	14.65	2*	0
			3*	0
			4	0.753
	Ormco*	11.4	1*	0
			3	0.728
			4*	0
	G&H*	12	1*	0
			2	0.728
			4*	0
	Thai (colored)	15.22	1	0.753
			2*	0
			3*	0
0.5	Thai	15.86	2*	0.009
			3*	0.075
			4	0.528
	Ormco*	13.6	1*	0.009
			3	0.857
			4*	0
	G&H*	14.15	1*	0.075
			2	0.857
			4*	0.001
	Thai (colored)	16.8	1	0.528
			2*	0
			3*	0.001
0.75	Thai	16.52	2*	0.034
			3	0.438
			4	0.433
	Ormco*	14.36	1*	0.034
			3	0.593
			4*	0
	G&H	15.34	1	0.438
			2	0.593
			4*	0.017
	Thai* (colored)	17.7	1	0.433
			2*	0
			3*	0.017

* The mean difference is significant at the 0.05 level.

Table 40. Multiple comparison of percentage of force relaxation of 1/4” elastics in static testing (cont.)

Scheffe

Time (Hrs)	Elastic (1= Thai, 2= Ormco, 3= G&H, 4= Thai(colored))			P-value
	% of force relaxation			
1	Thai	17.31	2	0.067
			3	0.389
			4	0.517
	Ormco	15.43	1	0.067
			3	0.803
			4*	0.001
	G&H	16.11	1	0.389
			2	0.803
			4*	0.02
	Thai* (colored)	18.35	1	0.517
			2*	0.001
			3*	0.02
1.5	Thai	17.8	2	0.305
			3	0.982
			4	0.167
	Ormco*	16.67	1	0.305
			3	0.517
			4*	0.001
	G&H	17.56	1	0.982
			2	0.517
			4	0.075
	Thai* (colored)	19.14	1	0.167
			2*	0.001
			3	0.075
2	Thai	18.49	2	0.467
			3	0.993
			4	0.281
	Ormco*	17.6	1	0.467
			3	0.314
			4*	0.009
	G&H	18.65	1	0.993
			2	0.314
			4	0.427
	Thai* (colored)	19.58	1	0.281
			2*	0.009
			3	0.427

* The mean difference is significant at the 0.05 level.

Table 40. Multiple comparison of percentage of force relaxation of 1/4” elastics in static testing (cont.)

Scheffe

Time (Hrs)	Elastic (1= Thai, 2= Ormco, 3= G&H, 4= Thai(colored))			P-value
	% of force relaxation			
4	Thai	19.36	2	0.948
			3	0.07
			4	0.242
	Ormco	19.67	1	0.948
			3	0.221
			4	0.541
	G&H	20.77	1	0.07
			2	0.221
			4	0.933
	Thai (colored)	20.43	1	0.242
			2	0.541
			3	0.933
8	Thai	19.83	2	0.225
			3	0
			4	0.268
	Ormco	20.86	1	0.225
			3*	0.032
			4	1
	G&H*	22.35	1*	0
			2*	0.032
			4*	0.024
	Thai (colored)	20.8	1	0.268
			2	1
			3*	0.024
12	Thai	20.11	2	0.133
			3*	0
			4	0.331
	Ormco	21.42	1	0.133
			3*	0.018
			4	0.96
	G&H	23.22	1*	0
			2*	0.018
			4*	0.004
	Thai (colored)	21.13	1	0.331
			2	0.96
			3*	0.004

* The mean difference is significant at the 0.05 level.

Table 40. Multiple comparison of percentage of force relaxation of 1/4" elastics in static testing (cont.)

Scheffe				
Time (Hrs)	Elastic (1= Thai, 2= Ormco, 3= G&H, 4= Thai(colored))			P-value
	% of force relaxation			
24	Thai	22.02	2	0.112
			3*	0
			4	0.133
	Ormco	23.36	1	0.112
			3*	0.019
			4	1
	G&H*	25.13	1*	0
			2*	0.019
			4*	0.015
	Thai (colored)	23.31	1	0.133
			2	1
			3*	0.015

* The mean difference is significant at the 0.05 level.

Table 41. Multiple comparison of percentage of force relaxation of 5/16” elastics in static testing

Scheffe				
Time (Hrs)	Elastic (1= Thai, 2= Ormco, 3= G&H, 4= Thai(colored)			P-value
	% of force relaxation			
0.25	Thai	13.21	2	1
			3	0.302
			4	0.988
	Ormco	13.12	1	1
			3	0.355
			4	0.996
	G&H	11.61	1	0.302
			2	0.355
			4	0.484
	Thai (colored)	12.92	1	0.988
			2	0.996
			3	0.484
0.5	Thai	14.16	2	0.962
			3	0.673
			4	0.978
	Ormco	14.66	1	0.962
			3	0.375
			4	0.812
	G&H	13	1	0.673
			2	0.375
			4	0.886
	Thai (colored)	13.75	1	0.978
			2	0.812
			3	0.886
0.75	Thai	14.8	2	0.952
			3	0.878
			4	0.992
	Ormco	15.39	1	0.952
			3	0.581
			4	0.846
	G&H	13.99	1	0.878
			2	0.581
			4	0.968
	Thai (colored)	14.49	1	0.992
			2	0.846
			3	0.968

* The mean difference is significant at the 0.05 level.

Table 41. Multiple comparison of percentage of force relaxation of 5/16” elastics in static testing (cont.)

Scheffe

Time (Hrs)	Elastic (1= Thai, 2= Ormco, 3= G&H, 4= Thai(colored))			P-value
	% of force relaxation			
1	Thai	15.05	2	0.796
			3	0.978
			4	0.999
	Ormco	16.07	1	0.796
			3	0.554
			4	0.73
	G&H	14.6	1	0.978
			2	0.554
			4	0.992
	Thai (colored)	14.92	1	0.999
			2	0.73
			3	0.992
1.5	Thai	15.96	2	0.444
			3	0.967
			4	0.996
	Ormco	17.44	1	0.444
			3	0.731
			4	0.324
	G&H	16.42	1	0.967
			2	0.731
			4	0.906
	Thai (colored)	15.74	1	0.996
			2	0.324
			3	0.906
2	Thai	16.69	2	0.171
			3	0.33
			4	0.996
	Ormco	18.3	1	0.171
			3	0.983
			4	0.108
	G&H	18.01	1	0.33
			2	0.983
			4	0.227
	Thai (colored)	16.51	1	0.996
			2	0.108
			3	0.227

* The mean difference is significant at the 0.05 level.

Table 41. Multiple comparison of percentage of force relaxation of 5/16" elastics in static testing (cont.)

Scheffe				
Time (Hrs)	Elastic (1= Thai, 2= Ormco, 3= G&H, 4= Thai(colored))			P-value
	% of force relaxation			
4	Thai*	17.49	2*	0.002
			3*	0.014
			4	0.985
	Ormco	20.23	1*	0.002
			3	0.92
			4*	0
	G&H	19.76	1*	0.014
			2	0.92
			4*	0.005
	Thai* (colored)	17.23	1	0.985
			2*	0
			3*	0.005
8	Thai*	18.4	2*	0
			3*	0
			4	0.992
	Ormco	21.93	1*	0
			3	0.997
			4*	0
	G&H	21.78	1*	0
			2	0.997
			4*	0
	Thai* (colored)	18.21	1	0.992
			2*	0
			3*	0
12	Thai*	18.72	2*	0
			3*	0
			4	0.988
	Ormco	22.09	1*	0
			3	1
			4*	0
	G&H	22.16	1*	0
			2	1
			4*	0
	Thai* (colored)	18.49	1	0.988
			2*	0
			3*	0

* The mean difference is significant at the 0.05 level

Table 41. Multiple comparison of percentage of force relaxation of 5/16” elastics in static testing (cont.)

Scheffe

Time (Hrs)	Elastic (1= Thai, 2= Ormco, 3= G&H, 4= Thai(colored))			P-value
	% of force relaxation			
24	Thai*	20.29	2*	0
			3*	0
			4	0.99
	Ormco	24.84	1*	0
			3	1
			4*	0
	G&H	24.82	1*	0
			2	1
			4*	0
	Thai* (colored)	20.49	1	0.99
			2*	0
			3*	0

* The mean difference is significant at the 0.05 level.

Table 42. Multiple comparison of percentage of force relaxation of 1/4” elastics in dynamic testing

Scheffe

Time (Hrs)	Elastic (1= Thai, 2= Ormco, 3= G&H, 4= Thai(colored))			P-value
	% of force relaxation			
0.25	Thai	16.14	2	0.449
			3	0.991
			4	0.534
	Ormco*	15.35	1	0.449
			3	0.285
			4*	0.028
	G&H	16.3	1	0.991
			2	0.285
			4	0.722
	Thai* (colored)	16.86	1	0.534
			2*	0.028
			3	0.722
0.5	Thai	17.23	2	0.998
			3	0.086
			4	0.327
	Ormco	17.13	1	0.998
			3	0.055
			4	0.239
	G&H	18.44	1	0.086
			2	0.055
			4	0.902
	Thai (colored)	18.09	1	0.327
			2	0.239
			3	0.902
0.75	Thai	17.73	2	0.928
			3*	0.004
			4	0.282
	Ormco	18.07	1	0.928
			3*	0.025
			4	0.64
	G&H*	19.66	1*	0.004
			2*	0.025
			4	0.33
	Thai (colored)	18.72	1	0.282
			2	0.64
			3	0.33

* The mean difference is significant at the 0.05 level.

Table 42. Multiple comparison of percentage of force relaxation of 1/4” elastics in dynamic testing (cont.)

Scheffe				
Time (Hrs)	Elastic (1= Thai, 2= Ormco, 3= G&H, 4= Thai(colored)			P-value
	% of force relaxation			
1	Thai*	18.46	2	0.848
			3*	0.016
			4	0.417
	Ormco	18.94	1	0.848
			3	0.126
			4	0.886
	G&H*	20.25	1*	0.016
			2	0.126
			4	0.448
	Thai (colored)	19.37	1	0.417
			2	0.886
			3	0.448
1.5	Thai	18.86	2	0.385
			3*	0
			4	0.46
	Ormco	19.7	1	0.385
			3*	0.012
			4	0.999
	G&H*	21.35	1*	0
			2*	0.012
			4*	0.009
	Thai (colored)	19.64	1	0.46
			2	0.999
			3*	0.009
2	Thai	19.44	2	0.157
			3*	0
			4	0.795
	Ormco	20.76	1	0.157
			3	0.059
			4	0.634
	G&H*	22.34	1*	0
			2	0.059
			4*	0.002
	Thai (colored)	20.02	1	0.795
			2	0.634
			3*	0.002

* The mean difference is significant at the 0.05 level.

Table 42. Multiple comparison of percentage of force relaxation of 1/4” elastics in dynamic testing (cont.)

Scheffe

Time (Hrs)	Elastic (1= Thai, 2= Ormco, 3= G&H, 4= Thai(colored))			P-value
	% of force relaxation			
4	Thai	20.14	2	0.07
			3*	0
			4	0.631
	Ormco	21.68	1	0.07
			3*	0.006
			4	0.576
	G&H*	23.76	1*	0
			2*	0.006
			4*	0
	Thai (colored)	20.88	1	0.631
			2	0.576
			3*	0
8	Thai	21	2*	0.001
			3*	0
			4	0.541
	Ormco	22.87	1*	0.001
			3*	0
			4	0.062
	G&H*	25.19	1*	0
			2*	0
			4*	0
	Thai (colored)	21.65	1	0.541
			2	0.062
			3*	0
12	Thai*	21.33	2*	0.007
			3*	0
			4	0.63
	Ormco*	23	1*	0.007
			3*	0
			4	0.15
	G&H*	25.5	1*	0
			2*	0
			4*	0
	Thai (colored)	21.93	1	0.63
			2	0.15
			3*	0

* The mean difference is significant at the 0.05 level.

Table 42. Multiple comparison of percentage of force relaxation of 1/4” elastics in dynamic testing (cont.)

Scheffe

Time (Hrs)	Elastic (1= Thai, 2= Ormco, 3= G&H, 4= Thai(colored))			P-value
	% of force relaxation			
24	Thai*	22.2	2*	0.004
			3*	0
			4	0.617
	Ormco*	23.99	1*	0.004
			3*	0
			4	0.111
	G&H*	26.86	1*	0
			2*	0
			4*	0
	Thai (colored)	22.82	1	0.617
			2	0.111
			3*	0

* The mean difference is significant at the 0.05 level.

Table 43. Multiple comparison of percentage of force relaxation of 5/16” elastics in dynamic testing

Scheffe

Time (Hrs)	Elastic (1= Thai, 2= Ormco, 3= G&H, 4= Thai(colored))			P-value
	% of force relaxation			
0.25	Thai	15.74	2	0.992
			3	0.555
			4	0.998
	Ormco	15.93	1	0.992
			3	0.384
			4	0.969
	G&H	14.85	1	0.555
			2	0.384
			4	0.661
	Thai (colored)	15.62	1	0.998
			2	0.969
			3	0.661

Table 43. Multiple comparison of percentage of force relaxation of 5/16” elastics in dynamic testing (cont.)

Scheffe				
Time (Hrs)	Elastic (1= Thai, 2= Ormco, 3= G&H, 4= Thai(colored))			P-value
	% of force relaxation			
0.5	Thai	16.7	2	0.422
			3	0.987
			4	1
	Ormco	17.73	1	0.422
			3	0.248
			4	0.393
	G&H	16.47	1	0.987
			2	0.248
			4	0.992
	Thai (colored)	16.66	1	1
			2	0.393
			3	0.992
0.75	Thai	17.65	2	0.174
			3	1
			4	0.94
	Ormco	18.91	1	0.174
			3	0.159
			4	0.449
	G&H	17.62	1	1
			2	0.159
			4	0.926
	Thai (colored)	18	1	0.94
			2	0.449
			3	0.926
1	Thai*	17.88	2*	0.028
			3	0.995
			4	0.996
	Ormco*	19.69	1*	0.028
			3	0.052
			4	0.051
	G&H	18.03	1	0.995
			2	0.052
			4	1
	Thai (colored)	18.03	1	0.996
			2	0.051
			3	1

* The mean difference is significant at the 0.05 level.

Table 43. Multiple comparison of percentage of force relaxation of 5/16" elastics in dynamic testing (cont.)

Scheffe				
Time (Hrs)	Elastic (1= Thai, 2= Ormco, 3= G&H, 4= Thai(colored)			P-value
	% of force relaxation			
1.5	Thai	18.49	2	0.101
			3	0.527
			4	1
	Ormco	20.11	1	0.101
			3	0.774
			4	0.123
	G&H	19.44	1	0.527
			2	0.774
			4	0.584
	Thai (colored)	18.55	1	1
			2	0.123
			3	0.584
2	Thai*	18.8	2*	0.001
			3*	0.044
			4	0.984
	Ormco*	21.07	1*	0.001
			3	0.609
			4*	0.004
	G&H	20.35	1*	0.044
			2	0.609
			4	0.104
	Thai (colored)	19.01	1	0.984
			2*	0.004
			3	0.104
4	Thai*	19.46	2*	0
			3*	0.002
			4	0.929
	Ormco	22.3	1*	0
			3	0.674
			4*	0
	G&H	21.64	1*	0.002
			2	0.674
			4*	0.011
	Thai* (colored)	19.81	1	0.929
			2*	0
			3*	0.011

* The mean difference is significant at the 0.05 level.

Table 43. Multiple comparison of percentage of force relaxation of 5/16” elastics in dynamic testing (cont.)

Scheffe

Time (Hrs)	Elastic (1= Thai, 2= Ormco, 3= G&H, 4= Thai(colored))			P-value
	% of force relaxation			
8	Thai*	19.92	2*	0
			3*	0
			4	0.926
	Ormco	23.29	1*	0
			3	0.993
			4*	0
	G&H	23.14	1*	0
			2	0.993
			4*	0
	Thai* (colored)	20.28	1	0.926
			2*	0
			3*	0
12	Thai*	20.5	2*	0
			3*	0
			4	1
	Ormco	23.87	1*	0
			3	0.873
			4*	0
	G&H	23.43	1*	0
			2	0.873
			4*	0
	Thai* (colored)	20.53	1	1
			2*	0
			3*	0
24	Thai*	21.1	2*	0
			3*	0
			4	0.938
	Ormco	24.83	1*	0
			3	0.99
			4*	0
	G&H	25.01	1*	0
			2	0.99
			4*	0
	Thai* (colored)	21.46	1	0.938
			2*	0
			3*	0

* The mean difference is significant at the 0.05 level.

BIOGRAPHY

NAME	Miss Chidruthai Boonyanate
DATE OF BIRTH	8 October 1974
PLACE OF BIRTH	Loei, Thailand
INSTITUTIONS ATTENDED	Mahidol University, 1992-1997: Doctor of Dental Surgery Mahidol University, 2002-2004: Master of Science (Orthodontics)
POSITION & OFFICE	Dental division of Loei Hospital, Ministry of Public Health