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PRESSURE TRANSMISSION AND DISTRIBUTION OF DIFFERENT THERMOPLASTIC RESIN DENTURE BASES UNDER IMPACT LOAD

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A Thesis Submitted in Partial Fulfillment of the Requirements
for the Degree of Master of Science Program in Prosthodontics
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Field of Study	Prosthodontics
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ฮับบัน นาซูตัน : การส่งและการกระจายของแรงกดของวัสดุฐานฟันปลอมชนิดต่างๆ ที่อ่อนตัวเมื่อถูกความร้อนภายใต้แรงกระแทก (PRESSURE TRANSMISSION AND DISTRIBUTION OF DIFFERENT THERMOPLASTIC RESIN DENTURE BASES UNDER IMPACT LOAD) อ.ที่ปรึกษาวิทยานิพนธ์หลัก: แมนสรวง อักษรนุกิจ, 71 หน้า.

การส่งและการกระจายแรงกดของวัสดุฐานฟันปลอมมีความแตกต่างกันขึ้นอยู่กับชนิดของวัสดุฐานฟันปลอมที่เลือกใช้ วัตถุประสงค์ของการศึกษาครั้งนี้ คือ เพื่อทดสอบการส่งและการกระจายแรงกดของวัสดุฐานฟันปลอมชนิดที่อ่อนตัวเมื่อถูกความร้อนภายใต้แรงกระแทกและวัสดุฐานฟันปลอมโพลีเมทิล เมตาคริเลทชนิดบ่มตัวด้วยความร้อน รวมถึงเพื่อประเมินค่าความยืดหยุ่นของโมดูลัสและความแข็งผิวระดับนาโนของวัสดุฐานฟันปลอมชนิดที่อ่อนตัวเมื่อถูกความร้อนและวัสดุฐานฟันปลอมโพลีเมทิลเมตาคริเลทชนิดบ่มตัวด้วยความร้อน วัสดุฐานฟันปลอมที่นำมาศึกษาในครั้งนี้ประกอบด้วยวัสดุฐานฟันปลอมชนิดที่อ่อนตัวเมื่อถูกความร้อน 3 ชนิด (โพลีเอไมด์ 3 ชนิด: FRS TCS และ VAL โพลีคาร์บอเนต: BPC เอทิลีน โพรไพลีน: DUR) และวัสดุฐานฟันปลอมโพลีเมทิล เมตาคริเลทชนิดบ่มตัวด้วยความร้อน (TRI) โดยฝังซี่ฟันปลอมกรามล่างซี่แรกชนิดอะคริลิกเรซินในทุกชิ้นตัวอย่างของกลุ่มฐานฟันปลอม (จำนวนตัวอย่าง = 6) ค่าพื้นที่การส่งและกระจายแรง และค่าแรงดันสูงสุดของทุกชิ้นตัวอย่างภายใต้แรงกระแทกขนาด 50 นิวตันได้รับการตรวจด้วยแผ่นทดสอบแรงดันร่วมกับโปรแกรมวิเคราะห์ระดับดิจิทอล สำหรับค่าความยืดหยุ่นของโมดูลัสและค่าความแข็งผิวระดับนาโนของทุกกลุ่มวัสดุฐานฟันปลอม (จำนวนตัวอย่าง = 10) ถูกวัดโดยใช้ระบบเครื่องวัดความแข็งผิวระดับนาโน ข้อมูลพื้นที่การส่งและกระจายแรงกด ความยืดหยุ่นของโมดูลัสและค่าความแข็งผิวระดับนาโนนำมาวิเคราะห์ทางสถิติด้วยการวิเคราะห์ค่าความแปรปรวนทางเดียว ตามด้วยการวิเคราะห์เปรียบเทียบเชิงซ้อนชนิดเทมแฮน ขณะที่ค่าความแข็งผิวระดับนาโนใช้ทูกี้เฮชเอสดี สำหรับค่าแรงดันสูงสุดนำมาวิเคราะห์ค่าความแปรปรวนด้วยการทดสอบครัสครัล-วอลลิสตามด้วยการทดสอบแมนวิทนียูที่ระดับความเชื่อมั่น 0.05 ผลการศึกษาพบว่าพื้นที่การส่งและการกระจายแรงกดของกลุ่ม TCS แสดงค่าสูงที่สุดขณะที่กลุ่ม DUR แสดงค่าต่ำที่สุด ค่าแรงกดสูงสุดของกลุ่ม VAL TCS และ BPC มีค่าไม่แตกต่างกันและต่ำกว่ากลุ่ม TRI สำหรับค่าความยืดหยุ่นของโมดูลัสและค่าความแข็งผิวระดับนาโนของกลุ่มวัสดุฐานฟันปลอมชนิดที่อ่อนตัวเมื่อถูกความร้อนทั้งหมดมีค่าต่ำกว่ากลุ่ม TRI

ภาควิชา	ทันตกรรมประดิษฐ์	ลายมือชื่อนิสิต	....
สาขาวิชา	ทันตกรรมประดิษฐ์	ลายมือชื่อ อ.ที่ปรึกษาหลัก	....
ปีการศึกษา	2559		

5675836732 : MAJOR PROSTHODONTICS
KEYWORDS: IMPACT LOAD / PRESSURE TRANSMISSION AND DISTRIBUTION / THERMOPLASTIC RESIN DENTURE BASES

HUBBAN NASUTION: PRESSURE TRANSMISSION AND DISTRIBUTION OF DIFFERENT THERMOPLASTIC RESIN DENTURE BASES UNDER IMPACT LOAD. ADVISOR: ASSOC. PROF. MANSUANG ARKSORNNUKIT, Ph.D., 71 pp.

Pressure transmission and distribution under a denture base may be different depending on the denture base materials used. The purposes of the present study were to examine the pressure transmission and distribution of thermoplastic resin denture base materials and a heat-polymerized polymethyl methacrylate (PMMA) denture base material under an impact load, and to evaluate the modulus of elasticity and nanohardness of the thermoplastic resin denture bases. Five different thermoplastic resin denture base materials (three polyamide: FRS, TCS and VAL, one polycarbonate: BPC and one ethylene propylene: DUR) and one PMMA (TRI) denture base material with a mandibular first molar acrylic resin denture tooth set in each denture base specimen (n=6) were evaluated. Pressure transmission area and maximum pressure of the specimens under an impact load of 50 N were observed using pressure sensitive sheets and digital analysis software. The modulus of elasticity and the nanohardness of the denture bases (n=10) was measured using a nanoindentation system. The pressure transmission area, modulus of elasticity and the nanohardness data were statistically analyzed using one-way ANOVA, followed by Tamhane's post hoc multiple comparison test, whereas the nanohardness data was followed by Tukey HSD test (α = 0.05). The maximum pressure data were statistically analyzed using Kruskal-Wallis H test, followed by Mann-Whitney U test (α = 0.05). The pressure transmission area of the TCS group showed the greatest, while that of DUR showed the lowest ($P < 0.05$). The maximum pressure of VAL, TCS and BPC were comparable, and dramatically lower than that of TRI. All modulus of elasticity and nanohardness of all thermoplastic resin denture base material groups demonstrated lower than those of TRI ($P < 0.05$).

Department:	Prosthodontics	Student's Signature	....
Field of Study:	Prosthodontics	Advisor's Signature	....
Academic Year:	2016		

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LIST OF ABBREVIATIONS

PMMA	Polymethyl methacrylate
RPDs	Removable partial dentures
WHO	World health organization
kPa	Kilopascal
GPa	Gigapascal
w/w	Weight per weight
ISO	International organization for standardization
MPa	Megapascal
μm	Micrometer
psi	Pounds per square inch
RH	Relative humidity
mm	Millimeter
°C	Degree of celcius
min	Minute
rpm	Revolutions per minute
N	Newton
Kg	Kilogram
mN	Millinewton
ANOVA	Analysis of variance

CHAPTER I

INTRODUCTION

Edentulous patients often require treatment for replacement of missing teeth to improve esthetics, function, and speech. Removable prosthesis is one of the dental services which improving the quality of life in these patients.[1, 2] The worldwide incidence of edentulism has shown a decline, and the demand of the treatment may differ from several decades ago.[1, 2] The significant problem of the edentulism is the continuously residual ridge resorption both its height and width which leads to the reduction of the denture bearing area. The resorption of residual ridge is a chronic, gradually progressing, irreversible, and cumulative process.[3] The bone resorption rate is highest in the first 6 months after extraction and dramatically decelerates. It is, however, noticeable even 25-years post extraction. The loss of proprioceptors which are found especially in the periodontal ligament might be the reason of this bone loss phenomenon. After total teeth loss, the facial height and appearance of the patients are consequently violated.[5] Moreover, the aggressive pressure from the impropriate prosthesis is also an important factor in increasing residual ridge resorption in the denture wearers.[3]

The etiology of residual ridge resorption is considered to be multifactorial, which differs from one patient to the others. Several studies[4, 5] indicated that the high pressure applied on the ridge is a major concern. It is widely accepted that the bone loss is primarily induced by functional load transmitted to the soft tissue, and it continually happens through the rest of patient life.[6] The well-design denture might decrease the bone resorption rate by distributing the occlusal force and its direction under the physiological tolerance of the alveolar bone, and then the bone apposition would be observed. The artificial tooth and the denture base material selections are also the crucial steps for reducing pressure or avoiding stress concentration in the supporting tissue.[7]

The occlusal force reduction of the denture base and the artificial tooth might be the effect of the material selected. Polymethyl methacrylate (PMMA) is the common used denture base material. Currently, injection-molded thermoplastic resins (polyamide, polycarbonate, and ethylene propylene) are considered to be the alternative denture base materials especially in removable partial dentures (RPDs) due to their higher elasticity, esthetics, biocompatibility and comfort comparing to the conventional heat-polymerizing acrylic resin.[10, 12] These materials would be selected in the patients with the high esthetic demand, although the discoloration, the difficulty to polishing and adjusting retention, breakage of resin clasp and contributing in gingival recession have been reported.[12]

Several studies evaluated the amount and distribution of the occlusal pressure transmission under acrylic resin denture base[8-12], while those under the thermoplastic resin denture base materials are still unclear. Regarding the amount of the pressure transmission and the distribution measurements, the strain gauge and the pressure transducer are suggested as the common used methods, but they are suitable only for measuring pressure at certain sites.[12, 13] A pressure-sensitive sheets (Prescale Film, Fuji Photo Film Co. Ltd, Tokyo, Japan) would be an alternative method developed and used as a pressure-detecting device for measuring occlusal pressure, occlusal force, and occlusal contact areas.[14, 15] The pressure amount and distribution area beneath the denture base would be interpreted by the different red color shades change of the sheet after the load is applied. Due to its easiness and capacity in detecting large pressure ranges and large distribution areas, this film may be considered one of the most beneficial devices for pressure measurement.[14-16]

Regarding the mechanical properties of the denture base materials, the pressure transmission and distribution on the residual ridges might be under the influent of their modulus of elasticity and nanohardness because they describe the relative stiffness or the rigidity of the materials.[17] Theoretically, thermoplastic resin denture base have a lower modulus of elasticity and hardness comparing to the acrylic resin denture base.[18, 19] The nanohardness is defined as the resistance of a material to permanent surface indentation or penetration. Denture base with a higher nanohardness could endure excessive wear from toothbrush, denture cleanser and food better rather than a softer material.[20]

Therefore, the purposes of the present study were to examine the pressure transmission and the distribution of the thermoplastic resin denture base materials and a heat-polymerizing acrylic resin under an impact load, and to evaluate the modulus of elasticity and the nanohardness of the denture base materials. The null hypotheses were that there would be no significant differences in the pressure transmission, the pressure distribution, the modulus of elasticity and the nanohardness among the thermoplastic resin denture base materials and a heat-polymerizing acrylic resin.

CHAPTER II

LITERATURE REVIEW

2.1 Edentulism

Edentulism is defined as the multifactorial status of the patients with the state of being edentulous; without natural teeth.[21] The prevalence of the edentulism varies across countries, and the worldwide edentulism prevalence became to decrease since the several past decades. The edentulism is clearly cumulating into the senile population. There have been some arguments over the number of current and future edentulous patient status in Thailand. It was stated in Bulletin of WHO 2005 that the prevalence of edentulism in Thailand was 16% in the over 65-year-old population.[2] Additionally, the 7th Thailand National Oral Health Survey in 2012 stated that the percentage of over 60-year-old population with edentulism was 7.2%.[22] The causes of the teeth loss were mainly the dental caries and the periodontal disease. The global report[27] stated that the 30% of the 65 to 74-year-old population experienced the complete loss of natural teeth.

The loss of teeth, both partial loss and total loss, impairs the patient appearance and functions. The lip and cheek of the patients without teeth would be droopy, and facial sulci would be clearly observed. The facial height would be decrease because of loss of posterior teeth support. Apart from the esthetics, the phonetic and mastication would also be impaired. Some consonants need teeth, tongue and/or lips to express clearly, i.e. “F, V, S sound”. The edentulous condition would also disturb the chewing ability and consequently affected on the digestion and nutrient absorption.[5] Moreover, the presence of teeth would preserve and maintain the height of the alveolar ridge.

2.2 Alveolar Ridge Resorption

The alveolar ridges are the remaining part of the alveolar process covered with the oral soft tissue after the teeth removal.[21] According to Wolff's law, the alveolar bone is unique when the teeth exist because the presence of periodontal ligament will stimulate bone apposition, causing bone strengthening and continuously renewal. Teeth provide this direct stimulation which develops stronger bone around them.[23] The alveolar bone will reduce in height and width, when the teeth were removed due to loss of periodontal ligament. [24] Many factors such as age, oral hygiene, parafunction, occlusal load, impact force and osteoporosis were considered as the cause of alveolar bone resorption; however, the main factor of the residual ridge resorption had not yet been elucidated.[25] Tallgren showed that denture wearers had continuous bone loss over the years.[26] Severe residual ridge resorption may occur even though the remaining alveolar bone is observed.[27] The blood circulation inside the bone might be a clue to predict the bone resorption. The continuous mechanical pressure higher than 1.3 kPa should not be exerted to the denture-supporting tissues[28], because it might disturb normal blood circulation. The continuous mechanical pressure of 1.3 kPa would compress soft tissues to the thickness of 95% of the tissue at rest. On the other hand, the progressive bone loss without the proper prosthesis replacement and the rehabilitation of the masticatory organ can contribute to numerous unfavorable consequences.[29]

Alveolar ridge resorption could be reduced when the well-design prostheses were in function. While the occlusal force transmitting from the artificial teeth to the denture base is subsequently transferred to the supporting oral structures, the force would be minimized and were within the range of physiologically functional forces. It is clearly demonstrated that oral tissues placed under functional stress within their physiologic tolerance could maintain the quantitative and the qualitative of the bone. The term of atrophy is applicable to both periodontal tissues and the tissues of a residual ridge. The high pressure from poor prostheses is an important factor that would develop the residual ridge atrophy or resorption in the denture wearers. To control the residual ridge resorption, the proprioceptors in the oral mucosa beneath the denture play the important role to automatically trigger the neuromuscular reflex to inhibit the impact force which is greater than the physiologic functional force.[35] Moreover, the proper selections of denture teeth and denture base are the recommended methods to reduce the residual ridge resorption rate.[33]

2.3 Denture Teeth

The denture teeth available are made of the acrylic resin, the acrylic resin with copolymer or fillers and the porcelain. The acrylic resin teeth and their modification in molecular structure groups are commonly used in the fabrication of complete and partial dentures due to their appearance and cost. Porcelain denture teeth are the alternative because they have better color stability, higher strength and hardness. However, the porcelain is brittle and fractures easily after a period of service. The reason that the acrylic resin teeth is commonly selected in the dental service might be some advantages over the porcelain teeth, i.e. excellent fracture toughness, easy occlusal adjustment and high bond strength to denture base materials, but their wear resistance has been doubted. To improve the mechanical properties and wear resistance of the acrylic resin denture teeth, the modified polymer structure denture teeth, especially composite resin denture teeth, have been invented. The composite resins containing the filler particles and/or the cross-linked polymers are used as the alternative materials of choice for artificial teeth.[30-32]

One of the main properties of the denture teeth is the stress absorbance from the masticatory force to reduce the occlusal force that transferred to the oral tissue. Comparing to the porcelain denture teeth, the occlusal force transferring to the oral soft tissue is reduced approximately two-third of the force when the acrylic resin teeth used, while the composite resin denture teeth could reduce one-third of occlusal force.[31] This evidence supported that the porcelain denture teeth are rigid, whereas the acrylic resin and their structure modification denture teeth are comparable resilient.

The viscoelastic property of the denture teeth materials which might reduce the occlusal force was also reported. The viscoelastic property of acrylic resin teeth was greater than that of porcelain teeth. The acrylic resin teeth would absorb the transferred energy from the masticatory force approximately 20% greater than the porcelain teeth. It would be concluded that the acrylic resin teeth should be selected when the higher energy absorbance property is required. The differences between the acrylic resin teeth and the porcelain teeth are also described in the others mechanical properties. Although porcelain teeth have good hardness, they are not ideal because the material is brittle, and has no chemical bond to the denture base. The fracture load, ultimate strength, absorbed energy, and deformation in the static condition of the acrylic resin teeth were greater than those of the porcelain teeth, whereas the greater elastic modulus of the porcelain teeth were shown in the porcelain teeth.[33] Regarding the hardness, the hardness of the composite resin teeth (0.17 to 0.56 GPa) is equivalent to 0.03 hardness of the porcelain teeth and 1.67 hardness of acrylic resin teeth (0.22 to 1.22 GPa).[35, 39]

2.4 Denture Base

Denture base is a part of the removable denture that rests on the foundation tissues and to which the artificial teeth are attached.[21] The majority of denture bases are fabricated using common polymers due to their availability, dimensional stability, handling characteristics, appearance and compatibility to oral tissues. The physical properties of denture base materials are critical to fit the requirements of removable dental prostheses.[34] The physical and mechanical properties of the ideal denture base materials are summarized as follows: [33]

1. Biocompatible: nontoxic, no irritant
2. Adequate physical and mechanical properties:
   - High flexural, transverse and impact strength
   - High modulus of elasticity for better rigidity
   - Long fatigue life
   - High abrasion, creep and craze resistance

- Good thermal conductivity
- Low density
- Low solubility and sorption of oral fluids
- Softening temperature higher than that of oral fluids and food
- Dimensionally stable and accurate
- Superior esthetics and color stability
- Radiopacity
- Good bond with denture teeth and liners
- Ease of fabrication with minimum expenses
- Easily repaired if fractured
- Readily cleansable

At present, no denture base material achieves all requirements, nor is likely to be developed in the near future. However, the researchers have been continuously attempted to develop the denture base materials including the acrylic resin and metal alloy to achieve all the ideal requirements.

2.4.1 PMMA Denture Base

Since 1937, the PMMA has been used to fabricate the denture bases. This material becomes a recommended material due to its adequate physical properties and acceptable esthetics, simplicity for fabrication, and low cost. The PMMA has its inherent limitation and does not fulfill all the requirements of a hypothetically ideal denture base material. Several problems of the prostheses fabricated from the PMMA are the rigidity when the prostheses would be delivered to the patients with the residual ridge undercut, brittle that leads to fracture, and allergy to methyl methacrylate monomer.[29]

2.4.2 Thermoplastic Resin Denture Base Materials

The thermoplastic resin denture base materials were classified as an alternative denture base material because of their preferable esthetics, biocompatibility and no adverse reaction to the human. The manufacturers claim the benefit of their products that is more flexible than the conventional acrylic resin. The patients with high esthetic requirement or with the undercut through the residual ridge are recommended using this material.[41-46]

2.4.2.1 Polyamide

The innovation of nylon as a denture base material in the 1950s paved the way for a new type of dentures.[35] Nylon is a generic name used for certain types of thermoplastic polymers to the class known as polyamide, derived from diamine and dibasic acid. Several studies suggested the polyamide as an alternative denture base material according to their acceptable mechanical properties including flexural strength, modulus of elasticity, deflection at breakage, and tensile strength of nylon as a denture base material.[18, 19, 36-38]

2.4.2.2 Polycarbonate

Polycarbonate is used to fabricate temporary crown and denture base. The polycarbonate consists of the linear polyester of carbonic acid in which an aliphatic, aliphatic-aromatic, or aromatic groups are present. In comparison with the PMMA, these materials have excellent impact and fatigue strength and good dimensional stability.[39]

2.4.2.3 Ethylene Propylene

Ethylene propylene denture base material has a semi-crystalline polymer structure which causes improvement in both strength and durability. It is manufactured with non-polar elastomers which are resistant to polar solvents such as water, acids and alkalis and is highly resistant to water absorption. Ethylene propylene exhibits high chemical resistance and poor surface adhesions properties, food will not stick to the surface of the appliance assuring a clean denture, credited to the low surface free energy of the material. Ethylene propylene is inert and does not contain phthalates which mitigates the concerns in regards to the allergies. It is resilient and can be easily adjusted and polished chairside unlike nylon material which is quite difficult to polish after adjustment. It is also a transparent, life like, color stable and resilient material with natural translucency, assuring positive esthetics resulting in greater patient acceptance.[40]

2.4.3 Mechanical Properties of the Thermoplastic Resin Denture Base Materials

2.4.3.1 Flexural Strength and Modulus of Elasticity

Flexural strength and modulus of elasticity of polyamide denture base materials (Valplast, Lucitone FRS and Flexite Supreme) were lower than the other thermoplastic materials (polycarbonate and polyethylene terephthalate resin).[19] Polyamide did not have aromatic ring in the structure, thus, it is wondered that penetration of water molecules into the polymer structure influenced the flexural strength. However, they showed great toughness and endurance to fracture compared with conventional PMMA (Acron). Furthermore, the tensile strength test showed that polyamide can endure stress through a substantial degree of deflection. These properties offered the advantage for non-metal clasp dentures because of providing retention through the use of undercut on the remaining teeth, and therefore relieving the denture pain caused by the disproportionate local pressure.

The properties of a nylon 12 denture base material were compared with conventional denture base materials and a commercial nylon 12 with 50% glass spheres weight/weight to see the strength.[35] It showed that the strength of nylon 12 was significantly greater than that the other polymers tested and therefore nylon 12 is mostly useful in repeated fracture cases. Although patients often comment on the improved comfort of nylon denture bases, the flexibility of nylon may be regarded as a drawback where partial denture construction is concerned. The addition of glass spheres to the commercial nylon improved stiffness to the polymer, and so there may be advantages in investigating the role of different filler for this reason.

Flexural properties of a nylon denture base material (Lucitone FRS) were compared with a conventional compression molded heat-polymerized (Meliodent), compression molded microwave-polymerized (Acron MC), and injection-molded microwave-polymerized (Lucitone 199) PMMA polymers after stored in disinfectant solution.[41] Nylon showed a lower flexural strength than the two compression-molded PMMA polymers but a comparable value with Lucitone 199, it means that nylon is less rigid than the conventional PMMA polymers. In addition, Nylon also has the lowest flexural modulus when not disinfected, while the disinfected specimens (with an oxygen-releasing disinfectant solution) had a higher value.

Another study [36] investigated the mechanical properties of two polyamides (Nylon 12 and Nylon PACM12), one polyethylene terephthalate and one polycarbonate with a conventional heat-polymerized PMMA. It showed that all of the injection-molded thermoplastic resins had significantly lower flexural strength at proportional limit, lower modulus of elasticity, and higher or similar impact strength compared to the conventional PMMA. The findings imply that a denture base constructed from a polyamide tends to have permanent deformation during mastication. In this case, the residual ridge under the denture base will absorb the vertical stress occurred from the distortion. Therefore, it is recommended that a denture base constructed from polyamide denture base resin should be reinforced. The clinicians should be really conscious of these properties in order to choose the most appropriate one for RPDs without metal clasps that is suitable for each patient.

A study about thermocycling effect in thermoplastic materials [37] reported that thermocycling significantly decreased the flexural strength and elastic modulus of one polyamide (Valplast), while it significantly increased the same features in the other polyamide (Lucitone FRS). The impact strength of one of the polyamides (Lucitone FRS) also decreased by thermocycling, revealing that thermal stress would affect the mechanical properties of these materials.

A mechanical and thermal characteristics of polyamide (Valplast) were compared with the conventional PMMA and esthetic fiber (E-glass, Nylon 6, Nylon 6.6) reinforced PMMA denture base materials.[38] They used the three-point bending test on a computer-aided universal test device to conduct the transverse test; it showed that Valplast had the highest transverse strength, and no fracture was observed in this group. It was noticed that the values of maximum impact strength were the highest for Valplast compared to the other groups. The modulus of elasticity in all experimental groups was lower than that of the control group (PMMA). This might attribute to the chemical configuration of Valplast which allows it for superior force absorption and is different from PMMA.

Another research about polycarbonate [36] showed that polycarbonate has higher flexural strength at proportional limit compared to polyamide but lower than PMMA and polyethylene terephtalate. The modulus of elasticity of polycarbonate was higher than polyamide and polyethylene terephtalate but lower than PMMA. The impact strength of polycarbonate was higher than PMMA, polyethylene terephtalate and polyamide (except Lucitone FRS). These finding indicate that polycarbonate has a better dimensional stability and rigidity than polyamide but tend to cause stress transferred to the abutment teeth during insertion and removal of denture. Preferably, a thermoplastic resin denture base has a high flexural strength at proportional, low modulus of elasticity, and high impact strength because it can avoid permanent deformation and offers easiness of insertion and removal of a denture.

2.4.3.2 Hardness

PMMA demonstrated superior hardness values when compared with flexible resin. This might attribute to crosslinking in polymer structure of PMMA. Flexible resin demonstrated lower hardness values and showed a lower amounts of cross-linking agents. Therefore, crosslinking agent may influence surface hardness.[42]

Dentures made of a polyamide resin (Valplast), a polyester resin (Esthe Shot) and a conventional heat polymerized resin (Physio Resin) were compared in terms of the rigidity.[20] The polyamide resin denture showed the highest flexure sinking, exerted the highest pressure on the underlying mucosa, and showed significant differences with the other types of dentures. Also it showed that the denture made of polyamide resin had the lowest degree of elasticity; thus, the material could cause displacement of denture. It was concluded that this material required to be reinforced by using metal frames in order to avoid the deformations caused by occlusal forces.

2.4.3.3 Water Sorption and Dimensional Stability

A viscoelastic property study[43] of denture base resins obtained by underwater test showed that water absorption of the PMMA group which was 1.81-1.85% relatively large in comparison to other materials. This value was within the range from 0.38 to 1.74% for polycarbonate, polysulfone, and polyethersulfone. The diffusion coefficient of water for polycarbonate, polysulfone and polyethersulfone increased by approximately 1.5-2.7 times that of PMMA. It can be seen that this is closely connected with their molecular structure (including the benzene ring group which plays a role of preventing flow). In contrast, the PMMA group materials are apt to deform by water absorption.

Dimensional stability and dehydration of polycarbonate denture base resin were compared to two conventional PMMA denture base resins.[44] The mean palatal dimensional change in polycarbonate was generally less than the conventional resin during dehydration but was not statistically different from the conventional resins after processing and during immersion. For mean percentage of mass loss, the conventional resin constantly showed higher, statistically significant values compared with the polycarbonate. This difference in behavior between the polycarbonate and PMMA is probably because of a smaller water loss for the polycarbonate. The effect of water loss on dimensional change of denture would be essential in the event that a denture was not in use and not kept in water for an extended period of time. It was concluded that the polycarbonate should show dimensional changes in service comparable to PMMA, but less dimensional change caused by dehydration.

It was found that polycarbonate, PMMA and polyethylene terephtalate met the ISO standard type 3 denture base material that require more than 65 MPa of flexural strength and modulus elasticity of 2 MPa, while polyamide did not meet the standard.[19] Polyamide did not have aromatic ring in the structure. Thus, it is speculated that the penetration of water molecules into the polymer structure influenced the flexural strength of polyamide. Because polycarbonate has high contact angles with water and little surface free energy, their water repellency is also high, causing lower water sorption amounts. Polycarbonate would be hydrophobic property because it showed higher contact angle and a robust connection between contact angle and water sorption. Polyamide and polyethylene terephtalate would be hydrophilic because it has lower contact angle. All thermoplastic resins tested were within the range of standard and had lower water sorption than PMMA. Furthermore, thermoplastic resins had a hygienic nature that decrease the buildup of plaque.

2.4.3.4 Bonding Strength

Silica coating could improve the bonding strength of polycarbonate to autopolymerizing resin. A study [45] compared bonding strength of autopolymerizing resin to polycarbonate polymer subjected to different surface treatment (control, alumina sandblasting, resin primer coating, alumina sandblasting + resin primer coating, silica coating with Rocatec system + silane coupling. It showed that thermo cycling was found to significantly reduce bonding strengths of all group except for polycarbonate that was treated with resin primer coating.

2.5 Pressure Measurement

Several authors have attempted to evaluate pressure under the denture base and the amount and distribution of pressure transmission.[7-9, 46] Many devices and techniques have been developed and used.

An *in vivo* denture base pressure test was performed by Berg et al [28], using an inflatable soft plastic air bag with an attached pump bulb and pressure gauge. The arch shaped air bag was placed between the occlusal tables on the test bases for making pressure test. The subjects were then instructed to close their mouth on the bag with a definite positive pressure at a comfort level for any length of time. When a constant point was achieved on the gauge, the data was recorded.

A study by Watson and Hugget [12] explained about pressure at the denture base-mucosal surface in complete denture wearers. The study examined the reproducibility of the pressure obtained by using strain gauges and pressure transducers when the subjects chewed two test foods (carrot and peanut). Four sites were selected: *(a)* the mid-palatal region in the upper complete denture, *(b)* the labial to the mid-line lower complete denture, *(c)* directly under the lower left and *(d)* right first molar teeth. After chewing sequence, food debris beneath the dentures was removed, and the patient relaxed for 5 minutes. Four chewing sequences of carrot and four peanut were recorded. Only the last three chewing strokes of each food were analyzed.

Inoue et al [8] performed an *in vitro* study of the influence of occlusal scheme on the pressure distribution of complete denture at the supporting tissue area. This study compared lingualized occlusion and completely balanced occlusion, using a simulation device. Sixteen pressure transducers were placed at the buccal and lingual slope of the simulated residual ridge. A load that was applied on the pressure transducer increased the output voltage according to the decrease of the transducer thickness, and then the output voltage was recorded.

Another pressure measurement was done by Kubo et al [10] who developed a system to measure the *in vivo* pressure distribution measurement under the base of removable partial denture. The measurement system consists of a tactile sensor sheet with 100 sensing points and a measuring system. Three patterns of occlusal rest design (mesial and distal rest, mesial rest only, and without a rest) were performed in the measurement. The sensor sheet consisted of two PET (polyethylene terephtalate) film sheets. Longitudinal and latitudinal electrodes were placed at the same interval on each sheet. Special ink was applied into a film over the electrode. The intersecting points of longitudinal and latitudinal electrodes formed separate force detection points (sensor cells). Electrical resistance of sensor cells under no load was infinite, while it declined inversely proportional to applied force.

Nishigawa et al [47] used a two dimensional finite element method program to investigate the static for the contour of the complete denture and the residual ridge. With this program, the effect of the bucco-lingual position of the artificial posterior teeth under occlusal force on the denture supporting bone could be investigated.

The new method for pressure transmission and distribution measurement was performed by Phuntikaphard et al[7] and Arksornnukit et al[46]. They used pressure sensitive sheet to measure pressure transmission area and maximum pressure transmission under an impact load. The sheet would form colors in varying density when an impact load was applied, which was scanned to get the results.

2.6 Pressure Sensitive Sheet

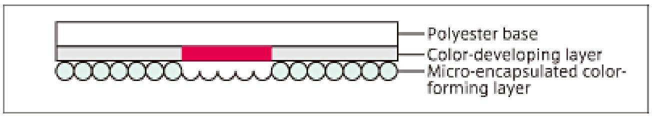
A pressure measuring device (Dental Prescale, Prescale Film, Fuji Photo Film, Tokyo, Japan) has been developed for measuring bite force, occlusal contact area and occlusal pressure. The system consists of pressure-sensitive sheets (Dental Prescale) and its analysis apparatus (Occluzer).[48-54]

Pressure sensitive sheet has been used in many dental studies. Regarding the field of oral surgery, it has been used to measure the changes of bite force and occlusal contact area after surgical procedures.[55, 56] In periodontics field, it has been used for measuring the effect of periodontal surgery on bite force, occlusal contact area and bite pressure.[57] The pressure sensitive sheet were also used in pediatrics to observed the association between clenching strength and the distribution of occlusal forces on a primary dentition. Orthodontists used the pressure sensitive sheet for examining the occlusal force and occlusal contact area in their patients.[58] The occlusal force and occlusal contact area could be measured in the intercuspal position because the thickness of the pressure sensitive sheet was only 0.097mm.[58]

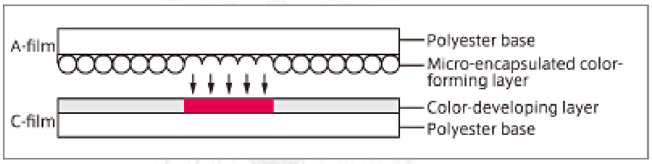
The Prescale film is claimed for precisely measuring pressure, pressure distribution, and pressure balance. The film is extremely thin and stable with less than 200-μm thickness (100μm x 2). Red patches will appear on the film when the pressure is applied, and then the color density changes according to the various pressure levels (0.05～300 MPa and 7.25 psi～43,500 psi). Contact pressure shown with differing concentrations of color can even be converted into numbers, which will provide accuracy of ± 10% or less (measured by densitometer at 23°C, 65% RH).[59]

The Prescale film is available under two categories, one based on single sheet (Figure 1a), and the other as a two sheets (A+C) (Figure 1b). [59]

Regarding the single sheet film, the color forming layer is coated on the polyester base of the film. Micro-encapsulated color forming material is single-layer coated on the top of the film.[59] The two sheets film consists of an “A film” which is coated with a specific micro-encapsulated color forming material, and “C film” which is coated with a specific color developing material. The two films should be placed with the coated (rough and opaque) surfaces facing each other. These are the sides with the matte finish.[59]



a



b

Figure 1. Single sheet film (a), two sheets film (b).

When the pressure is applied, the microcapsules are broken, and the color-forming materials transfer to the color-developing material and react, thereby generating a red color. According to the Particle Size Control (PSC) technology, the microcapsules are intended to react to various degrees of pressure, releasing their color-forming material at a density that relates to the pressure.[59]

The films provide eight different types ranging from the pressure of 0.05 to 300 MPa[59]

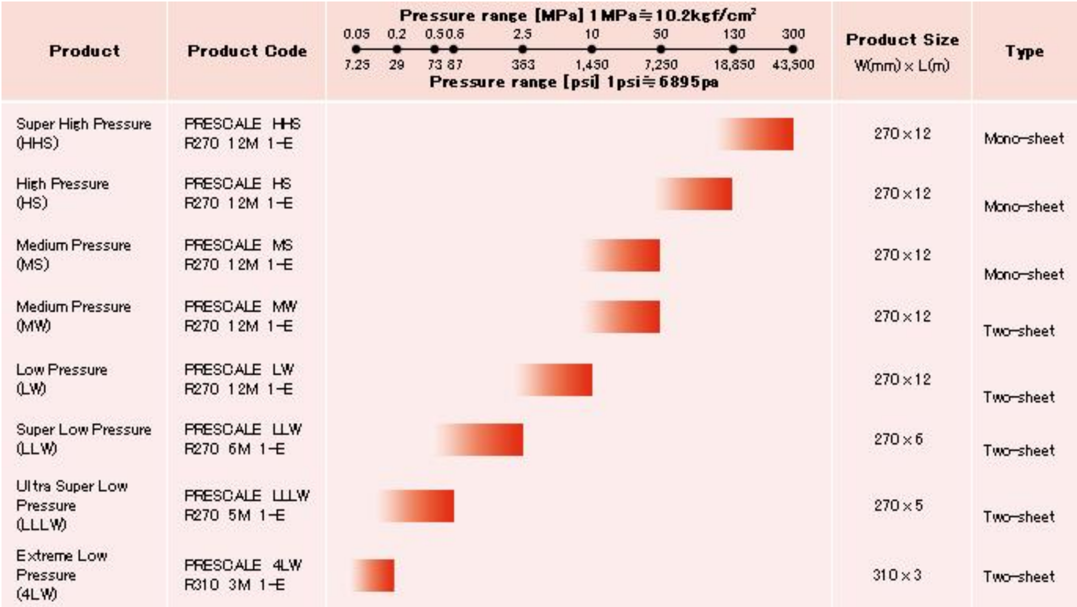


Figure 2. Pressure levels of the pressure sensitive sheet[59]

The pressure sensitive sheets were also found in a wide range of studies.[48, 50-52] Mainly, the prescale film was used to examine the bite force and occlusal pressure. The prescale film should be considered as one of the most useful devices for pressure measurement because of all its advantages above mentioned.

CHAPTER III

MATERIALS AND METHODS

Six different denture base materials: Polyamides [Valplast (VAL), Lucitone FRS (FRS), Thermoplastic Comfort System (TCS)], Polycarbonate (Basis PC (BPC)), Ethylene Propylene (Duraflex (DUR)) and PMMA (Triplex Hot (TRI)) as a control (n=6) with dimension 15mm x 15mm x 3mm and mandibular first molar acrylic resin denture tooth (FX, M36, A3.5,Yamahachi Dental MFG., Co., Ochigara, Aichi, Japan) on the bases (Figure 3.1) were examined in this study.

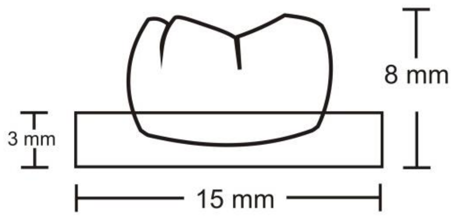


Figure 3. Schematic drawing of the specimen

3.1 Denture Base Specimens

Denture base specimens composed of artificial teeth on denture bases were fabricated using putty-type silicone impression material (Silagum Putty, DMG, Hamburg, Germany) as a mold. Melted wax was poured into the mold, and then each denture tooth was lowered into the wax using a surveyor (Ney Surveyor Parallometer System, DENTSPLY Ceramco, Burlington, NJ, USA) to ensure that the occlusal surface was parallel to the base. All specimens were prepared according to manufacturer instruction (Table 1)

Each denture tooth specimen for thermoplastic resin had small hole at mesial and distal cervical surface which acted as mechanical undercuts and allowed thermoplastic resin material bonded to the tooth. A 0.8 mm diameter wire was used to standardize the hole.

Table 1. Denture base materials used in this study

Materials (Manufacturer)	Code	Processing method	Type	Composition
Valplast (Valplast International Corp., Westbury, NY, USA)	VAL	Injection molding technique (290°C/ 15 min)	Polyamide	Trade secret component (99.9966%), colorant (0.0034%)
Lucitone FRS (Dentsply International Inc.,York, PA, USA)	FRS	Injection molding technique (302°C/17 min)	Polyamide	Semi-crystalline nylon
TCS (Thermoplastic Comfort System Inc., Signal Hill, CA.,USA),	TCS	Injection molding technique (287°C/11 min)	Polyamide	Nylon thermoplastic
Basis PC (Yamahachi Dental MFG., Co., Ochigara,Aichi Japan)	BPC	Injection molding technique (305°C/25 min)	Polycarbonate	Semi-flexible polycarbonate
Duraflex (Myerson LLC.,Chicago,ILL, USA)	DUR	Injection molding technique (230°C/12.5 min)	Ethylene Propylene	Ethylene propylene copolymer (>99.95%), pigments (<0.05)

Triplex Hot (Ivoclar Vivadent AG,Schaan, Liechtenstein)	TRI	Heat-polymerized, compression molding technique (100°C/45 min)	PMMA	Powder: Polymethyl methacrylate, catalyst, pigments. Liquid: Methyl methacrylate stab., dimethacrylate

After completion of the polymerization, the flasks were allowed to cool to room temperature before deflasking. The specimens were removed from the denture flasks, and any flash was removed with a carbide bur. The basal surfaces of the specimens were polished using an automatic polishing machine (Nano 2000 Grinder Polisher, Pace Technologies, Tucson, AZ, USA) at 100 rpm and constant water irrigation with abrasive paper grit number 800,1000, and 1200 and finally with 0.05-μm-particle-sized aluminum oxide slurry (Leco Corp, St. Joseph, Mich, USA). The specimens were stored in 37°C deionized water for 24 hours before testing.

3.2 Pressure Transmission and Distribution under Impact Drop Test

The pressure transmission and pressure distribution were examined by 2 types of pressure-sensitive sheets (PreScale Film, LLLW and LLW, Fuji Photo Film Co, Ltd, Tokyo, Japan). The reliable measuring ranges of the pressure of LLLW and LLW are between 0.2 and 0.6 MPa and between 0.5 and 2.5 MPa, respectively. The LLLW sheet type was primarily used for pressure measurements for each specimen. However, when average or maximum pressure was found to be above its measuring ranges, LLW sheets were used.

In the present study, the pressure was applied by dropping a mass on each denture tooth specimen with the film placed underneath to measure the force transmission and distribution. After the pressures were transferred onto the sheets, the sheets were scanned and analyzed by digital analysis software (Fuji Film Pressure Distribution Mapping System FPD-8010E, version 1.1, Fuji Photo Film Co. Ltd, Tokyo, Japan). The software automatically showed different amounts of pressure as different colors. Areas of no pressure were displayed as white. Pressure of less than 0.5 MPa was green, pressure range of 0.5 to 2.5 MPa was seen as different shades of red, depending on the intensity of the pressure and pressure higher than 2.5 MPa was yellow.

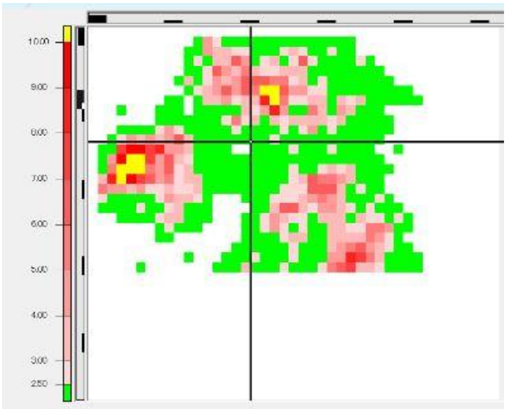


Figure 4. Display of the pressure area on the scanning system

3.3 Impact Drop Test

A load of 50 N, according to the previous study[15], dropped on occlusal surface of the specimens, simulating the complete dentures wearers, was used in the present study. A small piece of LW pressure sensitive sheet was placed over the occlusal surface of each type of denture base materials to measure the impact force at the impact site. The mass and the height were adjusted to achieve a 50 N impact force at the central fossa. A 1-kg mass load at 3-mm height generated a 50 N force, and, therefore, was used in the present study. The impact drop test used in the present study was modified from the previous study[7] In the impact drop test procedures, a pressure-sensitive sheet was placed beneath the denture base, which rested on a flat metal surface. A 1kg mass was released and allowed to fall on the central fossa of the artificial tooth specimen. The impact load testing apparatus is shown in Figure. 5)

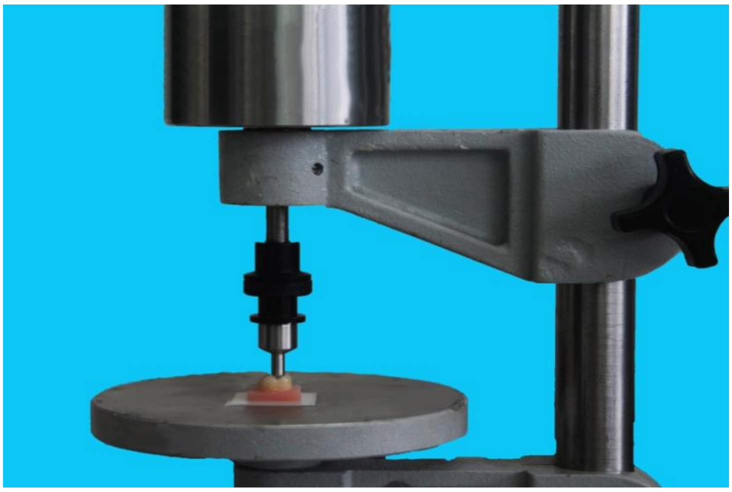


Figure 5. Impact load testing apparatus

3.4 Modulus of Elasticity and Nanohardness

An ultramicroindentation system (UMIS 2000, CSIRO, Lindfield, Australia) was used to determine the modulus of elasticity and nanohardness of the thermoplastic resin and PMMA specimens (n=10, dimension=15x15x3 mm). The load was composed of 25 incremental loading steps with a delay of 0.1 seconds at each increment and the maximum force applied was 25 mN. The distance between each indentation was 100 μm to prevent indentation overlap. The overall average value for each material was obtained to represent the modulus of elasticity and nanohardness of each type of denture base. The IBIS 1.0.75 software (Fischer-Cripps Laboratories Pty Ltd, NSW, Australia) was used to calculate nanohardness (H) using maximum load (Pmax) and surface area at maximum load (A) by the following equation: [60]

$$H = Pmax/A$$

The modulus of elasticity (E) was calculated using equations: [60]

$$1/E^* = (1-\upsilon^2)/E + (1-\upsilon'^2)/E'$$

where E* is the reduced modulus from the nanoindenter, E the modulus of the Berkovich diamond indenter (1.050 GPa),[60] E′ the modulus of the specimen, υ the Poisson’s ratio for the indenter (0.07),[60] and υ' the Poisson’s ratio for the specimens. The Poisson’s ratio of polyamide is 0.4,[61] polycarbonate is 0.4,[62] ethylene propylene is 0.39,[63] and PMMA is 0.38.[64]

3.5 Data Analysis

The pressure transmission area, modulus of elasticity, and nanohardness data were analyzed using one-way analysis of variance (ANOVA) (α=0.05). For the pressure transmission area and modulus of elasticity, the Tamhane's post hoc test was used as equal variance could not be assumed. Tukey HSD (Honestly Significant Difference) post hoc test was used to compare means of the nanohardness. Due to the not normally distributed data, the non-parametric tests (Kruskal-Wallis H test followed by Mann-Whitney U test) were used to analyze the maximum pressure data (α=.05).

CHAPTER IV

RESULTS

Pressure sensitive sheet was used with the different denture base materials to evaluate the amount of force and the patterns of force distribution when a load was dropped on them. The results of the one-way ANOVA for each of the three parameters are shown in Table 2.

Table 2. One-way Anova for pressure transmission area, modulus of elasticity and nanohardness among the materials

Source	**Sum of Squares**	***Df***	**Mean Square**	**F**	***P***
Pressure transmission area					
Between Groups	43885.102	5	8777.020	68.740	<.001
Within Groups	3830.537	30	127.685		
Total	47715.639	35			
Modulus of elasticity					
Between Groups	107.189	5	21.438	1822.271	<.001
Within Groups	.635	54	.012		
Total	107.825	59			
Nanohardness					
Between Groups	.259	5	.052	961.493	<.001
Within Groups	.002	54	.000		
Total	.261	59			

The total pressure transmission areas, measured from the pressure-sensitive sheets of the denture base material groups were determined. The denture base area calculated from the size of the denture base specimen was 225 mm^2 (15 x15 mm). The colored areas on each sheet represented the pressure transmission areas (Fig. 6). The means of the total pressure transmission areas detected on the sheets ranged from 93.72±15.39 mm^2 (DUR) to 198.61±9.04 mm^2 (TCS). The TCS showed the widest pressure transmission area, which was significantly different (P<.05) from the other groups (Fig. 7).

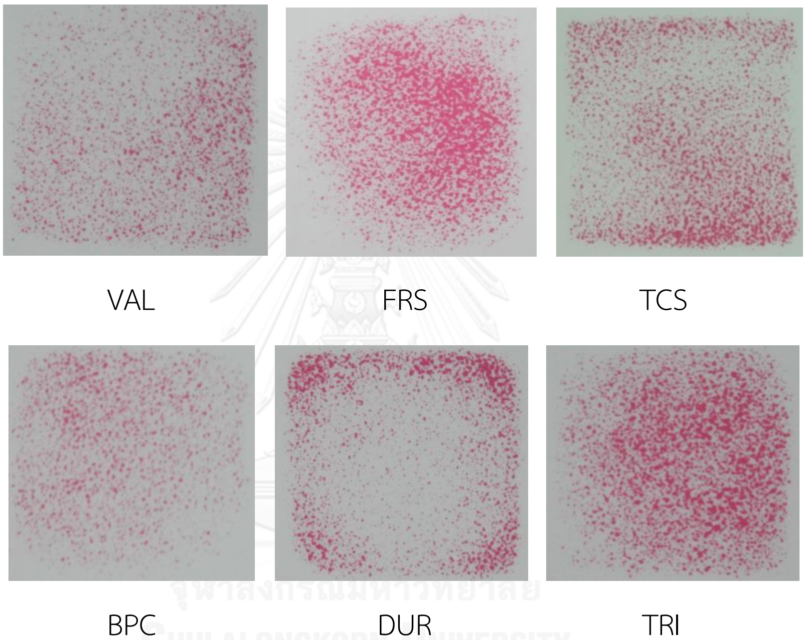


Figure 6. Representatives of pressure-sensitive sheets from all materials

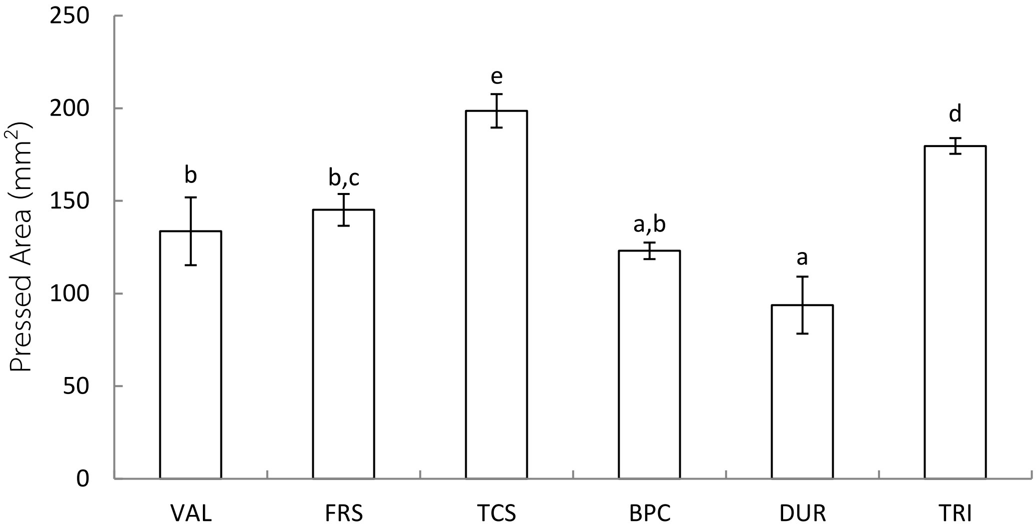


Figure 7. Total pressure transmission areas (mm^2) of all denture base groups (vertical bars shows standard deviation; bars with the same letter are not significantly different at *P*<.05)

The maximum pressure transmissions which appeared on the pressure sensitive sheets are shown in Figure 5. The greatest maximum pressure was observed in the TRI (1.41±0.11 MPa), which was significantly different from all thermoplastic resin groups (*P*<.05). The VAL was comparable with TCS and BPC (*P*<.05).

The modulus of elasticity and nanohardness of each type of denture base are shown in Figure 9 and Figure 10, respectively. The TRI showed a significantly higher modulus of elasticity (5.88±0.20 GPa) and nanohardness (0.27±0.01 GPa) compared with the thermoplastic resin denture bases (*P*<.05). TCS group were comparable with VAL in modulus of elasticity, DUR showed the lowest nanohardness (0.1±0.005 GPa) among all materials.

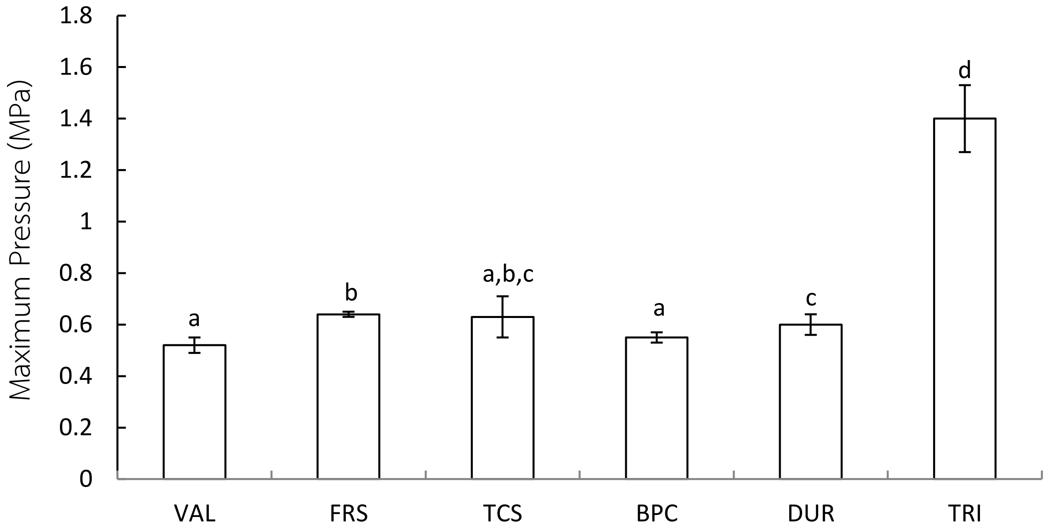


Figure 8. Maximum pressure (MPa) of all denture base groups (vertical bars shows standard deviation; bars with the same letter are not significantly different at *P*<.05).

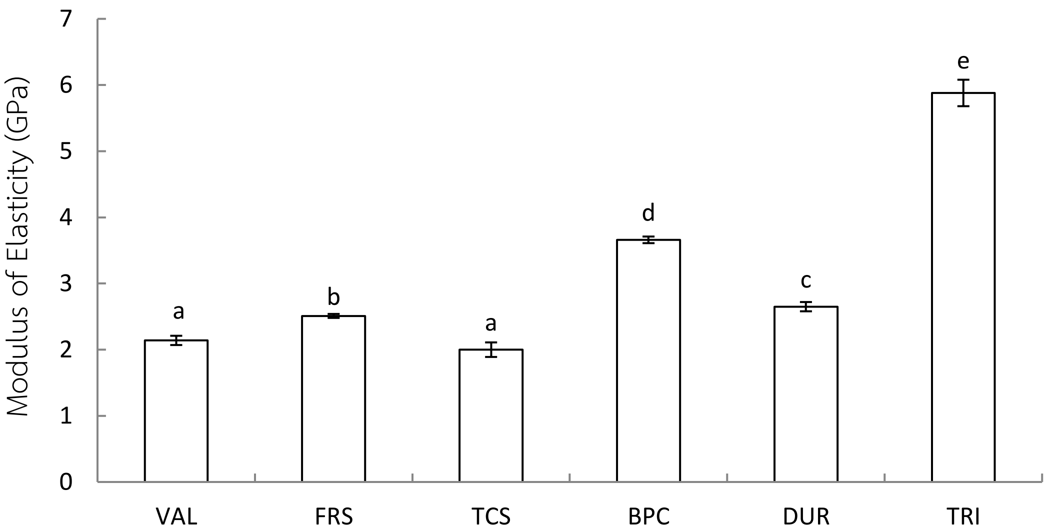


Figure 9. Modulus of elasticity (GPa) of the denture bases (bars with different letter indicates a significant difference among the materials, *P*<.05).

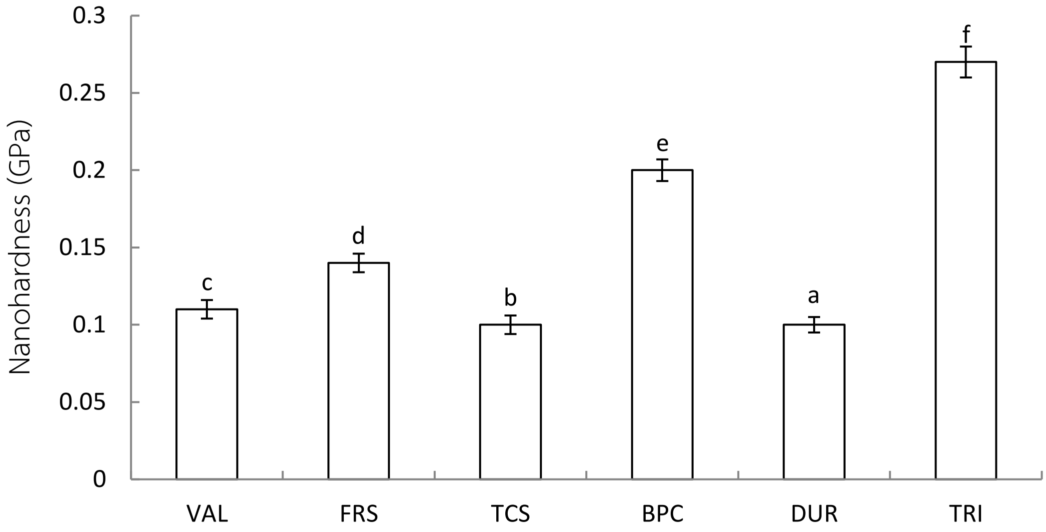


Figure 10. Nanohardness (GPa) of the denture bases (bars with different letter indicate the significant difference among the materials, *P*<.05).

CHAPTER V

DISCUSSION

The pressure transmission and distribution, and in the modulus of elasticity and the nanohardness of five thermoplastic denture base materials and one heat-polymerizing PMMA denture base material were evaluated. The results showed the significantly different among their tested properties; therefore, the null hypothesis that there would be no significantly different among six tested denture base materials was rejected.

The VAL and BPC have a comparable intensity of red dot on the pressure sensitive sheet. The FRS shows red dot intensity at the center of pressure sensitive sheet, while TCS shows the largest red dot area. The DUR shows red dot intensity along the edge. The TRI shows the highest red dot intensity among the all materials. It might be attributed to the degree of crystallinity of the materials which affect on its pressure distribution pattern.

The pressure transmission results indicated that the thermoplastic resin groups transmitted lower maximum pressure than the PMMA group. When impact load occurred, pressure would be transmitted through the denture tooth and denture base layer before being transferred to the pressure-sensitive sheet. Thermoplastic resin polymer is difficult to react with the monomers and resin primers because of its high chemical resistance and high degree of crystallinity, leading to the inadequate chemical bond with the denture teeth. Furthermore, the lack of chemical bond assists in dissipation of force at the interface of the thermoplastic resin denture base and denture teeth resulted in a smaller pressure transmission area underneath thermoplastic resin denture base specimens.[45]

The PMMA group showed higher maximum pressure compared with thermoplastic resin groups. Such pressure may attribute to result from the chemical bonding between denture teeth and the denture base. Theoretically, the polymerizable monomer plasticizes the surface of denture teeth, and diffuses into the denture tooth acrylic resin. Upon polymerization, an interwoven network of polymer chains that bonds the denture base to the resin tooth is formed.[65] Therefore, when the impact occurred, there were no energy loss along the interface of the denture teeth and PMMA denture base lead to a higher maximum pressure underneath PMMA denture base. The present study result contradicted to the previous study on the rigidity of dentures made of injection-molded materials which demonstrated that the force transmitted under the PMMA denture base was significantly lower than polyamide.[20] This was because of the previous study design was performed on removable partial denture which has metal rest as the supporting point at the anterior and posterior to the edentulous area. As a result, polyamides with the lowest modulus of elasticity flexed more and resulted in more loads were applied to the mucosa under the denture base.[20]

Regarding the thermoplastic materials, a significantly larger pressure transmission area and lower maximum pressure transmission were showed by polyamide compared to ethylene propylene. The aliphatic chain of polyamide polymer gave resistance to repeated stress and shock due to its low modulus of elasticity.[66] High content of ethylene propylene macromolecule may bring about fractional crystallization. This brought about the poorer mechanical and elastic properties.[67] Therefore, ethylene propylene was stiffer compared with polyamide, which resulted to a higher maximum pressure transmission and smaller pressure transmission area. Polycarbonate still demonstrated lower maximum pressure transmission and larger pressure transmission area compared to the other thermoplastic resin materials, in spite of its higher modulus of elasticity. The higher damping mechanism of polycarbonate nonlinear viscoelastic/viscoplastic reaction which permitted it to change impact energy into heat and internal energy was suggested responsible to this phenomena.[68] Therefore, when the impact occurred, a low intensity and equitably distributed of red color underneath the denture base made of polycarbonate were recorded.

The modulus of elasticity of a denture base material describes its relative stiffness or rigidity.[69] In the present study, the highest maximum pressure transmission was observed in the PMMA group, most likely resulting from the modulus of elasticity of the TRI denture base, which was the highest (5.88 ±0.2 GPa). In contrast, the moduli of elasticity values of the thermoplastic resin were lower: TCS (2.00±0.11 GPa), VAL (2.14±0.07 GPa), FRS (2.51±0.03 GPa), DUR (2.65±0.07 GPa), BPC (3.66±0.05 GPa). This finding supported previous study which demonstrated that modulus of elasticity of PMMA was higher than that of thermoplastic resin[19]. This demonstrated that PMMA is more rigid and less flexible compared with thermoplastic resin denture base. It is interesting to note that there were significant differences in modulus of elasticity among the polyamide thermoplastic resin group (VAL, FRS and TCS). The FRS showed the highest maximum pressure compared to VAL and TCS. This result might be credited to semi-crystalline nylon composition in FRS which causes to be firmer and less elastic.[70]

The TRI showed the significantly highest nanohardness (0.27±0.01 GPa) compared to the thermoplastic resin denture base groups. This result might be due to the cross linking agents in Triplex Hot. Crosslinking creates bridges between chains and intensely increases molecular weight. The cross-linked polymers can increase rigidity and resistance to solvent. The thermoplastic resin groups demonstrated lower hardness values because they have lower amounts of cross linking agents, suggesting that cross linking agents may play a role in nanohardness.[18, 42, 69]

The present study suggests that both thermoplastic resin denture base and PMMA denture base materials can act as a shock absorber during impact. Denture base with a lower modulus of elasticity may flex and absorb more impact force and transmit less pressure to the pressure-sensitive sheet. Well distributed pressure and low maximum pressure transfer would be desirable in denture base application, because there would be less force and more even pressure distribution to the supporting tissues. Therefore, to increase the supporting area and minimize the pressure, a maximum extension of a denture base within the physiological and anatomical perimeters is still recommended. In addition, denture teeth also play a role in resisting impact force and transfer light pressure to the supporting structures.[7, 46]

Thermoplastic resins have the positive advantage in absorbing the impact force, but they have the disadvantage. They could cause major damage when misused. Thermoplastic resin denture can be associated with abutment teeth displacement and residual ridge resorption under denture base because it lacks of rigidity that causing the unevenly occlusal force transferred to the supporting tissues. The indications should be scientifically verified in the future.[71] A study recommended that incorporating a metal framework into thermoplastic resin denture base can be used to overcome the drawback of its flexibility and deformation under impact load.[20]

PMMA is the most common denture base. Thermoplastic resin is an alternative material in the patient with hypersensitivity or allergy to PMMA. The present study showed that polycarbonate was similar to polyamide in the assessed parameters; low maximum pressure transmission and even pressure transmission area. Polycarbonate also has a high modulus of elasticity and nanohardness compared to polyamide and ethylene propylene. At this point, polycarbonate may be better regarding limited data acquired from the present study. Nevertheless, to completely support the above statement, the clinical assessment is expected.

The limitations of the present study were that pressure transmission and distribution were evaluated *in vitro*. The impact drop test was only a vertical load application that performed by utilizing a simplified apparatus. Therefore, an *in vivo* study using actual occlusal force application is suggested.

CHAPTER VI

CONCLUSIONS

Within the limitation of the present study, the following conclusions were obtained.

1. TCS showed significantly highest pressure transmission area compared to other materials ($P<.05$).
2. Maximum pressure transmission from PMMA denture base was significantly higher than that of the thermoplastic resin groups ($P<.05$).
3. Significant differences in modulus of elasticity and nanohardness were found among the denture base materials ($P<.05$). PMMA denture base showed significantly higher values in modulus of elasticity and nanohardness, followed by thermoplastic resin denture base ($P<.05$).

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APPENDIX

APPENDIX

Contents **Pages**

I. Statistical analysis for differences in pressure transmission areas

Descriptives

	DentureBase			Statistic	Std. Error
PressedArea	Valplast	Mean		133.6111	7.47510
		95% Confidence Interval for Mean	Lower Bound	114.3957	
			Upper Bound	152.8265	
		5% Trimmed Mean		133.8827	
		Median		136.5000	
		Variance		335.263	
		Std. Deviation		18.31019	
		Minimum		106.33	
		Maximum		156.00	
		Range		49.67	
		Interquartile Range		31.67	
		Skewness		-.427	.845
		Kurtosis		-.848	1.741
	Lucitone FRS	Mean		145.1667	3.50740
		95% Confidence Interval for Mean	Lower Bound	136.1506	
			Upper Bound	154.1827	
		5% Trimmed Mean		145.7222	
		Median		148.3333	
		Variance		73.811	
		Std. Deviation		8.59134	
		Minimum		129.00	
		Maximum		151.33	
		Range		22.33	
		Interquartile Range		11.58	
		Skewness		-1.720	.845
		Kurtosis		2.982	1.741
	TCS	Mean		198.6111	3.69325
		95% Confidence Interval for Mean	Lower Bound	189.1173	
			Upper Bound	208.1049	
		5% Trimmed Mean		198.3086	
		Median		196.3333	
		Variance		81.841	
		Std. Deviation		9.04659	
		Minimum		189.67	
		Maximum		213.00	
		Range		23.33	
		Interquartile Range		15.58	
		Skewness		.787	.845
		Kurtosis		-.587	1.741

Basis PC	Mean		123.0556	1.82456
	95% Confidence Interval for Mean	Lower Bound	118.3654	
		Upper Bound	127.7457	
	5% Trimmed Mean		122.9691	
	Median		122.1667	
	Variance		19.974	
	Std. Deviation		4.46924	
	Minimum		118.00	
	Maximum		129.67	
	Range		11.67	
	Interquartile Range		8.17	
	Skewness		.519	.845
	Kurtosis		-1.165	1.741
Duraflex	Mean		93.7222	6.28662
	95% Confidence Interval for Mean	Lower Bound	77.5619	
		Upper Bound	109.8825	
	5% Trimmed Mean		93.9877	
	Median		97.0000	
	Variance		237.130	
	Std. Deviation		15.39901	
	Minimum		69.67	
	Maximum		113.00	
	Range		43.33	
	Interquartile Range		26.08	
	Skewness		-.590	.845
	Kurtosis		-.076	1.741
Triplex Hot	Mean		179.6667	1.73632
	95% Confidence Interval for Mean	Lower Bound	175.2033	
		Upper Bound	184.1300	
	5% Trimmed Mean		179.6667	
	Median		179.3333	
	Variance		18.089	
	Std. Deviation		4.25310	
	Minimum		174.00	
	Maximum		185.33	
	Range		11.33	
	Interquartile Range		7.83	
	Skewness		.073	.845
	Kurtosis		-1.260	1.741

Tests of Normality

	DentureBase	Kolmogorov-Smirnov[a]			Shapiro-Wilk		
		Statistic	df	Sig.	Statistic	df	Sig.
PressedArea	Valplast	.196	6	.200*	.968	6	.880
	Lucitone FRS	.239	6	.200*	.785	6	.043
	TCS	.244	6	.200*	.910	6	.438
	Basis PC	.204	6	.200*	.948	6	.725
	Duraflex	.208	6	.200*	.967	6	.873
	Triplex Hot	.152	6	.200*	.976	6	.928

*. This is a lower bound of the true significance.

a. Lilliefors Significance Correction

Test of Homogeneity of Variances

PressedArea

Levene Statistic	df1	df2	Sig.
3.639	5	30	.011

ANOVA

PressedArea

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	43885.102	5	8777.020	68.740	.000
Within Groups	3830.537	30	127.685		
Total	47715.639	35			

Robust Tests of Equality of Means

PressedArea

	Statistic[a]	df1	df2	Sig.
Welch	126.609	5	13.536	.000
Brown-Forsythe	68.740	5	16.168	.000

a. Asymptotically F distributed.

Post Hoc Test

Multiple Comparisons

Dependent Variable: PressedArea
Tamhane

(I) DentureBase	(J) DentureBase	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
					Lower Bound	Upper Bound
Valplast	Lucitone FRS	-11.55556	8.25706	.967	-47.1339	24.0228
	TCS	-65.00000*	8.33770	.001	-100.4923	-29.5077
	Basis PC	10.55556	7.69455	.977	-26.8601	47.9712
	Duraflex	39.88889*	9.76723	.034	2.3300	77.4478
	Triplex Hot	-46.05556*	7.67411	.019	-83.5927	-8.5184
Lucitone FRS	Valplast	11.55556	8.25706	.967	-24.0228	47.1339
	TCS	-53.44444*	5.09333	.000	-72.8791	-34.0098
	Basis PC	22.11111*	3.95359	.010	5.4845	38.7377
	Duraflex	51.44444*	7.19885	.002	21.6604	81.2285
	Triplex Hot	-34.50000*	3.91365	.001	-51.1521	-17.8479
TCS	Valplast	65.00000*	8.33770	.001	29.5077	100.4923
	Lucitone FRS	53.44444*	5.09333	.000	34.0098	72.8791
	Basis PC	75.55556*	4.11936	.000	58.0196	93.0915
	Duraflex	104.88889*	7.29121	.000	75.0748	134.7030
	Triplex Hot	18.94444*	4.08105	.034	1.3679	36.5210
Basis PC	Valplast	-10.55556	7.69455	.977	-47.9712	26.8601
	Lucitone FRS	-22.11111*	3.95359	.010	-38.7377	-5.4845
	TCS	-75.55556*	4.11936	.000	-93.0915	-58.0196
	Duraflex	29.33333	6.54604	.065	-1.7349	60.4016
	Triplex Hot	-56.61111*	2.51870	.000	-66.2211	-47.0011
Duraflex	Valplast	-39.88889*	9.76723	.034	-77.4478	-2.3300
	Lucitone FRS	-51.44444*	7.19885	.002	-81.2285	-21.6604
	TCS	-104.88889*	7.29121	.000	-134.7030	-75.0748
	Basis PC	-29.33333	6.54604	.065	-60.4016	1.7349
	Triplex Hot	-85.94444*	6.52200	.000	-117.1329	-54.7560
Triplex Hot	Valplast	46.05556*	7.67411	.019	8.5184	83.5927
	Lucitone FRS	34.50000*	3.91365	.001	17.8479	51.1521
	TCS	-18.94444*	4.08105	.034	-36.5210	-1.3679
	Basis PC	56.61111*	2.51870	.000	47.0011	66.2211
	Duraflex	85.94444*	6.52200	.000	54.7560	117.1329

*. The mean difference is significant at the 0.05 level.

II. Statistical analysis for differences in maximum pressure transmission

Descriptives

	DentureBase			Statistic	Std. Error
MaxPressure	Valplast	Mean		.5306	.00586
		95% Confidence Interval for Mean	Lower Bound	.5155	
			Upper Bound	.5456	
		5% Trimmed Mean		.5306	
		Median		.5283	
		Variance		.000	
		Std. Deviation		.01436	
		Minimum		.51	
		Maximum		.55	
		Range		.04	
		Interquartile Range		.03	
		Skewness		.032	.845
		Kurtosis		-.475	1.741
	Lucitone FRS	Mean		.6361	.00389
		95% Confidence Interval for Mean	Lower Bound	.6261	
			Upper Bound	.6461	
		5% Trimmed Mean		.6370	
		Median		.6400	
		Variance		.000	
		Std. Deviation		.00953	
		Minimum		.62	
		Maximum		.64	
		Range		.02	
		Interquartile Range		.01	
		Skewness		-2.449	.845
		Kurtosis		6.000	1.741
	TCS	Mean		.6000	.03145
		95% Confidence Interval for Mean	Lower Bound	.5192	
			Upper Bound	.6808	
		5% Trimmed Mean		.6063	
		Median		.6383	
		Variance		.006	
		Std. Deviation		.07703	
		Minimum		.45	
		Maximum		.64	
		Range		.19	
		Interquartile Range		.08	
		Skewness		-2.208	.845
		Kurtosis		4.930	1.741

Basis PC	Mean		.5439	.00442
	95% Confidence Interval for Mean	Lower Bound	.5325	
		Upper Bound	.5553	
	5% Trimmed Mean		.5441	
	Median		.5500	
	Variance		.000	
	Std. Deviation		.01084	
	Minimum		.53	
	Maximum		.55	
	Range		.02	
	Interquartile Range		.02	
	Skewness		-.903	.845
	Kurtosis		-1.854	1.741
Duraflex	Mean		.6106	.00858
	95% Confidence Interval for Mean	Lower Bound	.5885	
		Upper Bound	.6326	
	5% Trimmed Mean		.6104	
	Median		.6083	
	Variance		.000	
	Std. Deviation		.02102	
	Minimum		.58	
	Maximum		.64	
	Range		.06	
	Interquartile Range		.04	
	Skewness		.191	.845
	Kurtosis		-1.162	1.741
Triplex Hot	Mean		1.4100	.04642
	95% Confidence Interval for Mean	Lower Bound	1.2907	
		Upper Bound	1.5293	
	5% Trimmed Mean		1.4080	
	Median		1.4033	
	Variance		.013	
	Std. Deviation		.11371	
	Minimum		1.25	
	Maximum		1.60	
	Range		.35	
	Interquartile Range		.13	
	Skewness		.673	.845
	Kurtosis		2.140	1.741

Tests of Normality

	DentureBase	Kolmogorov-Smirnov[a]			Shapiro-Wilk		
		Statistic	df	Sig.	Statistic	df	Sig.
MaxPressure	Valplast	.182	6	.200*	.970	6	.891
	Lucitone FRS	.492	6	.000	.496	6	.000
	TCS	.350	6	.021	.631	6	.001
	Basis PC	.380	6	.007	.724	6	.011
	Duraflex	.192	6	.200*	.971	6	.902
	Triplex Hot	.264	6	.200*	.930	6	.579

*. This is a lower bound of the true significance.

a. Lilliefors Significance Correction

Non-parametric test

Kruskal-Wallis Test

Hypothesis Test Summary

	Null Hypothesis	Test	Sig.	Decision
1	The distribution of MaxPressure is the same across categories of DentureBase.	Independent-Samples Kruskal-Wallis Test	.000	Reject the null hypothesis.

Asymptotic significances are displayed. The significance level is .05.

Median Test

Hypothesis Test Summary

	Null Hypothesis	Test	Sig.	Decision
1	The medians of MaxPressure are the same across categories of DentureBase.	Independent-Samples Median Test	.001	Reject the null hypothesis.

Asymptotic significances are displayed. The significance level is .05.

Mann-Whitney U test

1. Valplast vs Lucitone FRS

Hypothesis Test Summary

	Null Hypothesis	Test	Sig.	Decision
1	The distribution of MaxPressure is the same across categories of DentureBase.	Independent-Samples Mann-Whitney U Test	.002[1]	Reject the null hypothesis.

Asymptotic significances are displayed. The significance level is .05.

[1]Exact significance is displayed for this test.

2. Valplast vs TCS

Hypothesis Test Summary

	Null Hypothesis	Test	Sig.	Decision
1	The distribution of MaxPressure is the same across categories of DentureBase.	Independent-Samples Mann-Whitney U Test	.065[1]	Retain the null hypothesis.

Asymptotic significances are displayed. The significance level is .05.

[1]Exact significance is displayed for this test.

3. Valplast vs Basis PC

Hypothesis Test Summary

	Null Hypothesis	Test	Sig.	Decision
1	The distribution of MaxPressure is the same across categories of DentureBase.	Independent-Samples Mann-Whitney U Test	.065[1]	Retain the null hypothesis.

Asymptotic significances are displayed. The significance level is .05.

[1]Exact significance is displayed for this test.

4. Valplast vs Duraflex

Hypothesis Test Summary

	Null Hypothesis	Test	Sig.	Decision
1	The distribution of MaxPressure is the same across categories of DentureBase.	Independent-Samples Mann-Whitney U Test	.002[1]	Reject the null hypothesis.

Asymptotic significances are displayed. The significance level is .05.

[1] Exact significance is displayed for this test.

5. Valplast vs Triplex Hot

Hypothesis Test Summary

	Null Hypothesis	Test	Sig.	Decision
1	The distribution of MaxPressure is the same across categories of DentureBase.	Independent-Samples Mann-Whitney U Test	.002[1]	Reject the null hypothesis.

Asymptotic significances are displayed. The significance level is .05.

[1] Exact significance is displayed for this test.

6. Lucitone FRS vs TCS

Hypothesis Test Summary

	Null Hypothesis	Test	Sig.	Decision
1	The distribution of MaxPressure is the same across categories of DentureBase.	Independent-Samples Mann-Whitney U Test	.310[1]	Retain the null hypothesis.

Asymptotic significances are displayed. The significance level is .05.

[1] Exact significance is displayed for this test.

7. Lucitone FRS vs Basis PC

Hypothesis Test Summary

	Null Hypothesis	Test	Sig.	Decision
1	The distribution of MaxPressure is the same across categories of Denture.	Independent-Samples Mann-Whitney U Test	.002[1]	Reject the null hypothesis.

Asymptotic significances are displayed. The significance level is .05.

[1]Exact significance is displayed for this test.

8. Lucitone FRS vs Duraflex

Hypothesis Test Summary

	Null Hypothesis	Test	Sig.	Decision
1	The distribution of MaxPressure is the same across categories of Denture.	Independent-Samples Mann-Whitney U Test	.041[1]	Reject the null hypothesis.

Asymptotic significances are displayed. The significance level is .05.

[1]Exact significance is displayed for this test.

9. Lucitone FRS vs Triplex Hot

Hypothesis Test Summary

	Null Hypothesis	Test	Sig.	Decision
1	The distribution of MaxPressure is the same across categories of Denture.	Independent-Samples Mann-Whitney U Test	.002[1]	Reject the null hypothesis.

Asymptotic significances are displayed. The significance level is .05.

[1]Exact significance is displayed for this test.

10. TCS vs Basis PC

Hypothesis Test Summary

	Null Hypothesis	Test	Sig.	Decision
1	The distribution of MaxPressure is the same across categories of Denture.	Independent-Samples Mann-Whitney U Test	.065[1]	Retain the null hypothesis.

Asymptotic significances are displayed. The significance level is .05.

[1] Exact significance is displayed for this test.

11. TCS vs Duraflex

Hypothesis Test Summary

	Null Hypothesis	Test	Sig.	Decision
1	The distribution of MaxPressure is the same across categories of denture.	Independent-Samples Mann-Whitney U Test	.485[1]	Retain the null hypothesis.

Asymptotic significances are displayed. The significance level is .05.

[1] Exact significance is displayed for this test.

12. TCS vs Triplex Hot

Hypothesis Test Summary

	Null Hypothesis	Test	Sig.	Decision
1	The distribution of MaxPressure is the same across categories of Denture.	Independent-Samples Mann-Whitney U Test	.002[1]	Reject the null hypothesis.

Asymptotic significances are displayed. The significance level is .05.

[1] Exact significance is displayed for this test.

13. Basis PC vs Duraflex

Hypothesis Test Summary

	Null Hypothesis	Test	Sig.	Decision
1	The distribution of MaxPressure is the same across categories of DentureBase.	Independent-Samples Mann-Whitney U Test	.002[1]	Reject the null hypothesis.

Asymptotic significances are displayed. The significance level is .05.

[1] Exact significance is displayed for this test.

14. Basis PC vs Triplex Hot

Hypothesis Test Summary

	Null Hypothesis	Test	Sig.	Decision
1	The distribution of MaxPressure is the same across categories of DentureBase.	Independent-Samples Mann-Whitney U Test	.002[1]	Reject the null hypothesis.

Asymptotic significances are displayed. The significance level is .05.

[1] Exact significance is displayed for this test.

15. Duraflex vs Triplex Hot

Hypothesis Test Summary

	Null Hypothesis	Test	Sig.	Decision
1	The distribution of MaxPressure is the same across categories of DentureBase.	Independent-Samples Mann-Whitney U Test	.002[1]	Reject the null hypothesis.

Asymptotic significances are displayed. The significance level is .05.

[1] Exact significance is displayed for this test.

III. Statistical analysis for differences in modulus of elasticity

Descriptives

	Denture			Statistic	Std. Error
ElasticModulus	Valplast	Mean		2.1488	.02263
		95% Confidence Interval for Mean	Lower Bound	2.0976	
			Upper Bound	2.2000	
		5% Trimmed Mean		2.1456	
		Median		2.1163	
		Variance		.005	
		Std. Deviation		.07156	
		Minimum		2.07	
		Maximum		2.28	
		Range		.21	
		Interquartile Range		.10	
		Skewness		1.058	.687
		Kurtosis		-.134	1.334
	Lucitone FRS	Mean		2.5156	.00983
		95% Confidence Interval for Mean	Lower Bound	2.4934	
			Upper Bound	2.5379	
		5% Trimmed Mean		2.5170	
		Median		2.5192	
		Variance		.001	
		Std. Deviation		.03107	
		Minimum		2.45	
		Maximum		2.56	
		Range		.11	
		Interquartile Range		.05	
		Skewness		-.923	.687
		Kurtosis		1.273	1.334
	TCS	Mean		2.0047	.03722
		95% Confidence Interval for Mean	Lower Bound	1.9205	
			Upper Bound	2.0889	
		5% Trimmed Mean		2.0032	
		Median		2.0085	
		Variance		.014	
		Std. Deviation		.11770	
		Minimum		1.83	
		Maximum		2.20	
		Range		.37	
		Interquartile Range		.21	
		Skewness		.121	.687
		Kurtosis		-.888	1.334

	Basis PC	Mean		3.6668	.01889
		95% Confidence Interval for Mean	Lower Bound	3.6241	
			Upper Bound	3.7095	
		5% Trimmed Mean		3.6664	
		Median		3.6701	
		Variance		.004	
		Std. Deviation		.05973	
		Minimum		3.58	
		Maximum		3.76	
		Range		.18	
		Interquartile Range		.11	
		Skewness		.034	.687
		Kurtosis		-.899	1.334
	Duraflex	Mean		2.6508	.02388
		95% Confidence Interval for Mean	Lower Bound	2.5968	
			Upper Bound	2.7049	
		5% Trimmed Mean		2.6486	
		Median		2.6443	
		Variance		.006	
		Std. Deviation		.07551	
		Minimum		2.56	
		Maximum		2.78	
		Range		.22	
		Interquartile Range		.13	
		Skewness		.478	.687
		Kurtosis		-.810	1.334
	Triplex Hot	Mean		5.8861	.06432
		95% Confidence Interval for Mean	Lower Bound	5.7406	
			Upper Bound	6.0316	
		5% Trimmed Mean		5.8912	
		Median		5.8686	
		Variance		.041	
		Std. Deviation		.20341	
		Minimum		5.53	
		Maximum		6.15	
		Range		.63	
		Interquartile Range		.35	
		Skewness		-.278	.687
		Kurtosis		-.862	1.334

Tests of Normality

	Denture	Kolmogorov-Smirnov[a]			Shapiro-Wilk		
		Statistic	df	Sig.	Statistic	df	Sig.
ElasticModulus	Valplast	.238	10	.114	.850	10	.057
	Lucitone FRS	.143	10	.200*	.943	10	.591
	TCS	.104	10	.200*	.974	10	.928
	Basis PC	.147	10	.200*	.954	10	.720
	Duraflex	.140	10	.200*	.930	10	.445
	Triplex Hot	.156	10	.200*	.953	10	.704

*. This is a lower bound of the true significance.

a. Lilliefors Significance Correction

Test of Homogeneity of Variances

ElasticModulus

Levene Statistic	df1	df2	Sig.
8.726	5	54	.000

ANOVA

ElasticModulus

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	107.189	5	21.438	1822.271	.000
Within Groups	.635	54	.012		
Total	107.825	59			

Robust Tests of Equality of Means

ElasticModulus

	Statistic[a]	df1	df2	Sig.
Welch	1146.631	5	23.942	.000
Brown-Forsythe	1822.271	5	22.689	.000

a. Asymptotically F distributed.

Post Hoc Test

Multiple Comparisons

Dependent Variable: ElasticModulus
Tamhane

(I) Denture	(J) Denture	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
					Lower Bound	Upper Bound
Valplast	Lucitone FRS	-.36687*	.02467	.000	-.4561	-.2776
	TCS	.14410	.04356	.070	-.0074	.2956
	Basis PC	-1.51805*	.02948	.000	-1.6178	-1.4183
	Duraflex	-.50207*	.03290	.000	-.6130	-.3912
	Triplex Hot	-3.73731*	.06819	.000	-3.9895	-3.4851
Lucitone FRS	Valplast	.36687*	.02467	.000	.2776	.4561
	TCS	.51097*	.03849	.000	.3652	.6567
	Basis PC	-1.15118*	.02129	.000	-1.2266	-1.0758
	Duraflex	-.13520*	.02582	.003	-.2292	-.0412
	Triplex Hot	-3.37044*	.06507	.000	-3.6230	-3.1179
TCS	Valplast	-.14410	.04356	.070	-.2956	.0074
	Lucitone FRS	-.51097*	.03849	.000	-.6567	-.3652
	Basis PC	-1.66215*	.04174	.000	-1.8104	-1.5139
	Duraflex	-.64617*	.04422	.000	-.7991	-.4932
	Triplex Hot	-3.88141*	.07432	.000	-4.1413	-3.6215
Basis PC	Valplast	1.51805*	.02948	.000	1.4183	1.6178
	Lucitone FRS	1.15118*	.02129	.000	1.0758	1.2266
	TCS	1.66215*	.04174	.000	1.5139	1.8104
	Duraflex	1.01598*	.03045	.000	.9126	1.1194
	Triplex Hot	-2.21926*	.06704	.000	-2.4711	-1.9674
Duraflex	Valplast	.50207*	.03290	.000	.3912	.6130
	Lucitone FRS	.13520*	.02582	.003	.0412	.2292
	TCS	.64617*	.04422	.000	.4932	.7991
	Basis PC	-1.01598*	.03045	.000	-1.1194	-.9126
	Triplex Hot	-3.23524*	.06861	.000	-3.4876	-2.9829
Triplex Hot	Valplast	3.73731*	.06819	.000	3.4851	3.9895
	Lucitone FRS	3.37044*	.06507	.000	3.1179	3.6230
	TCS	3.88141*	.07432	.000	3.6215	4.1413
	Basis PC	2.21926*	.06704	.000	1.9674	2.4711
	Duraflex	3.23524*	.06861	.000	2.9829	3.4876

*. The mean difference is significant at the 0.05 level.

IV. Statistical analysis for differences in nanohardness

Descriptives

	Denture			Statistic	Std. Error
Nanohardness	Valplast	Mean		.1173	.00195
		95% Confidence Interval for Mean	Lower Bound	.1129	
			Upper Bound	.1217	
		5% Trimmed Mean		.1175	
		Median		.1171	
		Variance		.000	
		Std. Deviation		.00616	
		Minimum		.10	
		Maximum		.13	
		Range		.02	
		Interquartile Range		.01	
		Skewness		-.575	.687
		Kurtosis		1.201	1.334
	Lucitone FRS	Mean		.1432	.00208
		95% Confidence Interval for Mean	Lower Bound	.1385	
			Upper Bound	.1479	
		5% Trimmed Mean		.1434	
		Median		.1437	
		Variance		.000	
		Std. Deviation		.00657	
		Minimum		.13	
		Maximum		.15	
		Range		.02	
		Interquartile Range		.01	
		Skewness		-.682	.687
		Kurtosis		.415	1.334
	TCS	Mean		.1059	.00206
		95% Confidence Interval for Mean	Lower Bound	.1013	
			Upper Bound	.1106	
		5% Trimmed Mean		.1056	
		Median		.1054	
		Variance		.000	
		Std. Deviation		.00652	
		Minimum		.10	
		Maximum		.12	
		Range		.02	
		Interquartile Range		.01	
		Skewness		.759	.687
		Kurtosis		.384	1.334

	Basis PC	Mean		.2187	.00231
		95% Confidence Interval for Mean	Lower Bound	.2135	
			Upper Bound	.2239	
		5% Trimmed Mean		.2183	
		Median		.2191	
		Variance		.000	
		Std. Deviation		.00731	
		Minimum		.21	
		Maximum		.24	
		Range		.03	
		Interquartile Range		.01	
		Skewness		1.025	.687
		Kurtosis		2.903	1.334
	Duraflex	Mean		.1021	.00175
		95% Confidence Interval for Mean	Lower Bound	.0982	
			Upper Bound	.1061	
		5% Trimmed Mean		.1023	
		Median		.1032	
		Variance		.000	
		Std. Deviation		.00552	
		Minimum		.09	
		Maximum		.11	
		Range		.02	
		Interquartile Range		.01	
		Skewness		-.375	.687
		Kurtosis		-1.486	1.334
	Triplex Hot	Mean		.2785	.00339
		95% Confidence Interval for Mean	Lower Bound	.2708	
			Upper Bound	.2861	
		5% Trimmed Mean		.2785	
		Median		.2774	
		Variance		.000	
		Std. Deviation		.01073	
		Minimum		.26	
		Maximum		.30	
		Range		.04	
		Interquartile Range		.01	
		Skewness		.019	.687
		Kurtosis		1.863	1.334

Tests of Normality

	Denture	Kolmogorov-Smirnov[a]			Shapiro-Wilk		
		Statistic	df	Sig.	Statistic	df	Sig.
Nanohardness	Valplast	.186	10	.200*	.953	10	.706
	Lucitone FRS	.189	10	.200*	.947	10	.632
	TCS	.162	10	.200*	.929	10	.434
	Basis PC	.241	10	.104	.859	10	.073
	Duraflex	.168	10	.200*	.914	10	.313
	Triplex Hot	.199	10	.200*	.942	10	.575

*. This is a lower bound of the true significance.

a. Lilliefors Significance Correction

Test of Homogeneity of Variances

Nanohardness

Levene Statistic	df1	df2	Sig.
.477	5	54	.792

ANOVA

Nanohardness

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	.259	5	.052	961.493	.000
Within Groups	.003	54	.000		
Total	.261	59			

Post Hoc Test

Multiple Comparisons

Dependent Variable: Nanohardness

Tukey HSD

(I) Denture	(J) Denture	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
					Lower Bound	Upper Bound
Valplast	Lucitone FRS	-.02589*	.00328	.000	-.0356	-.0162
	TCS	.01137*	.00328	.013	.0017	.0211
	Basis PC	-.10142*	.00328	.000	-.1111	-.0917
	Duraflex	.01514*	.00328	.000	.0055	.0248
	Triplex Hot	-.16118*	.00328	.000	-.1709	-.1515
Lucitone FRS	Valplast	.02589*	.00328	.000	.0162	.0356
	TCS	.03726*	.00328	.000	.0276	.0469
	Basis PC	-.07553*	.00328	.000	-.0852	-.0658
	Duraflex	.04103*	.00328	.000	.0313	.0507
	Triplex Hot	-.13529*	.00328	.000	-.1450	-.1256
TCS	Valplast	-.01137*	.00328	.013	-.0211	-.0017
	Lucitone FRS	-.03726*	.00328	.000	-.0469	-.0276
	Basis PC	-.11279*	.00328	.000	-.1225	-.1031
	Duraflex	.00377	.00328	.858	-.0059	.0135
	Triplex Hot	-.17255*	.00328	.000	-.1822	-.1629
Basis PC	Valplast	.10142*	.00328	.000	.0917	.1111
	Lucitone FRS	.07553*	.00328	.000	.0658	.0852
	TCS	.11279*	.00328	.000	.1031	.1225
	Duraflex	.11656*	.00328	.000	.1069	.1262
	Triplex Hot	-.05976*	.00328	.000	-.0694	-.0501
Duraflex	Valplast	-.01514*	.00328	.000	-.0248	-.0055
	Lucitone FRS	-.04103*	.00328	.000	-.0507	-.0313
	TCS	-.00377	.00328	.858	-.0135	.0059
	Basis PC	-.11656*	.00328	.000	-.1262	-.1069
	Triplex Hot	-.17632*	.00328	.000	-.1860	-.1666
Triplex Hot	Valplast	.16118*	.00328	.000	.1515	.1709
	Lucitone FRS	.13529*	.00328	.000	.1256	.1450
	TCS	.17255*	.00328	.000	.1629	.1822
	Basis PC	.05976*	.00328	.000	.0501	.0694
	Duraflex	.17632*	.00328	.000	.1666	.1860

*. The mean difference is significant at the 0.05 level.

Nanohardness

Tukey HSD[a]

Denture	N	Subset for alpha = 0.05				
		1	2	3	4	5
Duraflex	10	.1022				
TCS	10	.1059				
Valplast	10		.1173			
Lucitone FRS	10			.1432		
Basis PC	10				.2187	
Triplex Hot	10					.2785
Sig.		.858	1.000	1.000	1.000	1.000

Means for groups in homogeneous subsets are displayed.

a. Uses Harmonic Mean Sample Size = 10.000.

V. Drop test data to attain 50N impact value

PMMA

	1st drop	2nd drop	3rd drop	4th drop	5th drop	6th drop	7th drop	8th drop	9th drop	10th drop	Average	SD
Prescale Effective Rate (%)	51.30	46.50	49.60	54.30	46.80	47.80	50.50	51.00	57.10	52.00	50.69	3.31
Pressed Area (mm2)	10.00	11.00	10.00	10.00	10.00	10.00	9.00	10.00	12.00	11.00	10.30	0.82
Ave Pressure (MPa)	5.55	6.00	5.50	5.35	5.30	5.90	5.60	5.55	5.70	5.45	5.59	0.22
Max Pressure (MPa)	12.75	12.75	12.75	12.75	12.75	12.75	12.75	12.75	11.50	12.75	12.63	0.40
Load (N)	50.00	53.00	51.00	49.00	50.00	50.00	49.00	51.00	53.00	51.00	50.70	1.42
Measured Area (mm2)	26.00	26.00	26.00	26.00	26.00	26.00	26.00	26.00	26.00	26.00	26.00	0.00

Valplast

	1st drop	2nd drop	3rd drop	4th drop	5th drop	6th drop	7th drop	8th drop	9th drop	10th drop	Average	SD
Prescale Effective Rate (%)	51.30	47.50	50.60	54.30	47.60	48.70	50.50	51.40	54.30	48.20	50.44	2.50
Pressed Area (mm2)	11.00	11.00	10.00	10.00	10.00	10.00	10.00	10.00	11.00	11.00	10.40	0.52
Ave Pressure (MPa)	5.55	7.00	5.50	6.00	5.30	5.80	5.60	5.65	5.60	5.45	5.75	0.48
Max Pressure (MPa)	12.75	12.75	12.75	12.75	12.75	12.75	12.75	12.75	12.75	12.75	12.75	0.00
Load (N)	51.00	52.00	48.00	49.00	53.00	50.00	51.00	53.00	53.00	51.00	51.10	1.73

Measured Area (mm2)	26.00	26.00	26.00	26.00	26.00	26.00	26.00	26.00	26.00	26.00	26.00	0.00

Lucitone FRS

	1st drop	2nd drop	3rd drop	4th drop	5th drop	6th drop	7th drop	8th drop	9th drop	10th drop	Average	SD
Prescale Effective Rate (%)	52.50	48.60	49.70	52.10	53.10	49.40	50.50	51.00	52.70	53.00	51.26	1.64
Pressed Area (mm2)	10.00	11.00	10.00	10.00	10.00	10.00	11.00	10.00	12.00	11.00	10.50	0.71
Ave Pressure (MPa)	5.45	6.00	5.55	5.35	5.30	5.80	5.70	5.55	5.35	5.45	5.55	0.22
Max Pressure (MPa)	12.75	12.75	12.75	12.75	12.75	12.75	12.75	12.75	11.50	12.75	12.63	0.40
Load (N)	48.00	49.00	51.00	49.00	50.00	51.00	49.00	53.00	52.00	51.00	50.30	1.57
Measured Area (mm2)	26.00	26.00	26.00	26.00	26.00	26.00	26.00	26.00	26.00	26.00	26.00	0.00

TCS

	1st drop	2nd drop	3rd drop	4th drop	5th drop	6th drop	7th drop	8th drop	9th drop	10th drop	Average	SD
Prescale Effective Rate (%)	51.30	47.80	48.70	53.80	47.10	48.10	50.50	51.50	56.30	54.20	50.93	3.09
Pressed Area (mm2)	10.00	11.00	10.00	10.00	9.00	10.00	9.00	11.00	12.00	11.00	10.30	0.95
Ave Pressure (MPa)	5.55	6.00	5.50	5.35	5.30	5.90	5.60	5.55	3.85	5.45	5.41	0.59

Max Pressure (MPa)	12.75	12.75	12.75	12.75	11.75	12.75	12.75	12.75	11.50	12.75	12.53	0.48
Load (N)	51.00	48.00	49.00	48.00	50.00	50.00	48.00	50.00	53.00	48.00	49.50	1.65
Measured Area (mm2)	26.00	26.00	26.00	26.00	26.00	26.00	26.00	26.00	26.00	26.00	26.00	0.00

Basis PC

	1st drop	2nd drop	3rd drop	4th drop	5th drop	6th drop	7th drop	8th drop	9th drop	10th drop	Average	SD
Prescale Effective Rate (%)	52.30	46.50	48.80	54.30	47.80	47.80	50.50	51.20	57.10	52.30	50.86	3.29
Pressed Area (mm2)	11.00	11.00	9.00	10.00	9.00	10.00	9.00	10.00	10.00	11.00	10.00	0.82
Ave Pressure (MPa)	5.55	6.00	5.50	5.35	5.30	5.40	5.60	5.55	3.85	5.45	5.36	0.56
Max Pressure (MPa)	12.75	12.75	11.75	12.75	12.75	12.75	12.75	12.75	11.50	12.75	12.53	0.48
Load (N)	48.00	51.00	51.00	49.00	50.00	53.00	49.00	51.00	53.00	53.00	50.80	1.81
Measured Area (mm2)	26.00	26.00	26.00	26.00	26.00	26.00	26.00	26.00	26.00	26.00	26.00	0.00

Duraflex

	1st drop	2nd drop	3rd drop	4th drop	5th drop	6th drop	7th drop	8th drop	9th drop	10th drop	Average	SD
Prescale Effective Rate (%)	52.30	46.50	49.60	53.40	46.80	47.50	50.50	51.00	56.30	49.00	50.29	3.11
Pressed Area (mm2)	10.00	10.00	10.00	10.00	10.00	10.00	9.00	9.00	12.00	11.00	10.10	0.88

Ave Pressure (MPa)	5.55	6.00	5.50	5.35	5.30	5.90	5.50	5.55	3.85	5.45	5.40	0.59
Max Pressure (MPa)	12.75	12.75	12.75	12.50	12.75	12.75	12.75	11.50	11.50	12.75	12.48	0.52
Load (N)	48.00	53.00	51.00	47.00	50.00	50.00	49.00	50.00	50.00	51.00	49.90	1.66
Measured Area (mm2)	26.00	26.00	26.00	26.00	26.00	26.00	26.00	26.00	26.00	26.00	26.00	0.00

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