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PRESSURE TRANSMISSION AND DISTRIBUTION UNDER IMPACT LOAD USING DIFFERENT TYPES OF ARTIFICIAL DENTURE TEETH

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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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ธิติมา พุนทิกาพัทร์ : การถ่ายทอดและการกระจายแรงของฟันปลอมแต่ละชนิดภายใต้แรงกระแทก. (PRESSURE TRANSMISSION AND DISTRIBUTION UNDER IMPACT LOAD USING DIFFERENT TYPES OF ARTIFICIAL DENTURE TEETH) อ. ที่ปรึกษาวิทยานิพนธ์หลัก : รศ.ทพ.ดร.แมนสรวง อักษรนุกิจ, 55 หน้า.

การถ่ายทอดและการกระจายแรงภายใต้ฐานฟันปลอมอาจแตกต่างกันขึ้นกับชนิดของฟันปลอมที่ใช้ การศึกษาในครั้งนี้มีวัตถุประสงค์เพื่อประเมินการถ่ายทอดและการกระจายแรงภายใต้แรงกระแทกโดยใช้ฟันปลอมที่ผลิตจากวัสดุต่างชนิดกัน และเพื่อศึกษาค่าความยืดหยุ่นของฟันปลอม ชิ้นงานที่ทดสอบประกอบด้วยซี่ฟันปลอมที่ผลิตจากวัสดุ 4 ชนิด (อะคริลิกเรซิน ไมโครฟิลคอมโพสิตเรซิน นาโนคอมโพสิตเรซิน และเซรามิก) ชนิดละ 10 ชิ้น โดยทำการประเมินแรงที่ถ่ายทอด การกระจายแรง และปริมาณแรงที่มากที่สุดที่ตรวจพบ โดยใช้แผ่นทดสอบแรง ภายใต้แรงกระแทก จากนั้นทำการวัดค่าความยืดหยุ่นของซี่ฟันปลอมโดยใช้เครื่องทดสอบแรงกดระดับอัลตร้าไมครอน ทำการวัดข้อมูลที่ได้ทางสถิติโดยใช้การทดสอบการแปรปรวนทางเดียวที่ระดับความเชื่อมั่น 95%

ผลการศึกษาพบปริมาณแรงถ่ายทอดที่มากที่สุดในกลุ่มฟันปลอมเซรามิก ฟันปลอมชนิดนาโนคอมโพสิตเรซินมีการถ่ายทอดแรงลงมาใต้ฐานฟันปลอมน้อยที่สุด การทดสอบค่าความยืดหยุ่นของซี่ฟันปลอมพบว่ามีความแตกต่างกันอย่างมีนัยสำคัญทางสถิติระหว่างฟันปลอมทั้ง 4 ชนิด การถ่ายทอดและการกระจายแรงมีความแตกต่างกันขึ้นกับวัสดุของซี่ฟันปลอม โดยพบความแตกต่างทั้งขนาดและรูปแบบการกระจายตัวของแรง การเลือกวัสดุฟันปลอมที่เหมาะสมอาจลดประมาณแรงที่จะถ่ายทอดลงสู่สันเหงือกได้

ภาควิชา ทันตกรรมประดิษฐ์ ลายมือชื่อนิสิต ธิติมา พุนทิกาพัทร์
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THITIMA PHUNTHIKAPHADR : PRESSURE TRANSMISSION AND DISTRIBUTION UNDER IMPACT LOAD USING DIFFERENT TYPES OF ARTIFICIAL DENTURE TEETH. THESIS ADVISOR : ASSOC. PROF. MANSUANG ARKSORNNUKIT, Ph.D., 55 pp.

Pressure transmission and distribution under denture bases may be different depending on the type of artificial denture teeth used. The purposes of this study were to evaluate pressure transmission and distribution under impact load using artificial denture teeth composed of different materials, and to examine the modulus of elasticity of the artificial denture teeth. The denture base specimens with artificial denture teeth made of 4 different materials (acrylic resin, microfilled composite resin, nanocomposite resin, and ceramic) were evaluated. Pressure transmission, distribution, and maximum pressure (n=10) were observed with pressure-sensitive sheets under an impact load. Modulus of elasticity of the artificial denture teeth (n=10) was measured by using an ultramicroindentation system. Data were statistically analyzed with 1-way ANOVA, followed by Tukey HSD and Tamhane's multiple range post hoc tests (α=.05).

Maximum pressure transmission observed from ceramic denture teeth was significantly higher than that of other groups (P<.001). Nanocomposite resin denture teeth presented the lowest pressure transmission, whereas a localized stress transmission area was observed in the ceramic denture teeth group. Significant differences in the modulus of elasticity were observed among the 4 types of artificial denture teeth (P<.001).

Pressure transmission and distribution varied among the denture tooth materials. Differences in the modulus of elasticity of each type of denture tooth were demonstrated. Artificial denture teeth composed of different materials showed different amounts and patterns of pressure distribution. Choosing the appropriate denture tooth material may lessen the force transmitted to the supporting structures.

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LIST OF ABBREVIATIONS

ANOVA	Analysis of Variance
cm	centimeter
Fig	figure
g	gram
KPa	kilopascal
MPa	megapascal
min	minute
ml	milliliter
mm	millimeter
°C	degree Celsius
µm	micrometer
SD	standard deviation
sec	second

CHAPTER I

INTRODUCTION

Pressure from a prosthesis is an important factor in increasing residual ridge resorption in denture wearers (1,2). Several authors have indicated that bone resorption was observed when high pressure was applied (3,4). Berg et al. (5) stated that to maintain normal blood circulation, a continuous mechanical pressure higher than 1.3 kPa should not be exerted to the denture-supporting tissues. Zarb et al. (6) mentioned that a continuous mechanical pressure of 1.3 kPa would compress soft tissues to the thickness of 95% of the tissue at rest. Matsuo et al. (7) investigated the intracellular response to hydraulic pressure in human periodontal ligament fibroblasts. The results suggested that fibroblasts started to respond to the pressure by increasing intracellular calcium at a threshold level of 27 to 68 g/cm^2 of pressure. According to these studies, dental prostheses should be fabricated with a goal of reducing the amount of force to the residual ridges. Choosing appropriate denture tooth materials is one of the crucial steps in prostheses fabrication that may reduce pressure and avoid stress concentration to the supporting tissues.

Artificial denture teeth should have the ability to resist impact force and transfer light and well distributed pressure to the supporting structures. Suzuki et al. (8) demonstrated that porcelain teeth showed poor impact resistance. Conventional acrylic resin teeth had superior impact resistance compared to highly crosslinked plastic teeth. These results were supported by Kawano et al, (9) who measured the impact values of different types of artificial denture teeth. The results demonstrated that acrylic resin teeth presented excellent impact resistance and shock absorbability, whereas porcelain denture teeth revealed the highest impact values. However, both studies (8,9) used measuring devices which showed only the impact values and not the pattern of impact force distribution.

Nanocomposite resins have been introduced as a material of choice for artificial denture teeth (10-12). Zheng et al. (13) studied the effects of nanoparticles on the performance of nanocomposite resins. The results revealed that nanoparticles serve as binding agents to modify the morphological structure of the epoxy resin. On the basis of this structure, numerous cavitation sites are created at the interface between the nanoparticles and the amorphous layer. When the impact occurs, the formed cavities will release the plastic constraint in the matrix and trigger large-scale plastic deformation. As a result, the fracture toughness of the matrix will be significantly improved. Moreover, the interfacial surfaces generated between polymer and nanoparticles also assist in absorbing stresses. Several authors have attempted to record pressure under the denture base and to evaluate the amount and distribution of pressure transmission (14-17). Several techniques and measuring devices have been developed and widely used. Strain gauge and pressure transducer measurements are 2 of the most common pressure recording methods (18-20). However, these 2 devices are only suitable for measuring pressure at specific sites. A pressure-sensitive sheet (Prescale Film; Fuji Photo Film Co, Ltd, Tokyo, Japan) has been developed and used as a pressure-detecting device for measuring occlusal pressure, occlusal force, and occlusal contact areas (21,22). When contact pressure is applied over the film, different shades of red color are developed which are correlated to the amount of pressure. This film may be considered one of the most useful devices for pressure measurement due to its simplicity and capability in detecting large pressure ranges and large distribution areas (21-23).

Modulus of elasticity (Young’s modulus or elastic modulus) describes the relative stiffness or rigidity of a material (24). The modulus of elasticity of artificial denture teeth for removable prostheses may be a factor that influences pressure transmission and pressure distribution on the underlying alveolar residual ridges.

The purposes of the present study were to examine pressure transmission and distribution using simplified models with artificial denture teeth of different materials under impact load, and to evaluate the modulus of elasticity of each type of denture tooth. The null hypotheses were that there would be no differences in pressure transmission and distribution and in the modulus of elasticity of the artificial denture teeth.

CHAPTER II

LITERATURE REVIEW

1. Alveolar mucosa under dentures

To ensure the success of removable prostheses, the dentist has to capture and maintain the morphologic and histologic characteristics of the oral mucous membrane that is in close contact with the prostheses (25). A number of studies regarding histological and histochemical changes in the oral mucous membrane subjected to stress under complete dentures were extensively established (25,26,27,28,29).

Sharma and associates (25) observed the palatal mucosa in denture wearers and non-denture wearers. They found an increase in thickness of epithelium but a decrease in keratinization in denture wearers. Furthermore, they also concluded that denture wearing not only results in changes within the epithelium, but also results in an equally significant reaction of the connective tissue. This reaction results in the appearance of a highly resistant and elastic oxytalan fiber system, which assists the connective tissue to react successfully to the stresses exerted on it, and prevent underlying bone resorption. Nedelman et al. (26) investigated the alveolar ridge mucosa in denture and non-denture wearers. Their study also demonstrated keratinized layer thickening in non-denture wearers and a thinning of this layer in denture wearers.

In contrast, a report in histological comparison of the palatal mucosa before and after wearing complete dentures by Jani and Bhargava (27), showed an increase in keratin thickness in most patients after dentures placement. They explained that after denture insertion, the entire masticatory load is distributed over the palatal mucosa and residual ridges. Thus, the palatal mucosa of denture-wearing patients is subjected to more mechanical forces than that of non-denture wearers. This may lead to the increase in thickness of keratin, which can be considered an adaptive phenomenon for wearing dentures comfortably.

Watson (30) suggested that literature on the nature of changes in oral mucosa is controversial because of three main reasons. First, mucosa from different sites have been examined. Secondly, mucosa covered by different types of prostheses have been compared. Thirdly, the methods of analysis have varied considerably in complexity and accuracy. Therefore, the purpose of his study was to develop a method of analysis which is accurate and easy to use, and which would provide quantitative information on various morphological parameters of oral mucosa. He examined the oral mucosa of non-denture and denture wearers and found no significant difference in epithelial thickness between two groups. Changing type of keratinization from complete orthokeratosis to incomplete orthokeratosis under dentures was also determined.

Since keratinization is the manifestation of the protective mechanism against functional forces, the response of oral mucous membrane can be inflammatory, degenerative, or hyperplastic, depending upon the nature and severity of injury and individual tissue responses. Therefore, the dentists should be responsible for providing good dentures so that stresses are within the biologic limits of tissue tolerance (27).

Literature publications not only propose information about histological and histochemical tissue changes, but also offer data about mucosal blood flow after wearing dentures. The effect of complete denture wearing on the palatal mucosal blood flow was further investigated by Atasever et al. (31). The investigators measured blood flow changes before and after denture insertion by using ^{133}Xe inert gas. Before the insertion of dentures, the mean blood flow to palatal mucosa was 18.9 ± 7.1 ml/ 100g/ min. Seven and forty days after wearing dentures, the mean blood flows were 10.6 ± 4.5 and 12.6 ± 5.3 ml/ 100g/ min, respectively. However, blood flow returned to near normal levels after resting the oral tissues for about 24 hours. The conclusion was made from the study that there was a significant decrease in blood flow after using complete dentures for seven and forty days. It was clearly shown that wearing dentures continuously hindered blood supply to the palatal mucosa. Nevertheless, hindrance of blood supply is not an irreversible condition. The blood flow almost returned to normal after a short (24 hours) rest. Permanent effects of the lowering of blood supply might, however, result from the wearing of dentures for long periods of time. Hence, leaving dentures out of the mouth for a minimum of 6 hours per day during sleep is generally recommended, and may be essential for the recovery of the blood supply to the palatal mucosa.

2. Bone resorption and pressure

The relationship between bone resorption and pressure has become a topic of interest amongst experts. The published literatures are divided into two groups, animal studies and clinical studies.

2.1 Animal studies

Several animal studies demonstrated that excessive and constant pressure caused an increase in bone resorption (32,33,34,35,36).

Early animal research in the 1960s related to pressures on bone was performed in male white Carneau pigeons, by Ackerman et.al. (37). It was summarized from the experiment that pressure applied to bone caused bone resorption. Using lower pressure (33 to 113 Gm. per square centimeter) applied for a long period of time caused more severe resorption than using higher pressure (293 to 548 Gm. per square centimeter) applied for a short period of time. Applying low and high pressure for the same period of time caused resorption of nearly the same degree. Thus, it was concluded from this study that the duration of pressure application was a more important factor in regard to bone resorption than the amount of pressure applied.

An impressive series of studies by a group of researchers at the Okayama University Dental school, presented the results in histopathological changes under simulated denture in rats (32,33,34,35,36,38). One of their studies (33) revealed that the lowest load continuous pressure (1.5 kPa) did not cause bone resorption, whereas when using higher pressure (3.4 and 4.9 kPa) bone resorption was observed. This study used experimental dentures adhere to the palate of the molar region of Wistar strain rats. Another study accomplished by Sato et al. (34), aimed to clarify whether osteoclastic bone resorption is pressure-threshold regulated or merely a proportionally pressure-dependent phenomenon. The simulated dentures were exerted on the rat hard palate with a defined amount of continuous or intermittent compressive pressure. They found no bone resorption when the continuous pressure was ≤1.96 kPa or when the intermittent pressure was ≤9.8 kPa. On the other hand, continuous compressive pressure ≥6.86 kPa or intermittent pressure ≥19.6 kPa caused significant bone resorption. It was concluded from the study that osteoclastic bone resorption was a pressure-threshold regulated incidence with a lower threshold for continuous, than for intermittent pressure.

Histomorphometric analysis was also undertaken to determine bone dynamics in denture supporting tissue under masticatory and continuous pressure in rats (35,36). It was revealed that masticatory pressure caused different time courses of the bone dynamics depending on the initial intensity of the pressure. The pressure under bone resorption threshold induced the transient increase of osteoid formation in denture supporting bony tissue, compared with non-pressure denture base tissue. However, other bone dynamic parameters were not affected. It was shown that masticatory pressure over the threshold for bone resorption caused higher bone resorption upon the increase in the intensity of the pressure (35).

Similar research was done by Imai et al. (36) but focused on the effect of continuous pressure. Bone dynamics under a fabricated denture base, in relation to the intensity of continuous pressure exerted through the denture supporting tissue, was investigated. It was summarized from the study that bone dynamics under continuous pressure showed a time course depending on the intensity of the initial pressure. The amount of bone resorption also corresponded to the initial intensity of the pressure. Both the Ohara et al. (35) and Imai et al. (36) observations revealed that bone formation following bone resorption was not equivalent to the bone surface level observed in the case without bone resorption in their studies.

2.2 Clinical studies

Clinical studies have suggested that residual ridge resorption is due more to the effects of denture wearing than to disuse atrophy (39). There are several factors related to residual ridge resorption (40). One of the few firm facts relating to edentulous patients is that wearing dentures is almost invariably accompanied by undesirable and irreversible bone loss. The magnitude of this loss is extremely variable, and little is known about which factors are the most important for the observed variations (41).

The tissue support for complete dentures is conspicuously limited in both its adaptive ability and inherent capability of simulating the role of the periodontium. As complete denture movement is related to the resiliency of the supporting mucosa, almost all “principles” of complete denture construction have been formulated to minimize the forces transmitted to the supporting structures, or to decrease the movement of the prostheses in relation to them (41).

The alteration of forces exerted by the denture to the supporting tissue has been the subject of much discussion. Cutright et al. (42) observed the pressure movements beneath the dentures during various masticatory and non-masticatory activities. The results of the study showed that stable dentures produce high pressures on the supporting tissues and transmit these pressures from region to region. The results varied depending on how the patient used the dentures. Surprisingly, non-masticatory pressures produced under dentures were found to be as great as, or greater than, masticatory pressures. The researchers implied from the study that effect of the continually occurring, non-masticatory, induced pressure changes and pressure waves beneath the dentures may well be of greater significance than that of mastication.

Since the 1960s, most investigators have paid attention to the alveolar ridge resorption. Atwood and associates (43) examined the reduction of residual ridges by measuring anterior vertical bone loss. The clinical examination, cephalometric, and densitometric measurements were compared for the average time of 31 months. The findings suggested that the rate of residual ridge resorption varied between different individuals and also varied between the upper and lower jaw. The rate of resorption of the mandible was four times greater than the maxilla. They came to the conclusions that residual ridge resorption is a chronic, progressive, irreversible, and disabling disease, probably of multifactorial origin. Moreover, it was suggested that residual ridge resorption is almost universal but with wide individual variation. Because the amount of resorption was very important, longitudinal, cumulative, and repeat examinations were necessary.

Atwood (44) examined and divided the factors related to the rate of residual ridge resorption into anatomic, metabolic, functional, and prosthetic factors. When concentrating on the functional factors, the frequency, intensity, duration, and direction of forces applied to bone which were translated into cellular activity were included. This results in either bone formation or bone resorption, depending on individual response. Prosthodontic factors are extremely difficult to evaluate because of the tremendous number of variables. The factors include the myriad of techniques, materials, concepts, principles, and practices which are incorporated into the prostheses.

Campbell (45) compared the alveolar ridge resorption between denture-wearers and non-denture wearers and found that denture-wearing jaws lost more bone than those without dentures. According to this result, leaving out the dentures at night time might reduce bone resorption. Jozefowicz (46), in his study of bone loss among 1012 patients, made the supposition that wearing dentures at night induces atrophy of the residual ridges. This is because of the constant pressure on the soft tissues which is then transmitted to the bone. Thus, correlation can be established between continuous denture wearing and bone resorption. However, the research done by Kalk and Baat (40) did not show a significant correlation between alveolar bone resorption and dentures being worn day and night. Tautin (47) had reviewed the literatures and commercial booklets for complete denture patients' education, and discovered a difference of opinion regarding continuous denture wearing. The literature indicates that it would be beneficial to remove dentures at night or for some extended period every 24 hours, but the commercially prepared booklets do not emphasize denture removal as a preventive practice. It has been shown that the routine removal of dentures at night or for some extended period helps in maintaining the health of the underlying tissues. He suggested that dental professions are in charged with the responsibility of preserving and maintaining the health of the oral tissues. Therefore, dentists should make an effort to educate edentulous patients about oral tissue health and the length of time that dentures should be worn.

An interesting early study in alveolar bone loss by Tallgren (48) showed the relationship between facial morphology and the anterior bone loss during a 7-year period of denture wear by lateral cephalometric films. The observation indicated that changes in position of the lower incisors due to denture construction may contribute to alveolar resorption. Therefore, a more lingual positioning of the incisal edge of the artificial lower incisors than that of the natural teeth was found to be associated with a marked mandibular resorption. However, resorption of the alveolar process was not found to be related to age, and no significant associations between resorption and the initial height of the alveolar processes was found in his study.

Another classic literature presented by Tallgren (49), who observed two groups of complete denture wearers to the 15 year and 25 year stages of denture wear, revealed a continuous reduction of the residual ridges, particularly marked on the lower ridge. The most likely reason for the obvious lower ridge reduction is because of the smaller area and less advantageous shape of the lower basal seat. Moreover, correlations between the shape of the mandible and the anterior mandibular bone loss indicated a pronounced resorption in subjects with a marked mandibular base bend, and a less marked resorption in subjects with a flattened mandibular base. Hence, he suggested that careful examination of the mandibular shape can provide valuable information on the response of the residual ridge to the wearing of dentures.

The non-conclusive results about denture-related bone resorption are still often seen in dental literature. Probable explanations are, among other things, the enormous individual variation in the rate of bone loss reported in many studies. This great variation makes size and selection of samples critical for establishing comparable results (39).

3. Artificial denture teeth

Tooth placement and physiological tooth arrangement are considered the almost last step in complete denture construction. Proper selection of artificial denture teeth is one of the important factors to determine the success of the complete denture.

Fenton (50) mentioned that dentists require knowledge and understanding of a number of physical and biological factors, directly related to the patient for appropriately select artificial teeth to rehabilitate the occlusion. The goals for this phase of treatment are to construct complete dentures that *(1)* function well, *(2)* allow the patient to speak normally, *(3)* are esthetically pleasing, and *(4)* will not abuse the tissues over residual ridges. In order to achieve those objectives, dentist must accumulate, correlate, and evaluate the biomechanical information so that the artificial teeth selected will meet the individual needs of the patient. Fenton also suggested that selection of artificial teeth is a relatively simple non-time-consuming procedure, but it requires the development of experience and confidence.

Several denture tooth materials are available on the market. Porcelain and acrylic resin teeth have been used for many years. However, neither of them completely accomplishes the requirements for an ideal prosthetic denture tooth (51).

Comparisons of properties of plastic and porcelain teeth are as follows (52);

Plastic teeth	Porcelain teeth
• High resilience	• Very brittle
• Tough	• Friable
• Soft-low abrasion resistance	• Hard-high abrasion resistance
• Insoluble in mouth fluids-some dimensional change	• Inert in mouth fluids-no dimensional change
• Low heat-distortion temperature, cold flow under pressure	• High heat-distortion temperature; no permanent deformation under forces of mastication
• Bond to denture base plastic	• Poor bond-to-denture base plastic; mechanical retention provided in tooth design
• Natural appearance	• Natural appearance
• Natural feel-silent	• Possible clicking sound in use
• Easy to grind and polish	• Grinding removes surface glaze
• Crazing and blanching-if non-cross Linked	• Occasional cracking

In an effort to deliver the best possible treatment, it is incumbent upon the practitioner to become acquainted with the materials, and then quantitatively decide which material is most suited for the individual patient. The choice of materials and tooth morphology should be based on a sound philosophy and rationale of treatment and must be made by the dentist, not the laboratory technician (51).

The majority of resin teeth are based on poly (methyl methacrylate) compositions. Poly (methyl methacrylate) resins used in the prosthetic teeth fabrication are very similar to those used in denture base construction. However, the degree of cross-linking within prosthetic teeth is much greater than that within polymerized denture bases. This increase is achieved by elevating the amount of cross-linking agent in the denture base liquid. The resultant polymer displays enhanced stability and improved clinical properties (53).

Acrylic resin (PMMA) denture teeth are manufactured either by the compression-molded dough technique or by injection molding (54). The wear resistance of acrylic resin teeth has improved since the time of their introduction when they were molded under high heat from powdered polymer. These early teeth were of poor quality and had a tendency to partially revert to their original powder form in the mouth. Injection machines were used to force molten polymer into a mold cavity, using manufacturing technology in the late 1940s. These teeth, however, had a tendency to craze and undergo dimensional changes from water imbibition and exposure to organic solvents. Marked improvements occurred with the development of cross-linking agents, which solved the crazing problem. Changing the types and amounts of the cross-linking agents has been done to improve the physical properties (55). However, cervical portions of prosthetic teeth often exhibit little or slight cross-linking. This feature facilitates chemical bonding with denture base resins. Additional enhancement of chemical bonding may be achieved by removing the glossy “ridge-lap” surfaces of resin teeth (53).

Since the introduction of resin denture teeth in the mid-20th century, there have been steady developments in order to improve their properties. Polymer-based denture teeth have been categorized into 5 groups by Shahdad et al. (56) as follows;

1. Polymethylmethacrylate (PMMA)
2. PMMA with filler
3. Cross-linked polymer and matrix (Double Cross-Linked [DCL])
4. Interpenetrating Polymer Network (IPN)
5. Microfilled urethanedimethacrylate (Composite resin based)

All of them except the composite-resin based material contain PMMA as their basic constituent. Various manufacturers also have their own brands available within these categories (56). The major difference between acrylic and modified resin teeth is the microstructure. The acrylic has a linear polymer chain structure, while all modified resin teeth have a cross-linked structure (57).

Double Cross-Linked [DCL] is an acrylic material constructed using a dough molding procedure in which both the bead pre-polymer and the freshly polymerized monomer are cross-linked. Traditional acrylic materials contain only cross-linked matrix methacrylate, and this restricts the beneficial effect of cross-linking. Cross linking both the matrix PMMA and the original bead PMMA offers a potential advantage. This is provided that the bead PMMA is not cross-linked to an extent which prevents interpenetrating networks of the matrix and discrete phase polymers (56).

An Interpenetrating Polymer Network [IPN] artificial tooth was introduced into the market by a major manufacturer in an effort to minimize the disadvantages of acrylic resin teeth and enhance certain of their desirable qualities. IPN tooth material was constructed of an unfilled, highly cross-linked copolymer with an interpenetrating polymer network. Interpenetrating polymer networks are structures formed when a polymer is cross-linked into a three-dimensional network, occupied by a second cross-linked polymer. The cross-linked networks coexist in the same volume of space, one physically trapped within the other, and cannot be disassociated without rupture of chemical bonds. This interpenetrating polymer network structure allows polymeric materials to be used in new ways that result in enhanced physical properties (55). Several in vitro studies about wear rates of IPN artificial tooth and conventional acrylic resin tooth have been well documented (58,59). Coffey et al. (58) evaluated the acrylic resin, IPN, and natural teeth for wear characteristics using an artificial oral environment that simulated in vivo conditions. The study showed that IPN denture teeth were more resistant to wear than acrylic resin teeth when opposing each other in function. The result was supported by Whitman et al. (59), who compared the wear rates of three types of commercial denture tooth materials. Their study indicated that interpenetrating-polymer network tooth denture material is more wear resistant than conventional acrylic resin.

Microfilled resin composite tooth composed of urethane dimethacrylate (UDMA), 100% crosslinked, containing a small hydrophobic silicon dioxide microparticle filler aerosol (60). The inorganic fillers in the composite teeth are subjected to a silane-coupling treatment to enhance the adhesion of these particles to the matrix base of tooth material (61). Composite resin tooth has been claimed to possess increased wear resistance and greater bond strength to denture bases. Most investigations indicated that micro-filled composite denture teeth had a superior wear resistance compared to conventional acrylic resin and IPN denture teeth (59,61,62). An interesting research in wear resistance accomplished by Zeng et al. (63) showed a remarkable result. The investigators compared the wear resistance of three types of composite resin denture teeth in vitro based on composite resin filler content. It was shown from the study that composite resin denture teeth with 68% (Duracross) and 47% (Endura) organic filler had a higher wear resistance than 42%- filled composite resin teeth (Duradent). Therefore, it was concluded that artificial teeth containing more organic filler exhibited less wear than the type containing less filler.

Effect of filler size in dental composites on laboratory wear was also determined. Schwartz and Soderholm (64) compared the wear rates of three composites containing silane-treated filler particles with the average particle diameters of 1.5, 3.0, and 10.0 μm. The wear analysis showed that the finer composites (1.5 μm filler diameter) wore the least and the coarsest composites (10 μm filler diameter) the most. The authors from the study explained that finer filler particles and shorter filler spacing slow down diffusion of plasticizing agents, and the lower plasticizing effect caused by the finer particles is the key reason why wear decreases as filler size decreases. They summarized that dental composites containing smaller filler particles are more wear-resistant than composites containing larger filler particles.

A new type of denture tooth, fabricated of nano-composite resin, has recently been developed as a highly polishable, stain and impact resistant material. It consists of a co-monomer of urethane dimethacrylate (UDMA) and methylmethacrylate (MMA), polymethylmethacrylate (PMMA), and uniformly dispersed nano-sized filler particles (65). Suzuki (65) questioned the wear rate of this material. He suggested that even the material contains PMMA, cross-linked with UDMA and reinforced by inorganic fillers, excellent wear resistance might not be expected. Therefore, he compared the wear rates of a recently developed nano-composite denture tooth with the various types of resin denture teeth, including micro-filled composite teeth, cross-linked acrylic resin teeth, and traditional acrylic resin denture teeth. He found no statistically difference in wear depth between nano-composite denture tooth and those of micro-filled composite and cross-linked acrylic denture tooth. However, he suggested that nano-composite denture teeth may be a promising selection for denture teeth, as this material has wear resistance equivalent to most micro-filled composite teeth and improved impact resistant and anti-staining properties.

4. Pressure measurement

To measure and record the pressure at the denture base-mucosal surface interface involving complete denture construction, many techniques and measuring devices have been developed and widely used.

Frank (66) performed an investigation to measure pressures produced during edentulous impression procedures. A pressure gauge was constructed of brass tubing with one end covered with a thin flexible rubber membrane and the other end connected to a polyethylene tube and a wire strain gauge. When pressure was applied to the rubber membrane, it caused water displacement in the closed system, which was then converted to an electrical signal by strain gauge.

Another pressure measurement involved in edentulous impression making was evaluated by Rihani (67). The measure equipment apparatus consisted of flexible polyethylene tubes placed on the special custom trays and connected to the glass tubes to form simple manometers. Pressure applied to any part of the flexible tubing caused a movement of the column of liquid in the glass tubes which could then be measured.

A different method of pressure recording at the denture base-mucosal surface interface was used in the study by Watson and Huggett (68). The authors examined the forces generated by complete dentures during mastication by using strain gauge and pressure transducers. Those transducers were used for the following reasons: *(1)* the sensitivity of the transducer could be varied by altering the size and thickness of the diaphragm; *(2)* it was of small size and weight; *(3)* it was simple to assemble and repair; *(4)* the assembly time for each transducer was approximately 3 hours and the total cost of all the component parts, including the strain gauge, was low, making it a very economical system; *(5)* the resistance strain gauge could be used with an a.c. or d.c. excitation system. However, the transducers lead-based system was a major disadvantage that should be one of the devices main concerns.

Pressure transducers were also used in some studies aiming to examine the amount of pressure developed during impression making (69,70). The oral analog was constructed with the embedded metal tubes attached to the pressure transducers. The tubes were filled with distilled water and no air bubbles. When pressure was applied to the water in the tubes, the pressure was then transferred through the transducers and amount of pressure could be evaluated.

The new convenient method for pressure measurement was used by Komiyama et al. (71), who investigated the pressure characteristics of the maxillary edentulous impressions. The miniature pressure sensors were embedded into a cast which was attached to a rheometer to apply a continuous isotonic force. Data obtained from the miniature pressure sensor were calculated using a sensor interface and then pressure were recorded on a personal computer.

4.1 Pressure sensitive sheet (Dental Prescale, Prescale film)

A new pressure measuring device (Dental Prescale System, Fuji Photo film, Tokyo) has been developed in Japan. The system composed of pressure-sensitive sheets (Dental Prescale) and its analysis apparatus (Occluzer). This device has been improved for dental use and now widely applied for bite force, occlusal contact area, and occlusal pressure measurement (72-83).

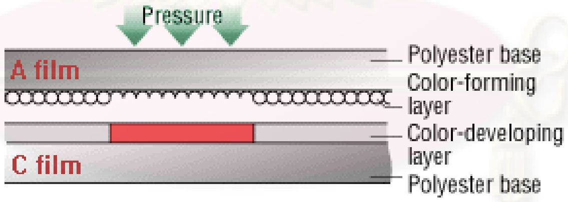
4.1.1 Fundamentals of Pressure sensitive sheet (84)

Pressure sensitive sheet or “Prescale film” is used for measuring contact linear and planar pressures. The structure is a thin film consisting of micro-encapsulated color forming and color developing materials. When pressure is applied to the film, a red color impression is formed in varying density according to the amount of pressure and pressure distribution. The film can be used in both stationary and moving applications to measure pressures up to 130 MPa

Prescale film is available under two possible formats, one based on two sheets (A + C), and another as a single sheet. Their usage depends on the measuring range.

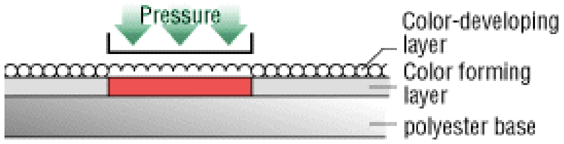
Two sheet film

Two sheet type of Prescale film composed of an “A film” which is coated with a particular micro encapsulated color forming material, and a “C film”, which is coated with a specific color developing material. When use in conjunction, the two films should be placed with the coated (rough and opaque) surfaces facing each other.



Single sheet film

With the single sheet film, the color forming layer is coated on the polyester base of the film. Micro encapsulated color forming material is layered on the top of the film.



When pressure is applied, the microcapsules are broken and the color-forming material that is released reacts with the color-developing material to generate color. Through Particle Size Control (PSC) technology, the microcapsules are designed to react to various degrees of pressure, releasing their color-forming material at a density that corresponds to the pressure.

There are six different types of films ranging from 0.2 to 130 MPa

MODEL	Description	Measuring ranges	Dimensions	Type
LLLW	ultra super low pressure	from 0,2 to 0,6 MPa *(from 2 to 6 kg/cm²)*	270 mm (w) x 4 m (l)	*two sheet*
LLW	super low pressure	from 0,5 to 2,5 MPa *(from 5 to 25 kg/cm²)*	270 mm (w) x 5 m (l)	*two sheet*
LW	low pressure	from 2,5 to 10 MPa *(from 25 to 100 kg/cm²)*	270 mm (w) x 10 m (l)	*two sheet*
MW	medium pressure	from 10 to 50 MPa *(from 100 to 500 kg/cm²)*	270 mm (w) x 10 m (l)	*two sheet*
MS	medium pressure	from 10 to 50 MPa *(from 100 to 500 kg/cm²)*	270 mm (w) x 10 m (l)	*single sheet*
HS	high pressure	from 50 to 130 MPa *(from 500 to 1300 kg/cm²)*	270 mm (w) x 10 m (l)	*single sheet*

Note : 1 MPa = 10 kgf/cm² = 145 lbf/in² (psi)

4.1.2 Pressure sensitive sheet analysis (84)

Approximate density and pressure can be easily determined by visual comparison of the displayed pattern with the pressure chart, which will provide the accuracy of +/-10%. However, more precise and refined results can be evaluated by using the digital analysis system.

4.2 Application of pressure sensitive sheet in dental research

Pressure sensitive sheets have been used in various fields of dental research. In prosthodontics, Prescale film was used for clinical measurements of the parameters which were related to the analysis of occlusion in complete denture wearers (72). Those parameters composed of occlusal force, mean pressure, the deviation of the center of the occlusal loads from the median line, occlusal contact area, and the number of occlusal contact points. The authors suggested that Dental Prescale was preferable in the examination because of the following advantages: *(1)* the thin material induces only a small change in the occlusal vertical dimension; *(2)* it is not necessary to prepare special measurement equipment; *(3)* it needs a short period of time for evaluation; *(4)* record storage is simplified; and *(5)* it is easy to explain the treatment to patients by using dental images.

In dental surgery, the pressure sensitive device was applied for measuring the changes of bite force and occlusal contact area after surgical procedures (73,74,75). The researchers indicated that this device was very easy to apply and was a simple way to evaluate the bite force and occlusal contact area of patients. Moreover, the occlusal balance was also measured by the analysis system (73). Ohkura et al. (74) examined the changes in bite force and occlusal contact area after orthognathic surgery in the prognathous mandibular patients. It was shown from the study that measuring with the pressure-sensitive sheet may indicate the masticatory ability of the patients after orthognathic surgery.

Pressure sensitive sheets were also applied for use in Paediatric dentistry. Karibe et al. (76) observed a relationship between clenching strength and the distribution of occlusal forces on a primary dentition. They recommended that this measuring device made it possible to measure the occlusal force, the area of occlusal contact and the occlusal pressure of all the teeth at once.

In Orthodontics, Dental Prescale film was used to evaluate the occlusal force and occlusal contact area in orthodontic patients (77,78). The authors suggested that because the thickness of the pressure-sensitive sheet was merely 0.097 mm, the occlusal force and occlusal contact area could be measured in the state of intercuspal position. Moreover, it is independent from local factors such as wetness and temperature in the oral environment (77).

The pressure sensitive sheets were also found in a wide range of application in other research (79-83). Mostly, Prescale film was used to evaluate the bite force or occlusal pressure. Because of all its advantages, Prescale film should be considered as one of the most useful devices for pressure measurement.

CHAPTER III

MATERIAL AND METHODS

Forty mandibular right and left first molars made of 4 different types of denture tooth materials (acrylic resin, AR; microfilled composite resin, MC; nanocomposite resin, NC; and ceramic, CR) were examined in this study (Table I).

Table I. Artificial denture teeth used in the present study

Type	Brand name	Code	Mold	Manufacturer
Acrylic resin	Resin Kyushi	AR	M30	Shofu, Tokyo, Japan
Microfilled composite resin	Endura posterior	MC	M30	Shofu
Nano-composite	NC Veracia posterior	NC	M30	Shofu
Ceramic	Ace Kyushi	CR	M30	Shofu

The denture base specimen was composed of the artificial tooth on denture base acrylic resin. Ten denture bases with each type of denture tooth, 15 x 15 mm and a thickness of 3 mm, were fabricated by using putty-type silicone impression material (Provil; Heraeus Kulzer GmbH, Hanau, Germany) as a mold. Melted wax was poured into the mold, and each denture tooth was lowered into the wax using a surveyor (Ney Surveyor Parallometer System; Dentplsy Ceramco, Burlington, NJ) to ensure that the occlusal surface was parallel to the base. All specimens were then invested in denture flasks (Hanau; Water Pik, Inc, Ft. Collins, Colo), followed by conventional packing procedures using heat-polymerizing acrylic resin (Lucitone 199; Dentsply Trubyte, York, Pa). Long polymerizing cycles were used for acrylic resin packing procedures. The temperature was slowly raised from room temperature to 73°C and held for 9 hours. After completion of the polymerizing cycles, the flasks were allowed to cool to room temperature before deflasking. All specimens were then removed from the denture flasks, and any flash was removed with a carbide bur (Abbott-Robinson HP Burs; Buffalo Dental Mfg Co, Syosset, NY). The basal surfaces of all specimens were polished using an automatic polishing machine (DPS 3200; Imptech, Boksburg, South Africa) with 0.05-µm-particle-sized aluminum oxide slurry (Leco Corp, St. Joseph, Mich) under slow speed and constant water irrigation. A total of 40 specimens were stored in water for 1 day before testing. The specimen illustration is shown in Figure 1.

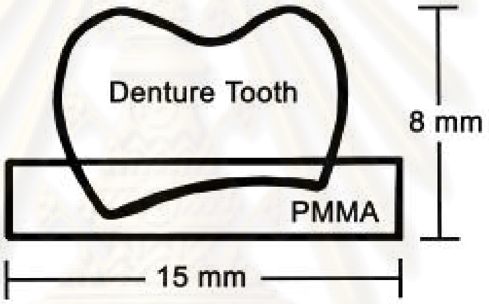


Fig. 1. Schematic drawing of denture base specimen with denture tooth.

Pressure transmission and pressure distribution were examined by 2 types of pressure-sensitive sheets (Prescale Film, LLW and LW; Fuji Photo Film Co, Ltd). The reliable measuring ranges of the pressure of LLW and LW were between 0.5 and 2.5 MPa and between 2.5 and 10 MPa, respectively. The system includes pressure-sensitive film and digital analysis software. The LLW pressure-sensitive film was used primarily to evaluate pressure distribution. The structure of the pressure-sensitive sheet consists of microencapsulated color-forming and color-developing materials. When contact pressure is applied to the film, a red color impression is formed in various densities according to the amount of pressure and pressure distribution. In the present study, the pressure was applied by dropping a weight freely onto 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 (FujiFilm Pressure Distribution Mapping System FPD-8010E, version 1.1; Fuji Photo Film Co, Ltd). Different amounts of pressure were shown as different colors, which were automatically designated by the software. Areas of no pressure were displayed as white. Pressure of less than 0.5 MPa was green, whereas pressure higher than 2.5 MPa was yellow. The pressure range of 0.5 to 2.5 MPa was seen as different shades of red, depending on the intensity of the pressure. However, if pressure over 2.5 MPa was observed, the LW sheet type was used to determine the maximum pressure transmission.

According to the manufacturer, the accuracy of Prescale film is ±10%. However, authors of a previous study (85) stated that the accuracy of the color scanner for area and pressure measurements is within 0.5%, and the accuracy of Prescale film for area and pressure measurements is within 10% and 2%, respectively. Another study (86) suggested that for the greatest accuracy and reliability, Prescale films should be analyzed within 8 hours of exposure to pressure. Thus, Prescale films were analyzed immediately after testing for maximum accuracy and reliability.

The impact drop test used in the present study was modified from the study by Kawano et al. (9) In that study, an accelerometer was used to evaluate only the impact values, while in the present study, pressure-sensitive sheets were used to evaluate the amounts, transmission areas, and distribution of the pressure underneath the denture bases. According to results from previous studies, the mean maximum occlusal force for complete denture wearers was approximately or under 100 N (87-89). Therefore, 100 N was chosen as the impact load used in the present study. A glass tube was set perpendicular to the long axis and central fossa of the denture tooth specimen. A small piece of the LW pressure-sensitive sheet was put over the occlusal surface of each type of denture tooth specimen to measure the impact force at the contact sites. The mass and height of the drop test were adjusted to achieve a 100-N impact force at the central fossa. A fixed mass of 15 g and height of 20 cm were found to be appropriate, and, therefore, used in the present study. In the impact drop test procedures, pressure-sensitive sheets were placed underneath the acrylic resin denture bases, over the flat surface. A 15-g mass with a 5-mm-diameter ball tip was released and allowed to fall to the central fossa of the artificial tooth specimens. The impact load testing apparatus is shown in Figure 2.

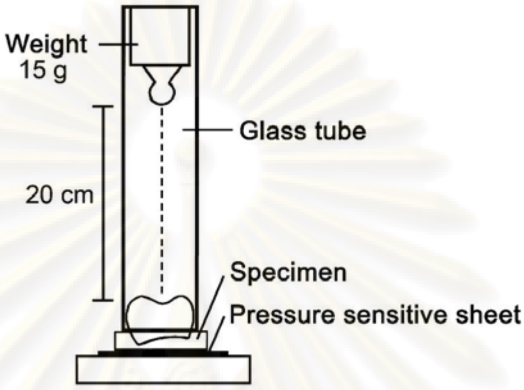


Fig. 2. Impact load testing apparatus.

Modulus of elasticity at the surfaces of the artificial denture teeth was determined after load testing by an ultramicroindentation system (UMIS 2000; CSIRO, Lindfield, Australia). The load applied was composed of 25 incremental loading steps with a delay of 0.1 seconds at every increment. The maximum force applied was 25 mN. The modulus of elasticity can be automatically calculated from the load-displacement curve instead of visual measurement of the indentation impression (90). Ten specimens of each type of denture tooth were evaluated for the modulus of elasticity. Three indentations were performed on the enamel layer of each specimen. The distance between each indentation was 100 µm to prevent indentation overlapping. The overall average value for each material was obtained to represent the modulus of elasticity of each type of denture tooth.

Pressure transmission area, maximum pressure transmission, and modulus of elasticity were analyzed using 1-way analysis of variance (ANOVA) (α=.05). Tukey's HSD (Honestly Significant Difference) post hoc test was used to compare means of the maximum pressure transmission among groups. For the pressure transmission area and modulus of elasticity, the robust tests of equality of means and Tamhane's post hoc test were used, as equal variances could not be assumed.

CHAPTER IV

RESULTS

Pressure-sensitive sheets obtained from artificial denture teeth made of different materials showed different amounts of force and different patterns of force distribution (Fig. 3).

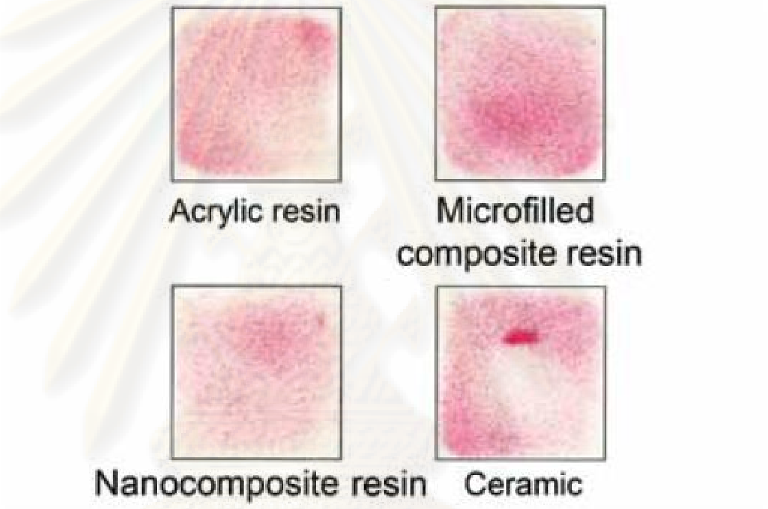


Fig. 3. Representative pressure sensitive sheets from all test groups.

Pressure transmission was divided into 3 group ranges: low (pressure of less than 0.5 MPa), intermediate (pressure range between 0.5 to 2.5 MPa), and high (pressure higher than 2.5 MPa), as designated by the software. The total pressure transmission area was calculated from the sum of the 3 group ranges. The results of the ANOVA for each of the 3 measured parameters are shown in Table II.

Table II. One-way ANOVA results for pressure transmission area, maximum pressure transmission, and modulus of elasticity

Source	**Sum of Squares**	***df***	**Mean Square**	**F**	***P***
Pressure transmission area					
Between Groups	19133	3	6378	32	<.001
Within Groups	7115	36	198		
Total	26248	39			
Maximum pressure transmission					
Between Groups	32	3	11	109	<.001
Within Groups	4	36	0.098		
Total	36	39			
Modulus of elasticity					
Between Groups	34649	3	11550	762	<.001
Within Groups	545	36	15		
Total	35195	39			

Percent pressure transmission areas calculated from the total pressure transmission areas for each type of artificial denture tooth are shown in Table III.

Table III. Percent pressure transmission areas calculated from total pressure transmission areas (P) for all specimens in different pressure ranges

Type / Pressure	**P <.5 MPa** **(Low range)**	**.5 ≤ P < 2.5 MPa** **(Intermediate range)**	**P ≥ 2.5 MPa** **(High range)**
AR	46.54%	53.46%	0.00%
MC	38.37%	61.63%	0.00%
NC	62.15%	37.85%	0.00%
CR	57.54%	41.82%	0.64%

NC and CR transferred more than half of the pressure in the low range (62.15% and 57.54%, respectively). In contrast, MC showed more than half of the pressure in the intermediate range (61.63%). AR demonstrated about half in the low and half in the intermediate range. Different pressure transmission areas of the different pressure ranges after software analysis are shown in Figure 4.

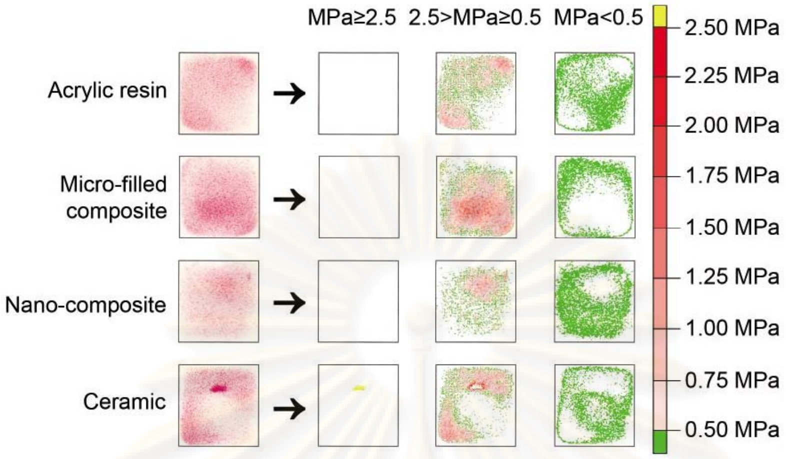


Fig. 4. Representative pressure sheets after analysis by software in 3 different pressure ranges (High, Intermediate and Low pressure ranges).

A 0.64% pressure transmission area above 2.5 MPa was observed only in the CR group, whereas no pressure above 2.5 MPa was found in the other groups. The total pressure transmission areas, measured from pressure-sensitive sheets of all types of artificial denture teeth, are shown in Figure 5.

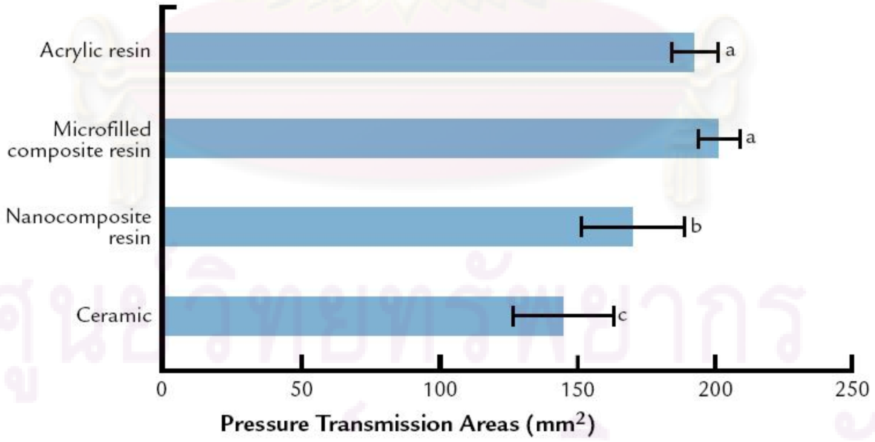


Fig. 5. Total pressure transmission areas (mm^2) of all types of artificial denture teeth (horizontal bars show standard deviation; bars with same letter are not significantly different at *P*<.05).

The total denture base area calculated by the size of the denture base specimen was 225 mm^2 (15 x 15 mm). Means of the total pressure transmission areas observed on the sheets ranged from 144.9 ±17.8 mm^2 (CR group) to 201.3 ±7.3 mm^2 (MC group). The areas of colors developed on the sheet represented the pressure transmission areas. MC exhibited the highest pressure transmission area, which was significantly different from the NC and CR groups (*P*=.002 and *P*<.001, respectively). AR also demonstrated a higher pressure transmission area than NC and CR, but was not significantly different from the MC group. NC presented a significantly higher pressure transmission area compared to the CR group. The maximum pressure transmission that appeared on the pressure-sensitive sheets is shown in Figure 6.

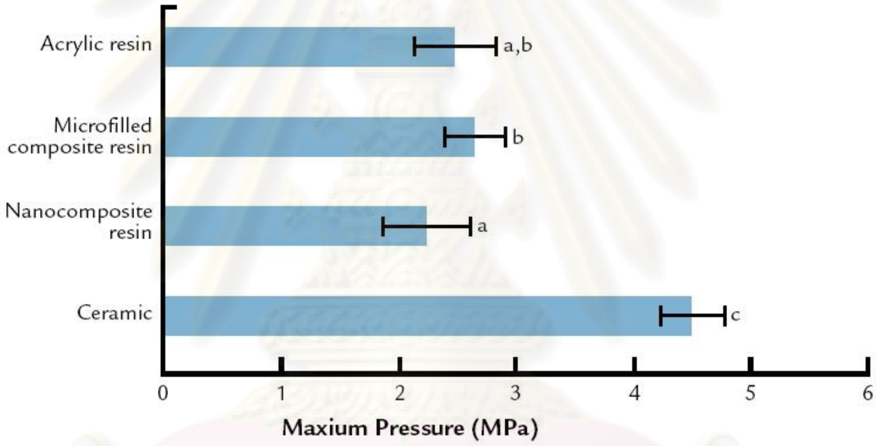


Fig. 6. Maximum pressure transmission observed on pressure-sensitive sheets (horizontal bars show standard deviation; bars with same letter are not significantly different at *P*<.05).

The highest maximum pressure was observed in CR, and was statistically different as compared to the other tooth materials (*P*<.001). NC showed significantly less maximum pressure than MC (*P*<.05); however, it was not significantly different from the AR group. No statistical differences were found between AR and MC. Comparisons of the modulus of elasticity of each type of denture tooth are shown in Figure 7.

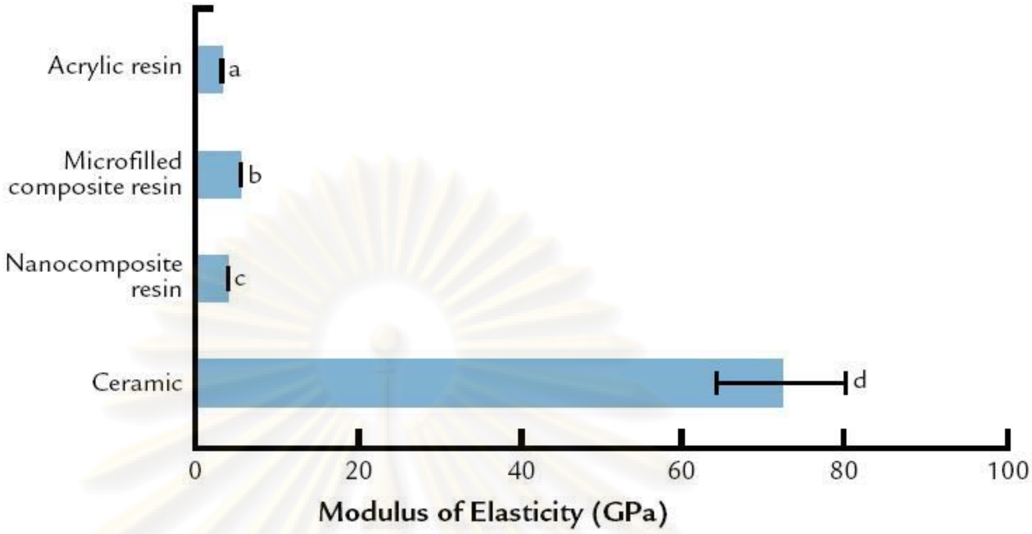


Fig. 7. Modulus of elasticity of all types of artificial denture teeth (horizontal bars show standard deviation; bars with same letter are not significantly different at *P*<.05).

The mean modulus of elasticity of CR (72.24 GPa) was significantly higher than the other denture teeth (*P*<.001). Tamhane’s post hoc test showed significant differences of the modulus of elasticity among the artificial denture teeth.

CHAPTER V

DISCUSSION

The results showed differences in pressure transmission and distribution with artificial denture teeth made with different materials and differences in the modulus of elasticity of each type of denture tooth; therefore, the null hypotheses were rejected.

Artificial denture teeth used in the present study were selected from the same mold and manufacturer in an attempt to minimize the effect of the size and shape of the specimens. In addition, the same type of pressure-sensitive sheet was used in all tests; therefore, pressure transmission areas between each type of denture tooth could be compared. However, only in the CR group, which demonstrated pressure above 2.5 MPa, was a higher pressure range sheet (LW type) used to determine the maximum pressure transmission.

A nanoindentation technique was chosen to evaluate the modulus of elasticity of each type of denture tooth. This technique is simple and reproducible for measuring mechanical properties of small specimens (90). Therefore, it was used for the modulus of elasticity measurement in the present study. Differences in pressure transmission and distribution under the impact force obtained from pressure-sensitive sheets were clearly demonstrated in the present study. When impact load occurred, pressure would be transmitted through the denture teeth and denture base layer before being transferred to the residual ridges. Low pressure with wide distribution would be preferable, as there would be less force and better pressure distribution to the supporting structures. Denture base fabrication in the present study was controlled to be the same in every specimen, and the size and shape of denture teeth used were equalized. Therefore, the results compared only the different tooth materials.

Regarding pressure transmission, both NC and CR specimens demonstrated pressure primarily in the low range (62.15% and 57.54%, respectively) (Table III) and significantly smaller pressure transmission areas than MC and AR (Fig. 5). Kawano et al.

(9) suggested that impact values obtained from porcelain teeth with polymethyl methacrylate (PMMA) resin may be less than porcelain teeth alone because there is no bond between porcelain teeth and PMMA resin, so the impact may be dissipated at the interface of the porcelain and PMMA. The results from the present study seemed to support this explanation. However, when pressure distribution was considered in the present study, a high stress concentration area in the CR group was observed. Such stress areas may result from a thin denture base support area. The results from the present study suggested that adequate thickness of the denture base resin might act as a shock absorber during impact when porcelain denture teeth were selected for removable prostheses. Moreover, when interarch space is limited, porcelain teeth might not be an appropriate choice because it would be difficult to provide adequate thickness for the PMMA denture base resin. The MC group exhibited larger pressure transmission areas compared to the NC group (Fig.5). MC showed most of the pressure in the intermediate range (61.63%) (Table III) and also presented significantly higher maximum pressure transmission compared to NC (Fig.6). This might be a result of the high modulus of elasticity of the MC tooth material.

The role of the modulus of elasticity of denture tooth material is relevant because it shows the ability of the material to flex (24). Denture teeth with a lower modulus of elasticity may flex and absorb the impact energy from the impact force and transfer less pressure to the underlying structures. In the present study, the highest maximum pressure transmission was observed in the CR group, which might have resulted from the modulus of elasticity of the CR teeth, which was highest (72.24 GPa) (Fig. 7). CR teeth were more rigid and less flexible; therefore, they did not absorb much pressure, and the higher forces were transferred onto the pressure-sensitive sheets. A similar trend was found in the MC group. The MC displayed the second highest pressure transmission and maximum pressure transfer and the second highest modulus of elasticity.

It is interesting to note that NC showed a higher modulus of elasticity than AR, but NC still presented the lowest maximum pressure transmission. As reported by Zheng et al. (13), numerous cavitations at the interfaces between nanoparticles and the resin matrix assisted in absorbing the impact. The impact energy was dissipated through these interfaces, so as to increase the impact strength of the nanocomposite resin.

Pressure refers to the force per unit area. The pressure observed in the present study was divided into 3 ranges: less than 0.5 MPa (5.1 kgf/cm^2), 0.5 to 2.5 MPa (5.1-25.5 kgf/cm^2), and more than 2.5 MPa (>25.5 kgf/cm^2). Matsuo et al. (7) suggested that a pressure of 27 to 68 g/cm^2 caused fibroblasts to increase the intracellular calcium which, in turn, initiated the alveolar bone remodeling. Berg et al. (5) reported that, to keep blood circulation normal, continuous mechanical pressure higher than 1.3 kPa should not be transferred to the denture-supporting tissues. The maximum pressure observed in the present study was much higher than these pressures. However, the size of the denture base specimen was only 225 mm^2; thus, it had a limited area to absorb the pressure. Therefore, maximum extension of the denture bases within the anatomical and physiological limits is recommended to increase the supporting areas and minimize the pressure.

Pressure transmission to the denture base in removable prostheses should be equally distributed to avoid high stress concentration areas which may result in discomfort, pain, inflammation, and bone resorption. From the results of the present study, NC appeared to be a favorable artificial denture tooth material because it displayed the best results within the measured parameters. NC presented well distributed pressure, the lowest pressure transmission, and the lowest maximum pressure transfer. CR should be avoided when limited interarch space is presented.

A limitation of the present study was that pressure transmission and distribution were evaluated in vitro and under simplified models with only a vertical load application. Therefore, future research should be aimed towards multidirectional force application with conditions similar to those of the oral environment.

CHAPTER VI

CONCLUSIONS

Within the limitations of the present study, the following conclusions were drawn.

1. Maximum pressure transmission with ceramic denture teeth was significantly higher as compared to all other groups (*P*<.001).

2. Significant differences in modulus of elasticity were observed among all 4 types of denture teeth (*P*<.001). Ceramic denture teeth demonstrated significantly highest values, followed by microfilled composite resin, nanocomposite resin, and acrylic resin (*P*<.001) denture teeth.

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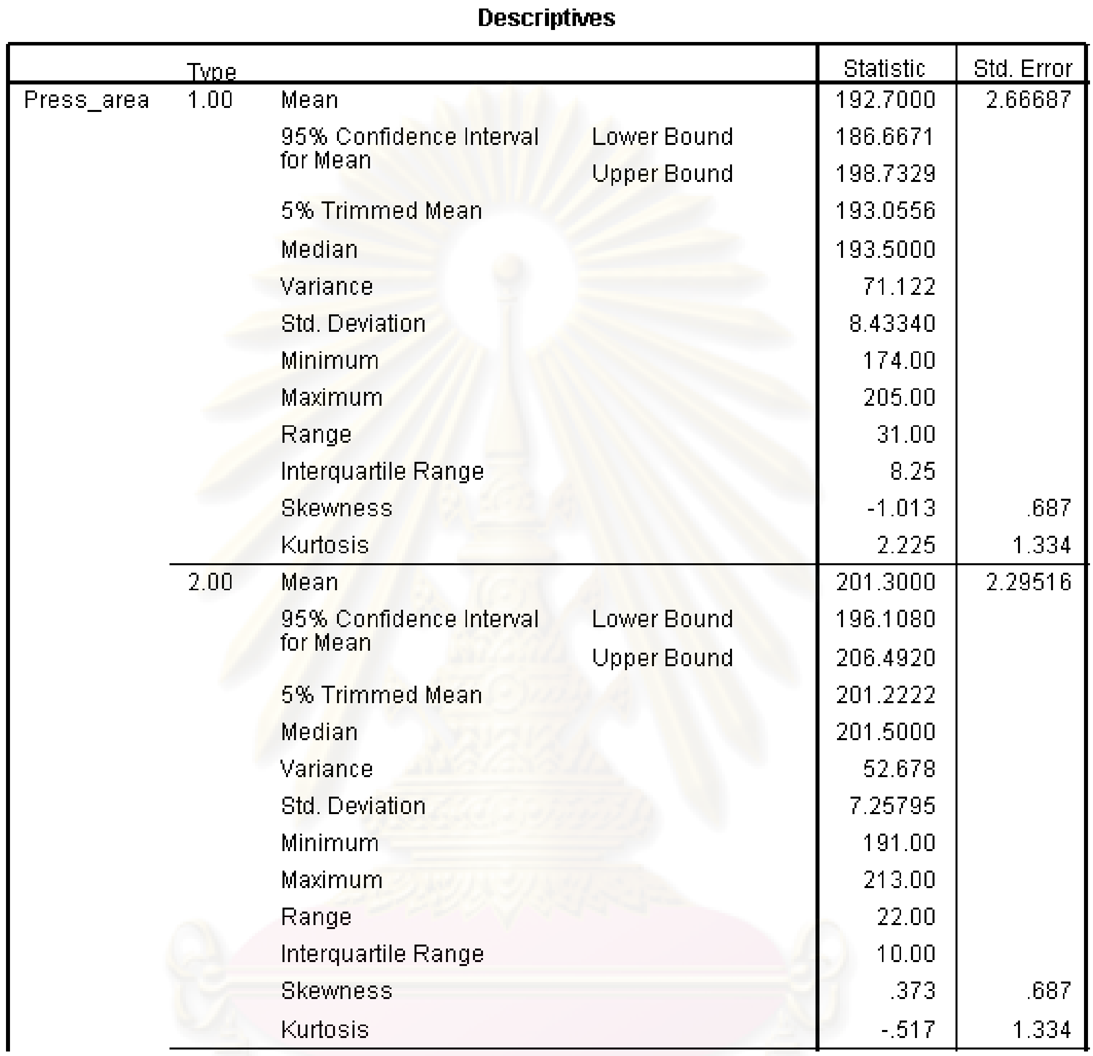
APPENDIX

APPENDIX

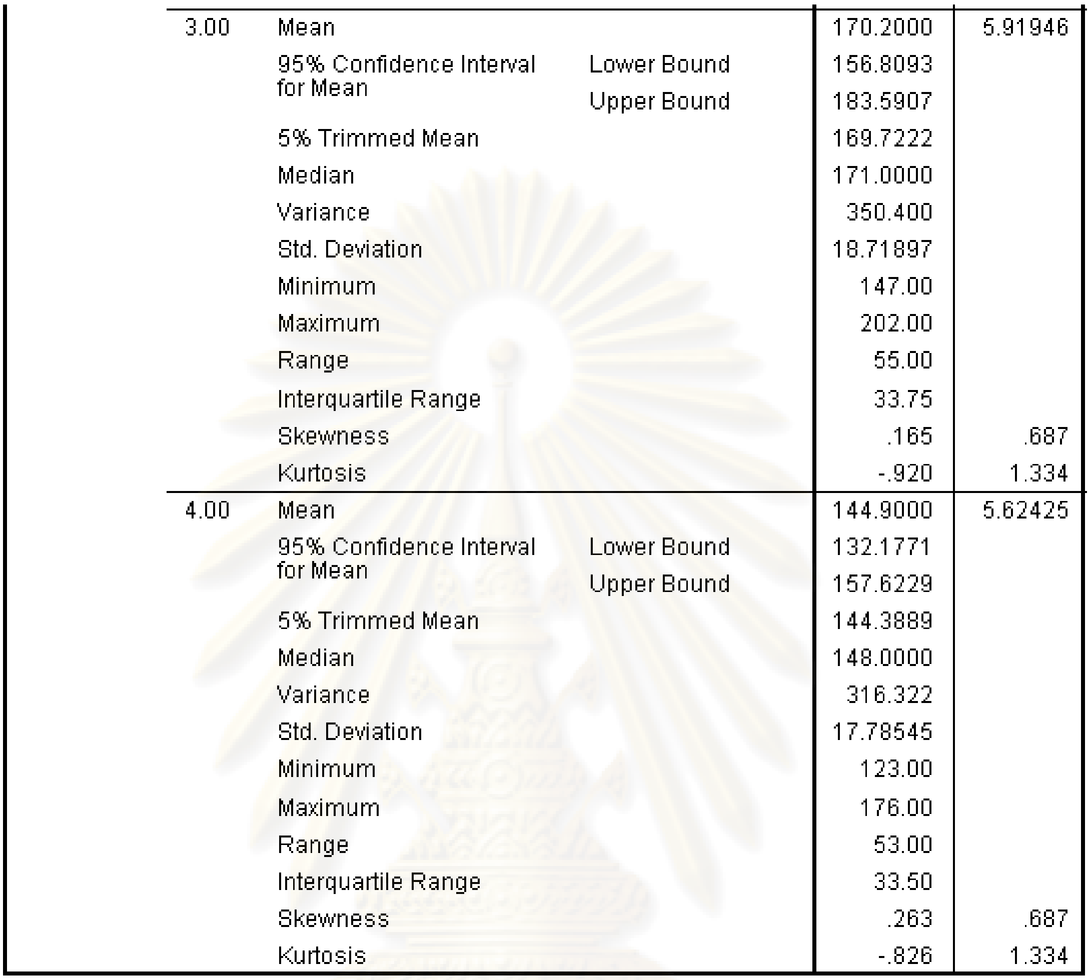
Contents **Pages**

Statistical analysis for differences in pressure transmission areas



Descriptives

	Type			Statistic	Std. Error
Press_area	1.00	Mean		192.7000	2.66687
		95% Confidence Interval for Mean	Lower Bound	186.6671	
			Upper Bound	198.7329	
		5% Trimmed Mean		193.0556	
		Median		193.5000	
		Variance		71.122	
		Std. Deviation		8.43340	
		Minimum		174.00	
		Maximum		205.00	
		Range		31.00	
		Interquartile Range		8.25	
		Skewness		-1.013	.687
		Kurtosis		2.225	1.334
	2.00	Mean		201.3000	2.29516
		95% Confidence Interval for Mean	Lower Bound	196.1080	
			Upper Bound	206.4920	
		5% Trimmed Mean		201.2222	
		Median		201.5000	
		Variance		52.678	
		Std. Deviation		7.25795	
		Minimum		191.00	
		Maximum		213.00	
		Range		22.00	
		Interquartile Range		10.00	
		Skewness		.373	.687
		Kurtosis		-.517	1.334



	Type			Statistic	Std. Error
	3.00	Mean		170.2000	5.91946
		95% Confidence Interval for Mean	Lower Bound	156.8093	
			Upper Bound	183.5907	
		5% Trimmed Mean		169.7222	
		Median		171.0000	
		Variance		350.400	
		Std. Deviation		18.71897	
		Minimum		147.00	
		Maximum		202.00	
		Range		55.00	
		Interquartile Range		33.75	
		Skewness		.165	.687
		Kurtosis		-.920	1.334
	4.00	Mean		144.9000	5.62425
		95% Confidence Interval for Mean	Lower Bound	132.1771	
			Upper Bound	157.6229	
		5% Trimmed Mean		144.3889	
		Median		148.0000	
		Variance		316.322	
		Std. Deviation		17.78545	
		Minimum		123.00	
		Maximum		176.00	
		Range		53.00	
		Interquartile Range		33.50	
		Skewness		.263	.687
		Kurtosis		-.826	1.334

Tests of Normality

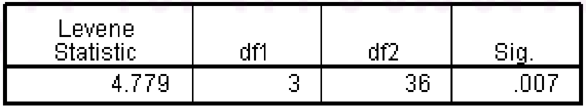
		Kolmogorov-Smirnov[a]			Shapiro-Wilk		
	Type	Statistic	df	Sig.	Statistic	df	Sig.
Press_area	1.00	.214	10	.200*	.922	10	.373
	2.00	.155	10	.200*	.943	10	.592
	3.00	.160	10	.200*	.941	10	.561
	4.00	.169	10	.200*	.931	10	.459

a. Lilliefors Significance Correction

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

Test of Homogeneity of Variances

Press_area



Levene Statistic	df1	df2	Sig.
4.779	3	36	.007

ANOVA

Press_area

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	19133.275	3	6377.758	32.271	.000
Within Groups	7114.700	36	197.631		
Total	26247.975	39			

Robust Tests of Equality of Means

Press_area

	Statistic[a]	df1	df2	Sig.
Brown-Forsythe	32.271	3	24.382	.000

a. Asymptotically F distributed.

Post Hoc Tests

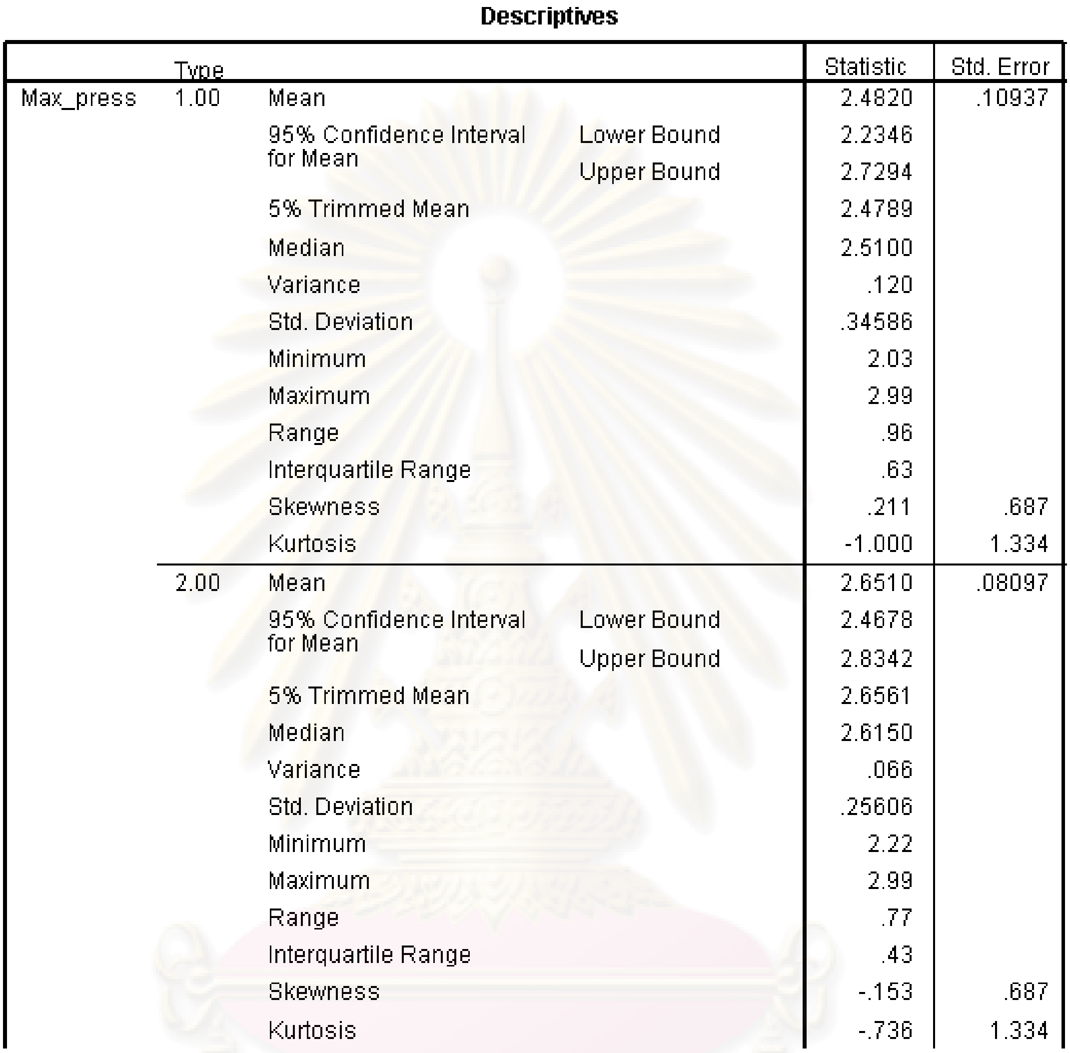
Multiple Comparisons

Press_area
Tamhane

(I) Type	(J) Type	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval Lower Bound	95% Confidence Interval Upper Bound
1.00	2.00	-8.60000	3.51852	.142	-19.0179	1.8179
	3.00	22.50000*	6.49247	.026	2.2620	42.7380
	4.00	47.80000*	6.22450	.000	28.4907	67.1093
2.00	1.00	8.60000	3.51852	.142	-1.8179	19.0179
	3.00	31.10000*	6.34884	.002	11.0414	51.1586
	4.00	56.40000*	6.07454	.000	37.2932	75.5068
3.00	1.00	-22.50000*	6.49247	.026	-42.7380	-2.2620
	2.00	-31.10000*	6.34884	.002	-51.1586	-11.0414
	4.00	25.30000*	8.16531	.037	1.1808	49.4192
4.00	1.00	-47.80000*	6.22450	.000	-67.1093	-28.4907
	2.00	-56.40000*	6.07454	.000	-75.5068	-37.2932
	3.00	-25.30000*	8.16531	.037	-49.4192	-1.1808

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

Statistical analysis for differences in maximum pressure transmission



Descriptives

	Type			Statistic	Std. Error
Max_press	1.00	Mean		2.4820	.10937
		95% Confidence Interval for Mean	Lower Bound	2.2346	
			Upper Bound	2.7294	
		5% Trimmed Mean		2.4789	
		Median		2.5100	
		Variance		.120	
		Std. Deviation		.34586	
		Minimum		2.03	
		Maximum		2.99	
		Range		.96	
		Interquartile Range		.63	
		Skewness		.211	.687
		Kurtosis		-1.000	1.334
	2.00	Mean		2.6510	.08097
		95% Confidence Interval for Mean	Lower Bound	2.4678	
			Upper Bound	2.8342	
		5% Trimmed Mean		2.6561	
		Median		2.6150	
		Variance		.066	
		Std. Deviation		.25606	
		Minimum		2.22	
		Maximum		2.99	
		Range		.77	
		Interquartile Range		.43	
		Skewness		-.153	.687
		Kurtosis		-.736	1.334

	3.00	Mean		2.2260	.11594
		95% Confidence Interval for Mean	Lower Bound	1.9637	
			Upper Bound	2.4883	
		5% Trimmed Mean		2.2178	
		Median		2.2150	
		Variance		.134	
		Std. Deviation		.36664	
		Minimum		1.73	
		Maximum		2.87	
		Range		1.14	
		Interquartile Range		.55	
		Skewness		.226	.687
		Kurtosis		-.614	1.334
	4.00	Mean		4.4950	.08513
		95% Confidence Interval for Mean	Lower Bound	4.3024	
			Upper Bound	4.6876	
		5% Trimmed Mean		4.5083	
		Median		4.4500	
		Variance		.072	
		Std. Deviation		.26921	
		Minimum		3.95	
		Maximum		4.80	
		Range		.85	
		Interquartile Range		.46	
		Skewness		-.615	.687
		Kurtosis		.490	1.334

Tests of Normality

		Kolmogorov-Smirnov[a]			Shapiro-Wilk		
	Type	Statistic	df	Sig.	Statistic	df	Sig.
Max_press	1.00	.159	10	.200*	.920	10	.357
	2.00	.109	10	.200*	.956	10	.740
	3.00	.120	10	.200*	.964	10	.829
	4.00	.171	10	.200*	.902	10	.230

a. Lilliefors Significance Correction

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

Test of Homogeneity of Variances

Max_press

Levene Statistic	df1	df2	Sig.
.836	3	36	.483

ANOVA

Max_press

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	32.189	3	10.730	109.463	.000
Within Groups	3.529	36	.098		
Total	35.718	39			

Post Hoc Tests

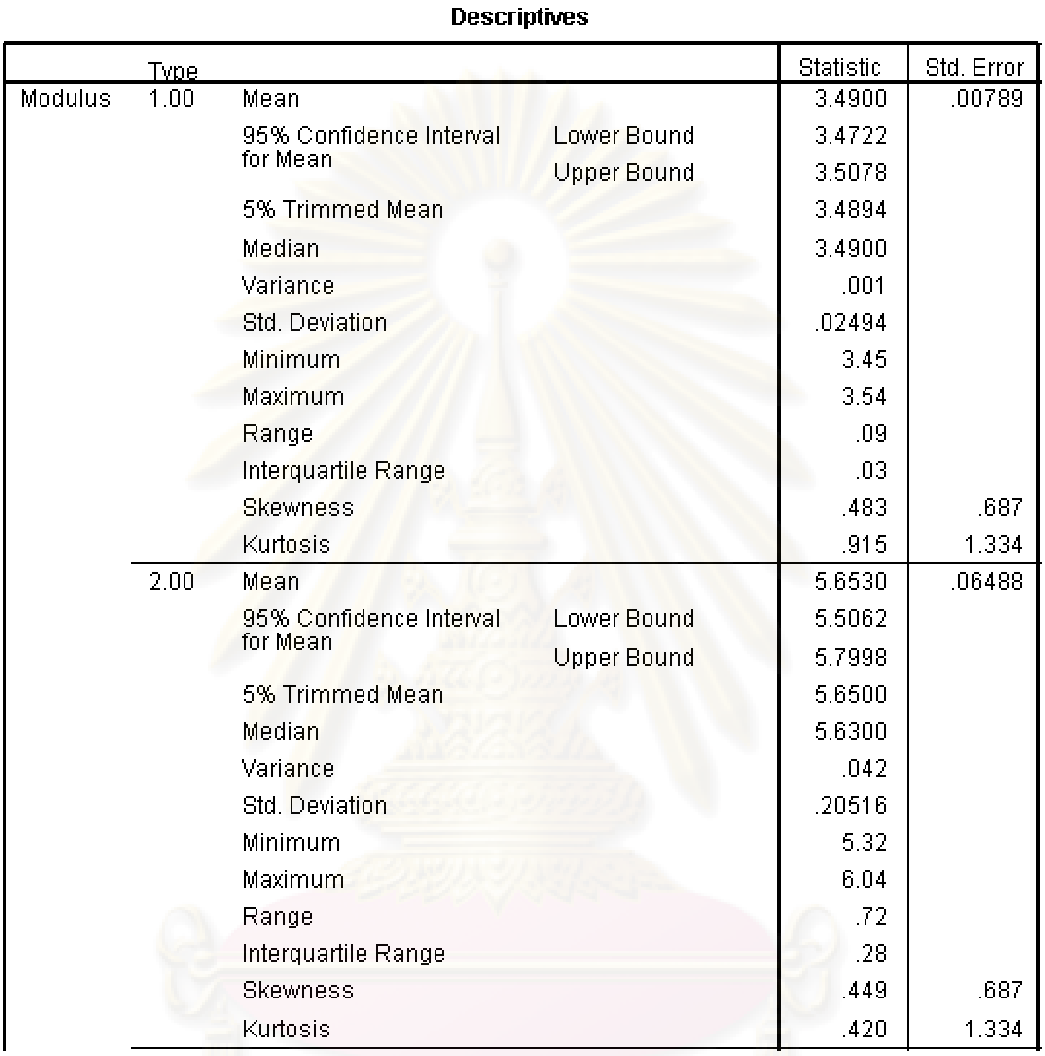
Multiple Comparisons

Max_press
Tukey HSD

(I) Type	(J) Type	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
					Lower Bound	Upper Bound
1.00	2.00	-.16900	.14001	.626	-.5461	.2081
	3.00	.25600	.14001	.277	-.1211	.6331
	4.00	-2.01300*	.14001	.000	-2.3901	-1.6359
2.00	1.00	.16900	.14001	.626	-.2081	.5461
	3.00	.42500*	.14001	.022	.0479	.8021
	4.00	-1.84400*	.14001	.000	-2.2211	-1.4669
3.00	1.00	-.25600	.14001	.277	-.6331	.1211
	2.00	-.42500*	.14001	.022	-.8021	-.0479
	4.00	-2.26900*	.14001	.000	-2.6461	-1.8919
4.00	1.00	2.01300*	.14001	.000	1.6359	2.3901
	2.00	1.84400*	.14001	.000	1.4669	2.2211
	3.00	2.26900*	.14001	.000	1.8919	2.6461

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

Statistical analysis for differences in modulus of elasticity



Descriptives

	Type			Statistic	Std. Error
Modulus	1.00	Mean		3.4900	.00789
		95% Confidence Interval for Mean	Lower Bound	3.4722	
			Upper Bound	3.5078	
		5% Trimmed Mean		3.4894	
		Median		3.4900	
		Variance		.001	
		Std. Deviation		.02494	
		Minimum		3.45	
		Maximum		3.54	
		Range		.09	
		Interquartile Range		.03	
		Skewness		.483	.687
		Kurtosis		.915	1.334
	2.00	Mean		5.6530	.06488
		95% Confidence Interval for Mean	Lower Bound	5.5062	
			Upper Bound	5.7998	
		5% Trimmed Mean		5.6500	
		Median		5.6300	
		Variance		.042	
		Std. Deviation		.20516	
		Minimum		5.32	
		Maximum		6.04	
		Range		.72	
		Interquartile Range		.28	
		Skewness		.449	.687
		Kurtosis		.420	1.334

	3.00	Mean		3.7580	.03043
		95% Confidence Interval for Mean	Lower Bound	3.6892	
			Upper Bound	3.8268	
		5% Trimmed Mean		3.7606	
		Median		3.7550	
		Variance		.009	
		Std. Deviation		.09624	
		Minimum		3.59	
		Maximum		3.88	
		Range		.29	
		Interquartile Range		.16	
		Skewness		-.301	.687
		Kurtosis		-1.064	1.334
	4.00	Mean		72.2430	2.46063
		95% Confidence Interval for Mean	Lower Bound	66.6767	
			Upper Bound	77.8093	
		5% Trimmed Mean		72.3039	
		Median		71.9250	
		Variance		60.547	
		Std. Deviation		7.78121	
		Minimum		57.92	
		Maximum		85.47	
		Range		27.55	
		Interquartile Range		9.12	
		Skewness		-.028	.687
		Kurtosis		.613	1.334

Tests of Normality

		Kolmogorov-Smirnov[a]			Shapiro-Wilk		
	Type	Statistic	df	Sig.	Statistic	df	Sig.
Modulus	1.00	.144	10	.200*	.969	10	.885
	2.00	.186	10	.200*	.975	10	.930
	3.00	.203	10	.200*	.921	10	.362
	4.00	.164	10	.200*	.973	10	.913

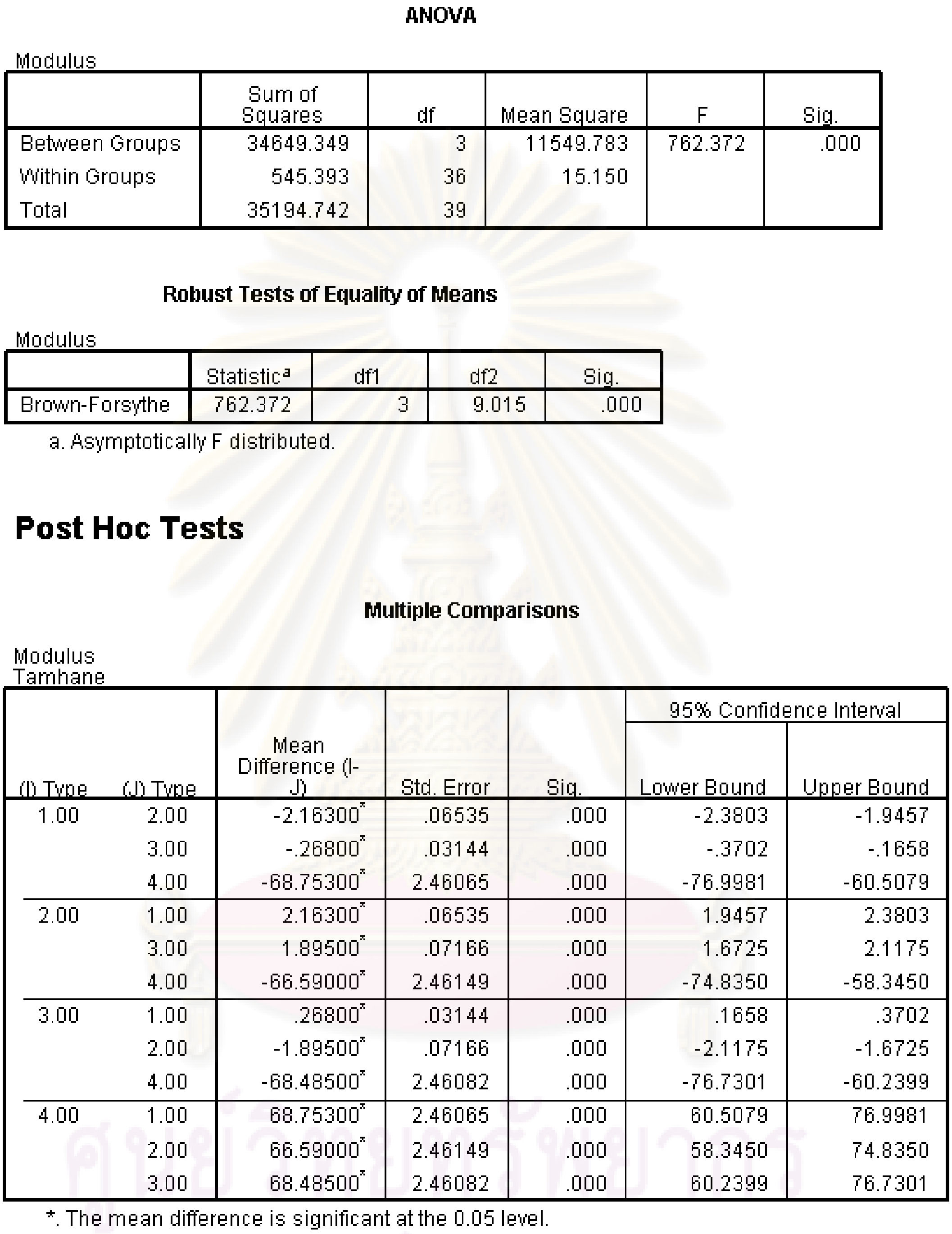
a. Lilliefors Significance Correction

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

Test of Homogeneity of Variances

Modulus

Levene Statistic	df1	df2	Sig.
11.043	3	36	.000



ANOVA

Modulus

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	34649.349	3	11549.783	762.372	.000
Within Groups	545.393	36	15.150		
Total	35194.742	39			

Robust Tests of Equality of Means

Modulus

	Statistic[a]	df1	df2	Sig.
Brown-Forsythe	762.372	3	9.015	.000

a. Asymptotically F distributed.

Post Hoc Tests

Multiple Comparisons

Modulus
Tamhane

					95% Confidence Interval	
(I) Type	(J) Type	Mean Difference (I-J)	Std. Error	Sig.	Lower Bound	Upper Bound
1.00	2.00	-2.16300*	.06535	.000	-2.3803	-1.9457
	3.00	-.26800*	.03144	.000	-.3702	-.1658
	4.00	-68.75300*	2.46065	.000	-76.9981	-60.5079
2.00	1.00	2.16300*	.06535	.000	1.9457	2.3803
	3.00	1.89500*	.07166	.000	1.6725	2.1175
	4.00	-66.59000*	2.46149	.000	-74.8350	-58.3450
3.00	1.00	.26800*	.03144	.000	.1658	.3702
	2.00	-1.89500*	.07166	.000	-2.1175	-1.6725
	4.00	-68.48500*	2.46082	.000	-76.7301	-60.2399
4.00	1.00	68.75300*	2.46065	.000	60.5079	76.9981
	2.00	66.59000*	2.46149	.000	58.3450	74.8350
	3.00	68.48500*	2.46082	.000	60.2399	76.7301

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

BIOGRAPHY

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