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Evaluation of Some Mechanical Properties of CAD/CAM Polymers (PEEK/PMMA) and Conventional PMMA Materials: An *In Vitro* Study

CAD/CAM Polimerlerinin (PEEK/PMMA) ve Geleneksel PMMA Materyallerinin Bazı Mekanik Özelliklerinin Değerlendirilmesi: *İn Vitro* Çalışma

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ABSTRACT Objective: The present study aims to investigate the mechanical properties of base materials [polymethyl methacrylate (PMMA)/polyether ether ketone (PEEK)] fabricated with computer-aided design/computer-aided manufacturing (CAD/CAM) and heat-polymerized conventional base materials. **Material and Methods:** Two different base polymers milled with CAD/CAM (Yamahachi PMMA Disk and Juvora Dental Disk PEEK) and heat-polymerized acrylic resin (Meliodent PMMA) were used in this study. A total of 120 specimens were prepared with 10 specimens in each subgroup of the test materials. Half of the test specimens were stored in distilled water, while the other half were subjected to a thermal cycle. After the thermal cycle, the flexural strength, elasticity module, and, surface hardness of all test specimens was evaluated. The Mann-Whitney U and Kruskal-Wallis tests were used in the analysis of the data. **Results:** According to the findings of flexural strength and elasticity module of the test specimens, the highest to lowest value ranking was as follows: CAD/CAM PEEK>CAD/CAM PMMA>heat-polymerized PMMA. In the PMMA group produced with CAD/CAM, surface hardness values were significantly higher in the thermocycle applied test specimens compared to those stored in distilled water (p<0.001). **Conclusion:** CAD/CAM PMMA and PEEK materials were compared with the heat-polymerized test specimens found to show better mechanical properties.

Keywords: Denture bases; computer aided design/computer aided manufacturing; polyether ether ketone; flexural strength; hardness

ÖZET Amaç: Bu çalışmanın amacı, bilgisayar destekli tasarım/bilgisayar destekli üretim [computer-aided design/computer-aided manufacturing (CAD/CAM)] ile şekillendirilen kaide materyalleri [polimetil metakrilat (PMMA)/polieter eter keton (PEEK)] ve ısı ile polimerize olan geleneksel kaide materyalinin mekanik özelliklerinin incelenmesidir. **Gereç ve Yöntemler:** Bu çalışmada, CAD/CAM ile frezelenmiş 2 farklı kaide polimeri (Yamahachi PMMA Disk ve Juvora Dental Disk PEEK) ve ısı ile polimerize olan akrilik rezin (Meliodent PMMA) kullanıldı. Test materyallerinin her bir alt grubunda 10 örnek olmak üzere toplam 120 örnek hazırlandı. Test örneklerinin yarısı distile suda bekletildi. Diğer yarısına ise termal döngü uygulandı. Termal döngüden sonra tüm test örneklerinin bükülme dayanımı, elastikiyet modülü ve yüzey sertliği değerlendirildi. Verilerin analizinde, Mann-Whitney U ve Kruskal-Wallis testleri kullanılmıştır. **Bulgular:** Test örneklerinin bükülme dayanımı ve elastikiyet modülü bulgularına göre, en yüksek değerden en düşüğe doğru sıralaması CAD/CAM PEEK>CAD/CAM PMMA>ısı ile polimerize PMMA şeklindedir. CAD/CAM ile üretilen PMMA grubu içerisinde, distile suda bekletilen örneklere göre termal döngü uygulanan örneklerde, yüzey sertlik düzeyi istatistiksel anlamlı olarak daha yüksek değerler vermiştir (p<0,001). **Sonuç:** CAD/CAM ile üretilen PMMA ve PEEK materyalleri, ısı ile polimerize olan test örnekleri ile kıyaslandığında daha iyi mekanik özellikler göstermektedir.

Anahtar Kelimeler: Protez kaideleri; bilgisayar destekli tasarım/bilgisayar destekli imalat; polieter eter keton; bükülme dayanımı; sertlik

In dentistry, polymethyl methacrylate (PMMA)-based acrylic resins, which are polymerized in fabricating removable prosthodontics, are the most widely used denture base materials.[1,2] Among the positive properties of acrylic resins are the fact that application, finishing, and polishing processes are quite easy;

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that they do not require expensive equipment; that they remain stable in the mouth; and that they meet aesthetic demands.[3,4] However, they do have some negative properties, among which are their low fracture toughness, residual monomer release, dimensional changes, retention of oral bacteria, and long-term waiting time relating to prosthesis fabrication.[2] All these limitations have, predictably, resulted in researchers seeking new polymeric materials and developing new production techniques, such as computer-aided design/computer-aided manufacturing (CAD/CAM), in constructing removable prostheses.[5]

Polyether ether ketone (PEEK) is a synthetically produced polymeric material belonging to the polyaryletherketone family.[6] PEEK is also a highly aromatic semi-crystalline thermoplastic with an aromatic base structure and a molecular chain, interconnected with ketone and ether functional groups.[7,8] The material is also known for having a high mechanical property, heat tolerance, chemical stability, and biocompatibility.[9] Because it is highly biocompatible and has optimal mechanical properties, it has been presented as a perfect material for dental restorations and the production of base structures through CAD/CAM.

Computer-aided technology is a broad term that involves using computing skills when designing, analyzing, or fabricating products.[10] CAD/CAM aids in the design and implementation of dental restorations, including the substructures of complete and removable prosthodontics.[10-12] In recent years, CAD/CAM technology has begun to be used in fabricating complete prosthodontics, thus enabling us to achieve digital scanning and record the zones of prosthodontics' fittings and the relevant mouth structures. Therefore, the fabrication of complete prosthodontics is made possible with the aid of a milling machine after the recorded data have been transferred to a software, including data related to the teeth.[13]

Compared with conventional prosthesis fabrication techniques, CAD/CAM now offers significant advantages, including a low monomer content and a better mechanical durability of acrylic base resins.[5] Added to that, polymerization shrinkage and *Candida albicans* (*C. albicans*) attachment to the denture base are also significantly lower after the use of CAD/CAM.[14] Furthermore, these improvements have resulted in fewer clinical sessions on the part of both the dentist and the patient, with elderly patients being particularly advantaged.

The compatibility and durability of prostheses prove much better in as much as pre-polymerized acrylic resin blocks are used in milling. Added to that, pre-polymerized acrylic resin blocks facilitate the reproduction of prostheses due to stored digital data. Clinical studies have shown that they provide a far better standardization for both complete and implant-supported prostheses.[10]

CAD/CAM has made available new dental materials with advanced properties. Hence, evaluating the mechanical and physical properties of these new materials, along with putting forward their clinical outcomes, has become essential for developments in dentistry.[2] Studies have also shown CAD/CAM acrylic resin base materials are suitable for clinical practices relating to the fabrication of removable prostheses.[2] However, the number of studies comparing their mechanical properties, whether PMMA- or PEEK-based, is quite small. Therefore, there is a need for in-vitro studies into the mechanical properties of CAD/CAM.

The present study aims to investigate the mechanical properties of denture base materials shaped by CAD/CAM, one of the currently popular techniques for fabricating prostheses, as well as of conventionally fabricated base materials. The flexural strength, elastic modulus, and, micro hardness of the denture base materials were tested. The null hypothesis of this study is that no significant differences could be found between CAD/CAM PMMA (YC), CAD/CAM PEEK (JC), and heat-polymerized PMMA (M) in terms of their mechanical properties (flexural strength, elastic modulus, and, micro hardness). In addition, the thermal cycle did not affect any of the samples' mechanical properties.

MATERIAL AND METHODS

The test specimens used in the study and their properties are presented in Table 1.

TABLE 1: The test specimens used in the study.

The test materials	Codes of the test materials	Lot number	Producing company
Heat-polymerized PMMA (Meliodent)	M	R010032	Heraeus Kulzer, Germany
CAD/CAM PMMA Disk (Yamahachi)	YC	2220000910103	Yamahachi Dental MFG, Aichi-Pref, Japan
CAD/CAM PEEK (Juvora dental disc)	JC	J000101	Juvora, UK

PMMA: Polymethyl methacrylate; CAD/CAM: Computer-aided design/computer-aided manufacturing; PEEK: Polyether ether ketone.

PREPARATION OF TEST SPECIMENS

For all test methods, a total of 120 specimens (n=10) were prepared (Figure 1, Figure 2, Figure 3, Figure 4). Each test material was divided into 2 main groups. Half of the test specimens were stored in distilled water, while the other half were subjected to a thermal cycle.

Preparation of Heat-Polymerized PMMA Test Specimens

Specimens of dental wax were prepared for each test group in line with the specimen size standardized by International Organization of Standardization (ISO) 20795-1 (2008), with the help of normal stainless-steel bars.[15] Compression molding technique was used in the production of heat-polymerized resin specimens. Acrylic resin (Meliodent, Heraeus Kulzer, Hanau, Germany) polymerization was achieved in the gap created by the lost wax technique after the powder/liquid ratio had been determined according to the instructions of the producing company. The burrs of acrylic test specimens were adjusted. One surface of each specimen was polished with 600-, 800-, and 1000-grit waterproof silicon-carbide paper (SiC; Struers GmbH, Copenhagen, Denmark), whereas the other surfaces did not undergo such polishing so that they could simulate the tissue surface of dentures. The size of the test specimens was checked by means of a digital caliper (Mitutoyo, Kawasaki, Japan).

Preparation of PMMA and PEEK Test Specimens by the CAD/CAM Technique

Using PMMA (Yamahachi Dental MFG, Aichi-Pref, Japan) discs, PEEK (JUVORA Dental Disc, JUVORA Ltd., Wyre, Lancashire, UK) discs, and a CAD/CAM milling machine (Yenadent DC40, Yenadent Ltd, İstanbul, Turkey), test specimens were prepared in the sizes suggested for each test group (Figure 5, Figure 6). Sanding process was done as previously described.

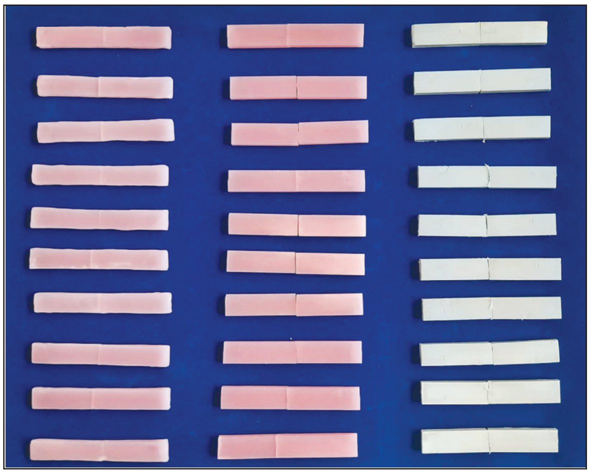

FIGURE 1: TC (-) specimens for flexural strength and elastic modulus tests.

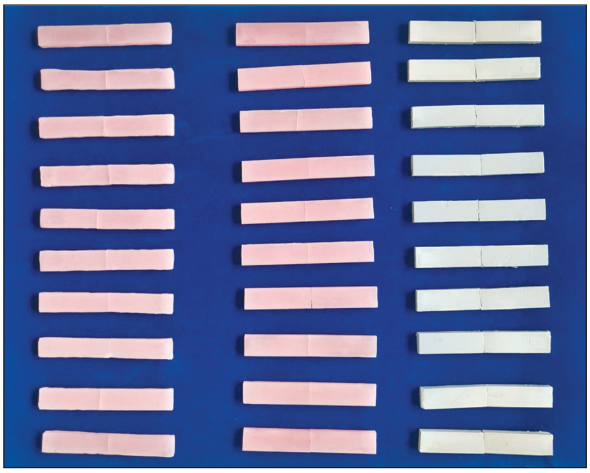

FIGURE 2: TC (+) specimens for flexural strength and elastic modulus tests.

TEST METHODS

Flexural Strength and Elastic Modulus Tests

During the flexural strength and elasticity module tests, universal testing criteria were used on the basis

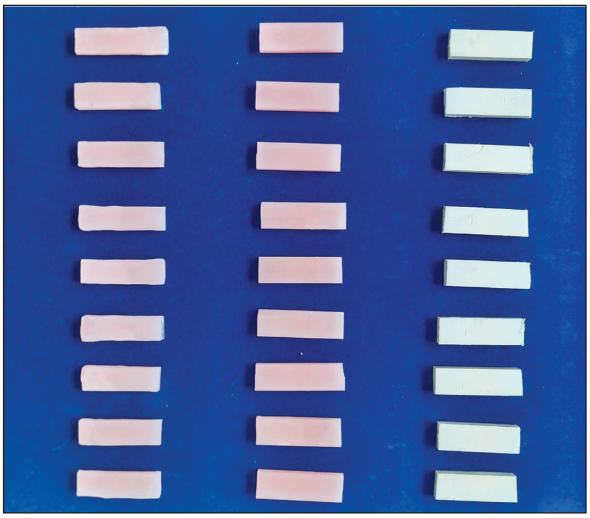

FIGURE 3: TC (-) specimens for surface micro hardness test.

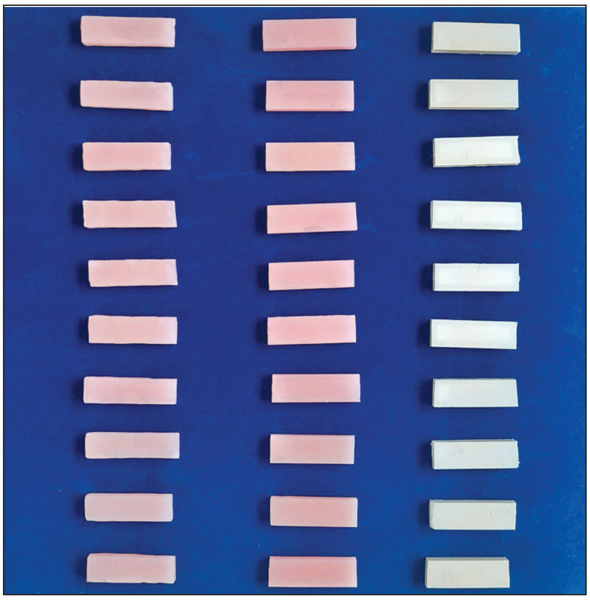

FIGURE 4: TC (+) specimens for surface micro hardness test.

of ISO 20795-1 (2008).[15] A total of 60 specimens (n=10) were prepared at a size of 64×10×3.3 mm, and immersed in water at 37 °C for 50±2 h before being subjected to the flexural strength test. Also, half of all the subgroup specimens were subjected to thermal cycling in a simulation device (SD Mechatronic Thermocycler, SD Mechatronic GMBH, Westerham, Germany), with a 30 second immersion period provided for 5,000 cycles at 5°C to 55°C.

The flexural strength and elasticity module properties were evaluated using the three-point bending test. Afterwards, the tested specimens were placed in corresponding supports distant from each other by 50 mm. Meanwhile, the speed of the device had been fixed at 5±1 mm/min, and strength was applied until fracture occurred. A universal mechanic test device (Lloyd Instruments, Fareham, Hampshire, England) was used for this test (Figure 7). The flexural strength and elasticity module values were calculated using the following formulae:

$$S=3Fl/2bh^2 \text{ and } E=Fl^3/4bh^3d$$

In these formulae, S stands for flexural strength (MPa), E for elasticity module (MPa), F for the maximum load at the moment of fracture (N), l for the distance between the supports, b for specimen width, and h for specimen thickness (mm).

Surface Micro Hardness Test

All the test specimens were prepared in rectangles of the size 30×10×2.5 mm. Testing of their surface micro hardness was achieved using the Vickers micro hardness test device (Shimadzu HMV Corporation, Tokyo, Japan), in which a strength of 50 g was ap-

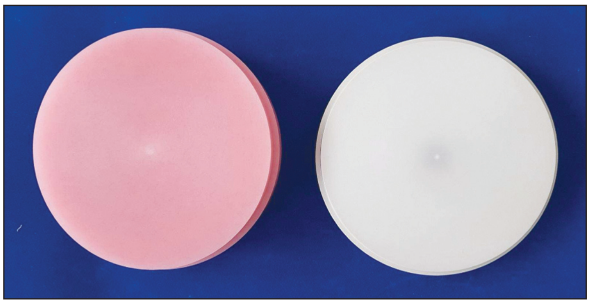

FIGURE 5: Computer-aided design/computer-aided manufacturing polymethyl methacrylate and polyether ether ketone discs used study.

FIGURE 6: Computer-aided design/computer-aided manufacturing milling machine.

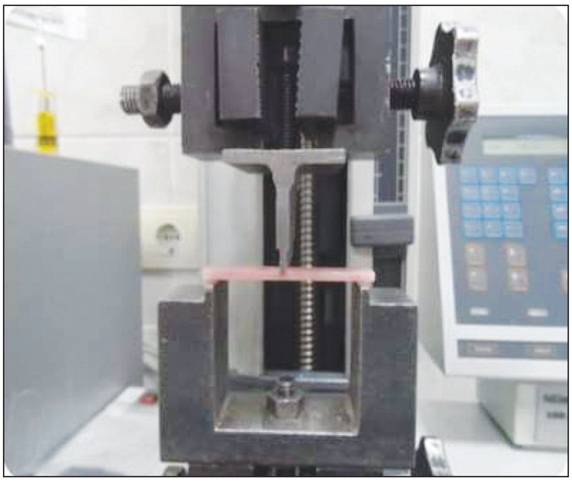

FIGURE 7: Three-point bending test.

plied for 10 seconds (Figure 8, Figure 9). The surface hardness of one specimen from each group was determined by performing three calculations over the specimen surface and then taking an average of the values obtained.

STATISTICAL ANALYSIS

Data analysis was done using the IBM SPSS Statistics 17.0 (IBM Corporation, Armonk, NY, USA) package program. The determination of whether the distribution of continuous numerical variables was near normal was conducted using the Shapiro-Wilk test, and the homogeneity of variances was determined using the Levene test. Descriptive statistics for continuous variables were expressed as median (IQR). If the number of independent groups examined was two, the significance of the difference between the flexural strength, elasticity module, and Vickers hardness levels of the specimens was examined using the Mann-Whitney U test; however, if this number was bigger than two, the significance of the difference between the test groups was examined using the Kruskal-Wallis test. If the statistical results of the Kruskal-Wallis test were found to be significant, then the group or groups causing the difference were determined with Conover's test of multiple comparisons. Unless otherwise determined, those resulting in $p<0.05$ were regarded as statistically significant. Nonetheless, Bonferroni correction was performed in all possible multi comparisons in order to check for Type I errors.

RESULTS

FLEXURAL STRENGTH AND ELASTIC MODULUS

Flexural strength and elasticity module values of test materials are presented in Table 2. The evaluation of flexural strength and elasticity module value was done for both groups -one of which was subjected to a thermal cycle [TC (+)] and the other of which was stored in distilled water [TC (-)]- and showed that the test specimens could be lined up as follows, from the group with the highest to lowest values: JC>YC>M.

Regarding the TC (-) specimens, the flexural strength and elasticity module values of the YC and JC groups were much higher than those of the M

FIGURE 8: Vickers micro hardness test device used this study.

FIGURE 9: Hardness measurement from test specimens.

TABLE 2: Flexural strength and elastic modulus of the test specimens.

	Stored in distilled water [TC (-)]	Subjected to thermal cycle [TC (+)]	p value†
Flexural strength			
M	81.60 (36.53)[a,b]	98.23 (34.53)[a,b]	0.218
YC	109.77 (26.05)[a,c]	118.97 (17.75)[a,c]	0.393
JC	220.56 (12.49)[b,c]	226.26 (5.34)[b,c]	0.052
p value‡	<0.001	<0.001	-
Elasticity module			
M	4497.14 (1627.77)[a,b]	4524.14 (1268.29)[a,b]	0.971
YC	6692.33 (1786.38)[a,c]	6808.10 (786.53)[a,c]	0.853
JC	8310.44 (980.60)[b,c]	8592.45 (611.04)[b,c]	0.353
p value‡	<0.001	<0.001	-

The data were expressed as median (IQR); †The comparisons between TC- and TC+ specimens within each group, Mann-Whitney U test and, a value of p<0.0167 was considered statistically significant according to the Bonferroni correction; ‡The comparisons among M, YC and JC groups within TC- and TC+ specimens, Kruskal-Wallis test and, a value of p<0.025 was considered statistically significant according to the Bonferroni correction; [a]Group M vs Group YC (p<0.01); [b]Group M vs Group JC (p<0.001); [c]Group YC vs Group JC (p<0.001).

group (the respective flexural strength values were p=0.005 and p<0.001, and the respective elasticity module values were p<0.001 and p<0.001). However, a numerical comparison between the JC and PMMA groups revealed that the JC group had significantly higher values [flexural strength: 220.56 (12.49) MPa; elasticity module: 8310.44 (980.60) MPa; p<0.001].

For the TC (+) specimens, there was a statistically significant difference between the flexural strength and elasticity module values (p<0.001). The flexural strength and elasticity module values of the YC and JC groups were even higher when compared with those of the M group [YC: 118.97 (17.75) MPa; JC: 226.26 (5.34) MPa; M: 98.23 (34.53) MPa].

SURFACE MICRO HARDNESS

The highest values were observed in the JC group for surface micro hardness in TC (-) test specimens [30.62 (3.59)]. Behind this was the YC group [26.13 (3.06)]. The lowest surface hardness values were found for M [21.88 (2.77)] (Table 3).

Among the TC (+) test specimens, the YC and JC groups had statistically higher values in terms of Vickers hardness when compared with M groups [YC: 32.27 (1.98); JC: 29.97 (3.09); M: 23.87 (2.68); p<0.001]. However, the JC group had statistically lower values than those of YC in terms of Vickers hardness values [YC: 32.27 (1.98); JC: 29.97 (3.09); p<0.001].

TABLE 3: Surface micro hardness of the test specimens.

	TC (-)	TC (+)	p value†
M	21.88 (2.77)[a,b]	23.87 (2.68)[a,b]	0.190
YC	26.13 (3.06)[a,c]	32.27 (1.98)[a,c]	<0.001
JC	30.62 (3.59)[b,c]	29.97 (3.09)[b,c]	0.579
p value‡	<0.001	<0.001	-

The data were expressed as median (IQR); †The comparisons between TC- and TC+ specimens within each group, Mann-Whitney U test and, a value of p<0.0167 was considered statistically significant according to the Bonferroni correction; ‡The comparisons among M, YC and JC groups within TC- and TC+ specimens, Kruskal-Wallis test and, a value of p<0.025 was considered statistically significant according to the Bonferroni correction; [a]Group M vs Group YC (p<0.001); [b]Group M vs Group JC (p<0.001); [c]Group YC vs Group JC (p<0.01).

The thermal cycle application showed no statistically significant values between the M and JC groups in terms of surface hardness parameters (M: p=0.190; YC: p=0.579). In the YC group, the surface hardness levels were statistically higher in TC (+) specimens when compared to TC (-) specimens (p<0.001).

DISCUSSION

CAD/CAM technology is used the fabrication of inlays, onlays, crowns, fixed and removable prostheses, implant abutments, maxillofacial prostheses, substructures of removable prostheses, fixed-implant-supported prostheses, and, more recently, complete dental prostheses.[10] Manufacturers argue that

CAD/CAM prostheses, when compared to conventionally fabricated prostheses polymerized by heat, exhibit much better mechanical properties and that they have better surface properties and superior fit.[3,16]

The null hypothesis of our study 'that no difference of statistical significance could be found between the surface hardness and mechanical properties of YC, JC, and M' has been completely rejected. Test specimens fabricated using CAD/CAM showed far better mechanical properties in terms of flexural strength, elasticity modules, and hardness parameters. In addition, our second null hypothesis 'that a thermal cycle process affects neither the flexural strength nor surface hardness of the specimens tested' has been partially rejected. While the thermal cycle process affected the surface hardness properties of YC specimens, it did not significantly affect other mechanical properties (flexural strength and elasticity module).

The flexural strength test is considered to reflect the endurance and hardness of the test material, including tensile, shearing, and compression strength.[16] This test can also be used in evaluating the polymerization quality of the material. It is known that flexural strength is one of the essential mechanical properties of resin materials.[17,18] The present study evaluated such mechanical properties as the flexural strength and elasticity modules of the test materials with the aid of the three-point bending test.

According to ISO 20795-1 (2008) standards, the flexural strength of acrylic resins polymerized and produced using a given method should not be less than 65 MPa.[15] In our study, it was determined that the average flexural strength values of the three test groups were all higher than those suggested by ISO 20795-1 (2008), not only before but also after exposure to a thermal cycle process. We believe this could provide denture prostheses with some clinical advantages, such as improved resistance to chewing and impact strength.

Al-Dwairi et al. evaluated the flexural strength, impact strength, and elasticity modules of two different brands of CAD/CAM PMMA (AvaDent and Schütz) and of heat-polymerized PMMA (Meliodent) and concluded that the CAD/CAM PMMA group showed better flexural strength and elasticity module values than did the heat-polymerized PMMA group; our study results are consistent with this finding.[16] We are of the opinion that the better flexural strength of YC and JC test specimens, compared to that of heat-polymerized ones, can be attributed to the pore spaces occurring during the fabrication of heat-polymerized PMMA. While the YC test materials used in our study contain PMMA plastics (100%), as well as a small amount of carbon, ferric acid, and titanium dioxide compounds, M contains powder (PMMA polymer), liquid (MMA monomer) (>90%), and tetramethylene dimethacrylate (0-5%). JC test materials consist entirely of PEEK (100%) and so do not contain additive materials such as color pigments, zirconium dioxide, nano glass, or fiber glass. We assume that the compact structures of the test materials, in addition to their content and composition, account for the JC and PMMA test materials having better mechanical properties. Added to that, the better mechanical properties of CAD/CAM prostheses could also be attributed to the fact that PMMA polymerization was performed under high pressure and heat.

In a study by Ayman, a comparison of the flexural strength of heat-polymerized acrylic resin (Vertex) and that of CAD/CAM pre-polymerized acrylic resin (Polident) showed the heat-polymerized acrylic resins had better flexural strength, although their elasticity module values were lower.[2] In our study, the flexural strength of YC and JC test specimens was better than that of heat-polymerized acrylic resin specimens. Therefore, our results are different from those reported by Ayman in relation to flexural strength. We assume the other study used an IsoMet precision sectioning saw to obtain their CAD/CAM test specimens from pre-polymerized blocks, but we used polymerized CAD/CAM blocks, which could account for this difference. Another possible reason is that we obtained our test specimens using a milling machine after having first fed the required dimensions into a computer.

A study by Srinivasan et al., in which the mechanical properties of CAD/CAM resins and conventional PMMA resins were compared, indicated that CAD/CAM resins have better mechanical properties than do heat-polymerized PMMA resins.[19] However, Steinmassl et al. observed that CAD/CAM resins lack good mechanical properties, after conducting a study in which the fracture resistance of five different CAD/CAM prosthesis base resins, along with that of heat-polymerized resins and autopolymerizing resins, was compared.[20] Hence, our study results appear to be consistent with those of Srinivasan et al. but different than those of Steinmassl et al.[19,20] We consider that the differences in mechanical properties results may be related to the composition of CAD/CAM resins.

The elasticity module of a material is known to be indicative of its hardness.[21] Also, a higher elasticity in prosthesis bases is effective in increasing the amount of energy absorbed prior to the fracture of the prosthesis. However, it is a prerequisite that prosthesis substructures should be rigid, especially when it comes to equally distributing forces across the tissues and structures remaining underneath, as far as the major connectors of removable dentures are concerned.[16] A higher level of flexural strength coupled with a lower level of elasticity usually offers a big advantage in clinical practice.[22] In accordance with ISO 20795-1 standards, the elasticity module value of an acrylic resin should not be smaller than 2 GPa.[10] In our study, not only CAD/CAM test specimens but also those heated using polymerization exhibited the mechanical properties required by ISO standards. Also, the JC test specimens showed the highest elasticity module values [TC (-): 8.31044 (0.9806) GPa; TC (+): 8.59245 (0.61104) GPa]. Denture base materials with high elasticity module values are known to be more resistant to elastic deformation, which helps produce thinner prosthesis bases.[20] Further, without compromising the mechanical properties of the prosthesis, high elasticity enables the production of a thinner palatal plate, resulting in less unnecessary volume for the patient. A prosthesis with a thinner palatal plate help patients speak more naturally and provides them with more comfort; hence, patient satisfaction is sure to increase with thinner palatal plates.[19]

"Surface hardness" is defined as the ability of a material to resist permanent penetration or indentation.[21] In our study, JC and YC showed higher numerical values of surface hardness than did heat-polymerized acrylic resins, which leads us to conclude that cross-linker polymer chains resulting from the polymerization of CAD/CAM resins have better surface hardness values. Therefore, our findings bear resemblance to those of Ayman and Al-Dwairi et al. in that surface hardness values of CAD/CAM resins are shown to be far better in comparison with those of heat-polymerized resins.[2,3]

Pacquet et al., who evaluated the mechanical properties of prosthesis base resins, such as flexural strength, fracture toughness, and hardness, in addition to the effects of the fabrication process, did not observe a statistically significant difference between heat-polymerized resin (Probase Hot) and CAD/CAM resin (Ivobase CAD).[23] However, they showed that high-impact resin (Ivocap), fabricated via the injection molding technique, had far lower hardness values than did both of the other groups. However, their numerical hardness values were much lower than those observed our study, which leads us to assume that this difference could either be due to the chemical content of the materials or the polymerization technique we used, or perhaps to differences in the force applied during the hardness test and its duration. Other reasons could be that the polymerization of CAD/CAM resins is achieved under high pressure and heat, which decreases their monomer content, and that the addition of inorganic fillers limits shrinkage; this helps improve such mechanical properties as surface hardness and abrasion resistance and helps in decreasing surface deformation, bacterial plaque and pigment adhesion, hence enabling a greater longevity in the dental prosthesis.[2,3,5]

Our study also investigated whether a thermal cycle process affected the mechanical properties of the test specimens in the study groups (Table 4). The 5,000-cycle process applied to our specimens corresponds to clinical use for a 5-year period.[24] Every single cycle involved a 30-second period of immersion, with the heat varying between, 5°C±1°C and 55°C±1°C; thus, thermal changes occurring in the mouth were simulated.[24] While the thermal cycle application did not cause any changes of statistical significance in flexural strength, elasticity module parameters for the study groups, the surface hardness values of these specimens did increase, which we be-

TABLE 4: TC (-) specimens according to the TC (+) specimens in the mechanical test, and Vickers hardness levels of the percentage change.

	M	YC	JC	p value†
Flexural strength	11.62 (39.24)	5.55 (15.75)	2.69 (2.42)	0.354
Elasticity module	0.48 (28.17)	2.05 (11.79)	3.99 (7.39)	0.876
Vickers hardness	6.87 (11.99)a	24.08 (7.62)a,b	0.10 (10.33)b	<0.001

The data were expressed as median (IQR); A result of p<0.05 was considered significant according to †the Kruskal-Wallis test; [a]Group M vs Group YC (p<0.001); [b]Group YC vs Group JC (p<0.001).

lieve may result in greater longevity in the clinical use of these dental prostheses.

In our study, when compared to M, JC and YC materials showed higher flexural strength values, suggesting that the fracture strength of these materials is also better. Greater flexural strength makes it possible to withstand greater flexural stress, which occurs during chewing. Clinically, our suggestions are that YC and JC base materials should be used in cases where mastication is supposed to more vigorous (e.g., cases in which distal extension bases oppose natural teeth, cases where a complete dental prosthesis is placed in one jaw, cases of overdenture prostheses, cases in which transient restorations are used for a long time, or cases in which implant-supported full-arch prostheses are used).

Thick prosthesis bases provide better resistance to fracture, mainly in the region of the incisors and in the middle line. However, using a large amount of material will cause gag reflex, phonetic changes, and retention loss and, hence, cause discomfort to the patient.[12]

Based upon our study results, which showed that prostheses fabricated with CAD/CAM have mechanical results, we conclude that it may be possible to fabricate thinner prostheses, in which case both the comfort of the patient and satisfaction of the dentist will increase. Further, we can suggest a promising alternative treatment in which implant-supported overdenture prostheses can be fabricated, especially for cases in which the distance between the maxillary and mandibular arches is limited. Nonetheless, further in-vitro studies and clinical studies are needed to assess the properties of PMMA and PEEK polymers cultivated via CAD/CAM technology and their appropriateness for possible uses in prosthetic dentistry.

CONCLUSION

The following conclusions can be drawn within the limits of our study:

CAD/CAM PMMA and PEEK test specimens showed higher numerical values than did heat-polymerized PMMA specimens in terms of flexural strength, elasticity module, and surface hardness parameters. The thermal cycle application did not significantly affect any flexural and elasticity properties. However, the surface hardness of CAD/CAM PMMA test specimens was found to have increased following the thermal cycle process.

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Conflict of Interest

No conflicts of interest between the authors and / or family members of the scientific and medical committee members or members of the potential conflicts of interest, counseling, expertise, working conditions, share holding and similar situations in any firm.

Authorship Contributions

Idea/Concept: *Zeynep Şahin, Gülfem Ergün, Ayşe Seda Ataol;* ***Design:*** *Zeynep Şahin, Gülfem Ergün;* ***Control/Supervision:*** *Zeynep Şahin, Gülfem Ergün;* ***Data Collection and/or Processing:*** *Zeynep Şahin, Ayşe Seda Ataol;* ***Analysis and/or Interpretation:*** *Zeynep Şahin, Gülfem Ergün;* ***Literature Review:*** *Zeynep Şahin, Ayşe Seda Ataol;* ***Writing the Article:*** *Zeynep Şahin;* ***Critical Review:*** *Zeynep Şahin, Gülfem Ergün;* ***References and Fundings:*** *Zeynep Şahin, Gülfem Ergün, Ayşe Seda Ataol;* ***Materials:*** *Zeynep Şahin;* ***Statistical Analysis:*** *Salih Ergöçen.*

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