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Research Article

Shear Bond Strength of Different Artificial Acrylic Teeth to Acrylic Denture Base After Thermal Cycling

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ABSTRACT: The current study aimed to evaluate how three distinct heat cycling times affected the acrylic teeth's shear bond strength to the acrylic denture base, **Materials and Methods:** The specimens number were (80) divided into four groups according to different manufacturers of acrylic artificial teeth which include: Group (I) Iraqi teeth, Group (II) Syria teeth, Group (III) Chinese teeth, and Group (IV) Italian teeth these groups were further divided into four groups based on how long they were allowed to thermal cycle—one week, one month, and two months in distilled water, where each subdivided group contain five samples. The shear test was conducted using a Universal testing machine following different heat cycles (70, 300, and 600 cycles) at a daily rate of ten cycles with alternating thermal cycling between 5° ±2°C and 55° ±2°C by the use of a manual thermal cycling machine. **Results**: The results showed that the control group had the highest value of shear strength compared to other thermal cycling groups, and the value of shear strength was the highest following a week of thermal cycling. Also, there were significant differences between the four groups under study and across all periods. **Conclusion:** Artificial acrylic teeth shear strength is negatively impacted by heat cycling compared to acrylic denture bases of control and specimens heated for three distinct lengths of time. Control specimens had a stronger shear bond than samples heated to a constant temperature. The shear bond strength decreases as the heat cycle period increases. Before heat cycling, teeth made by Italy had a higher shear bond than those made by other manufacturers in the study.

Keywords: Acrylic Denture Base Material; Artificial Teeth; Shear Bond; Thermal cycling.

INTRODUCTION

The Methyl Methacrylate (MMA) was, as stated by Walter in 1937, prepared as a more satisfactory denture foundation material [1,2]. About 95% of all plastics used in prosthetic dentistry is the plastic resin. They came in a variety of forms, including sheets, gels, powder, and liquid, and blanks; the powder and liquid forms are the most widely used [3]. Continuous research has been conducted to enhance not only their mechanical and chemical characteristics but also their properties to facilitate the laboratory's processing of complete dentures [4-6]. The principal advantages of the denture base are the poor aesthetic, odor, and unhygienic due to the accumulation of bacteria, the strength, and dimensional stability [7]. Over time, the resinous polymer absorbs water mainly because of its polar characteristics [8]. The material's water absorption during production or use indicates how much water was absorbed on its surface and within its body [9]. The absorbed water remains in the spaces between the interpolymeric chains that make up the structure of acrylic resin. The amount of water to be absorbed is determined by the size of these interpolymeric gaps [10]. When natural teeth are lost, prosthetic rehabilitation frequently requires the use of artificial teeth. Artificial teeth have been made using porcelain and acrylic resins [11]. Cross-linking agents are added to the modified acrylic resin in new types of artificial teeth to increase strength and resistance to crazing [12].

For over ten years, cross-linking has been utilized as an acrylic tooth material and introduced as a wear-resistant substance [13]. The amount of hot and cold food and liquid that is consumed causes the mouth's temperature to fluctuate significantly, which can wear down or stress the denture due to the cumulative reaction of shrinkage and expansion. This can potentially deteriorate certain material qualities like compressive and shear strength, as well as hardness and roughness [14]. Numerous scientists have demonstrated how temperature changes affect the hardness, roughness, color stability, microleakage, sorption and solubility, and bond strength of the acrylic base to the soft liner through research on the ageing process [15-17].

However, little was known regarding how heat cycling affects the resin denture base's shear strength. Therefore, these studies have looked into the degradation brought on by heat stress at the interface between acrylic teeth and denture base resin [18].

MATERIALS AND METHODS

The central incisor acrylic teeth, Syrian, Chinese, and Italian used as test specimens for the shear bond test were prepared and grouped into Group (I) Iraqi teeth (Karbala, Iraq), Group (II) Syria teeth(Saief Set teeth, Syria), Group (III) Chinese teeth (Dental8, China) and Group (IV) Italian teeth (Acryl Lux, Italian), and a 2.5-cm-long, 5 mm-radius acrylic resin (Ivoclar Vivadent, Germany) rod was attached to them, as illustrated in Figure (1). The T designs were prepared in the middle of the ridge lap surface of the teeth. The T-shape design is the most effective way to use resin to increase retention [19]. As seen in Figure 2, this design (diatorics) is prepared with dimensions of 2.5 mm for width, 3 mm for depth, and a 1 mm lateral extension. The carbide fissure bur was used to make the preparations.

Figure (1): Group (I) Iraqi teeth (Karbala, Iraq), Group (II) Syria teeth (Saief Set teeth, Syria), Group (III) Chinese teeth (Dental8, China) and Group (IV) Italian teeth (Acryl Lux, Italian) and Sample of acrylic teeth attached to a rod of acrylic resin denture base tooth

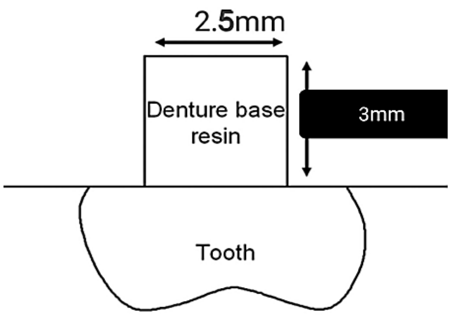

Figure (2): Mechanical retention means the T-shape

The wax pattern's 5 mm end was then applied to the acrylic ridge lap of the tooth surface. After that, the acrylic tooth and the wax pattern were placed in a denture flask, and the wax was replaced with denture base material. A tiny brush was used to apply a drop of monomer to the tooth's surface, and it was left for 60 seconds before packing. After dissolving in the monomer, the tooth surface forms a robust secondary semi-interpenetrating polymer network (IPN) structure, that is mean when the polymer dissolves in the monomer, the tooth surface forms a strong structure of polymer networks [20-22]. The resin samples were mixed and processed in compliance with the guidelines provided by the manufacturer. The specimens underwent a conventional curing cycle in a water bath, as per the manufacturer's instructions. The specimens were processed for 90 minutes at 74°C after the water path's temperature was first raised to boiling 100°C for 30 minutes [23]. The flasks were left to cool to room temperature on the bench, and then the flasks were opened, and the resin excesses were trimmed from the samples.

Before the shear bond strength test was conducted, the two groups (with and without ageing) were kept for one week, one month, and two months, respectively, in a water bath made of tap water that was maintained at a constant 37±1°C. Subjected to ten cycles of alternating manual thermal cycling by the use of (Alternating thermal-cycling machine/ Readymade, Iraq) which was digitally monitored and controlled at +5±2°C and +55±2°C per day Figure (3), the group underwent 15 seconds of transport time between the water baths and 30 seconds of dual time at each temperature [15-17,24-27]. Eighty samples in total were split into four groups based on the various acrylic resin artificial tooth manufacturers, which are as follows: Group I (Iraqi teeth), Group II (Syrian teeth), Group III (Chinese teeth), and Group IV (Italian teeth). These groups were further divided into four subgroups based on the length of the thermal cycling (one week, one month, and two months) and the immersion in distilled water as a control group without thermal cycling.

Figure (3): Alternating thermal-cycling machine/ Readymade, Iraq

Five samples were included in each of the three subgroups. The samples were kept in position during the testing, which was carried out on a Universal testing machine (Instron/ Model 1332 Servo Hydraulic Fatigue Test System 100kN Load Cell 2513-502), as shown in Figure 4, using the device holder (clamp). The load at breakage was made [28]. The mean and standard deviation were computed statistically. To find significant differences between tested groups at p ≤ 0.01, ANOVA and Duncan's multiple range tests were used.

Figure (4): Universal testing machine (Instron Model 1332 Servo Hydraulic Fatigue Test System 100kN Load Cell 2513-502)

RESULTS

In contrast to groups that did not engage in thermal cycling during the same period, the results in Table 1 and Figures, 5,6,7, and 8 demonstrated a decrease in the shear bond strength of thermal cycling groups. For all teeth in the thermal cycling group, after a week of thermal cycling, the highest shear bond strength value was found, while the lowest value was obtained after two months for all manufacturers of teeth.

Table (1): ANOVA Tests Shear bond strength between acrylic denture base materials and artificial acrylic teeth for four different types of teeth tested under three different thermal cycling conditions and without thermal cycling.

Time	Source of variance	Sum of square	DF	Mean square	F-value	P-value
Control	Between groups	0.20228	3	0.06743	8.17	0.002*
	Within groups	0.13211	16	0.00826		
	Total	0.33439	19			
1 Week	Between groups	0.1344	3	0.0448	3.14	0.055
	Within groups	0.2284	16	0.0143		
	Total	0.3628	19			
1 Month	Between groups	0.1231	16	0.041	0.826	0.499
	Within groups	0.7949	19	0.050		
	Total	0.9190	3			
2 Months	Between groups	0.3061	3	0.102	1.544	0.242
	Within groups	1.0563	16	0.066		
	Total	1.3620	19			

DF: degree of freedom, P*:Means are statistically significantly different at p ≤ 0.05

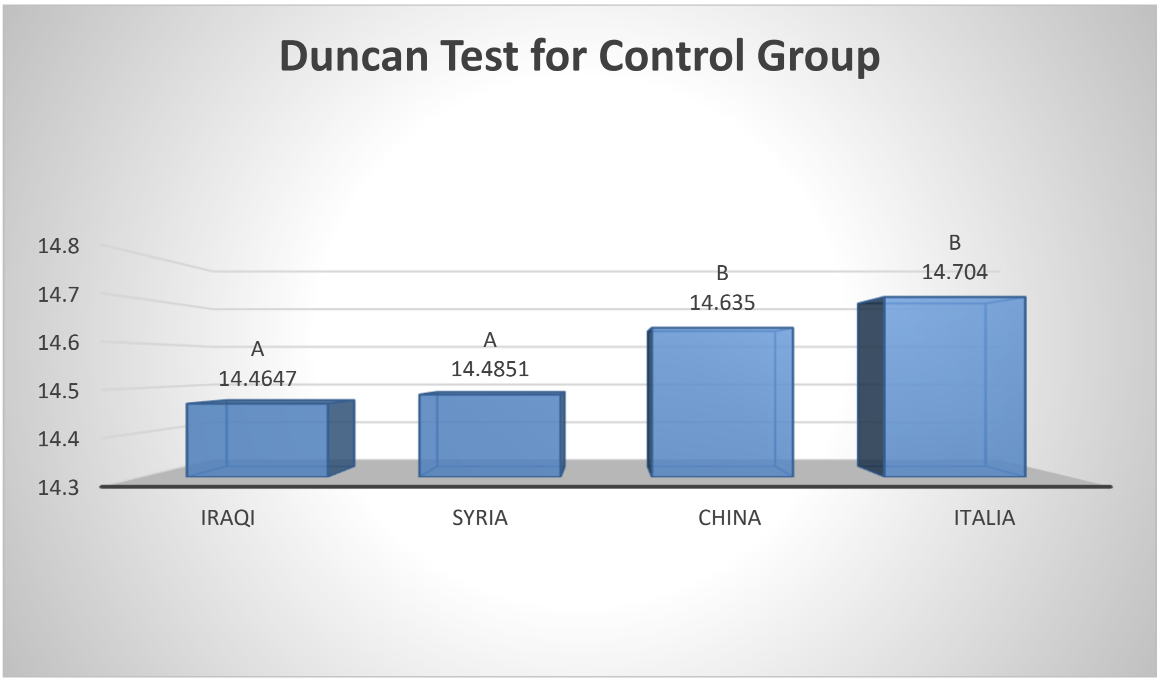

Figure (5): Duncan Test between subgroups (Iraq, Syria, China, and Italy), for the control group. Shear bond strength for four tested types of teeth after three cycles of thermal cycling and control without thermal cycling between acrylic denture base materials and artificial acrylic teeth.

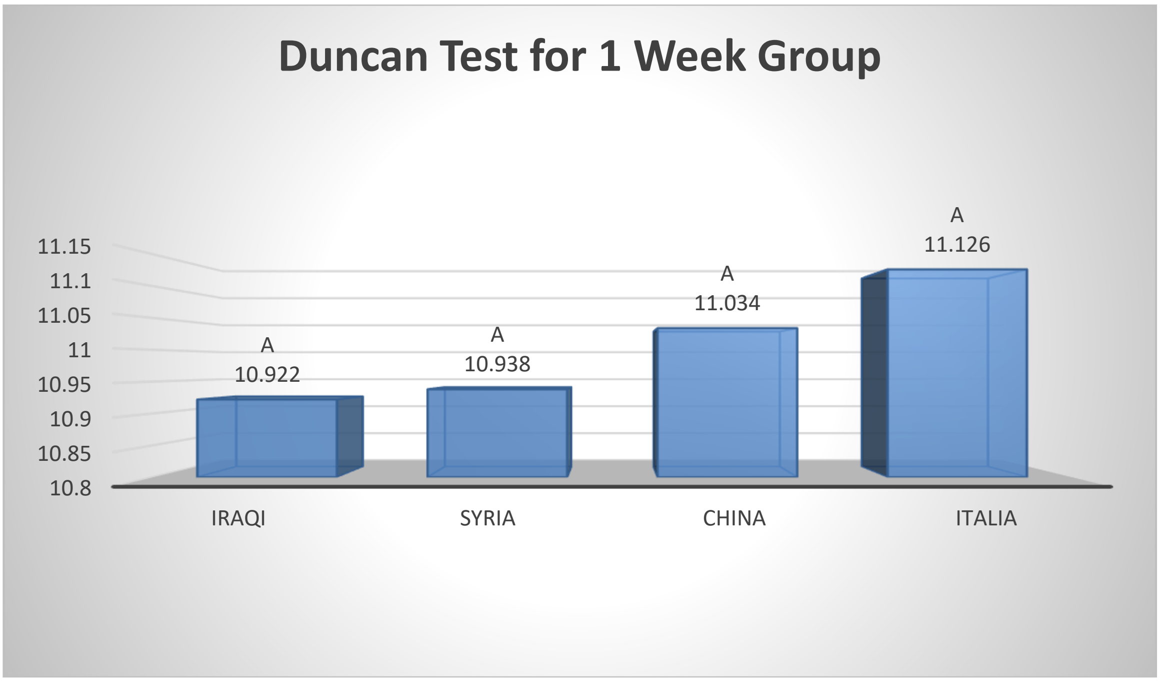

Figure (6): Duncan Test between subgroups (Iraq, Syria, China, and Italy), for one week group Shear bond strength for four tested types of teeth after three cycles of thermal cycling and control without thermal cycling between acrylic denture base materials and artificial acrylic teeth.

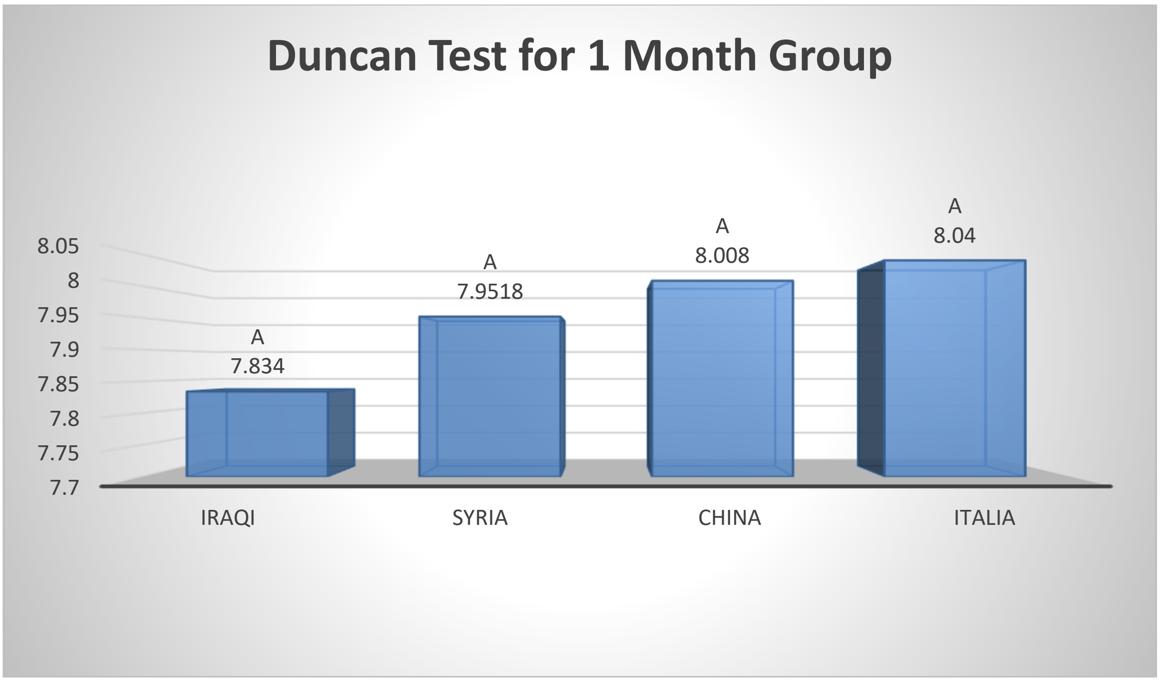

Figure (7): Duncan Test between subgroups (Iraq, Syria, China, and Italy), for one-month group. Shear bond strength for four tested types of teeth after three cycles of thermal cycling and control without thermal cycling between acrylic denture base materials and artificial acrylic teeth.

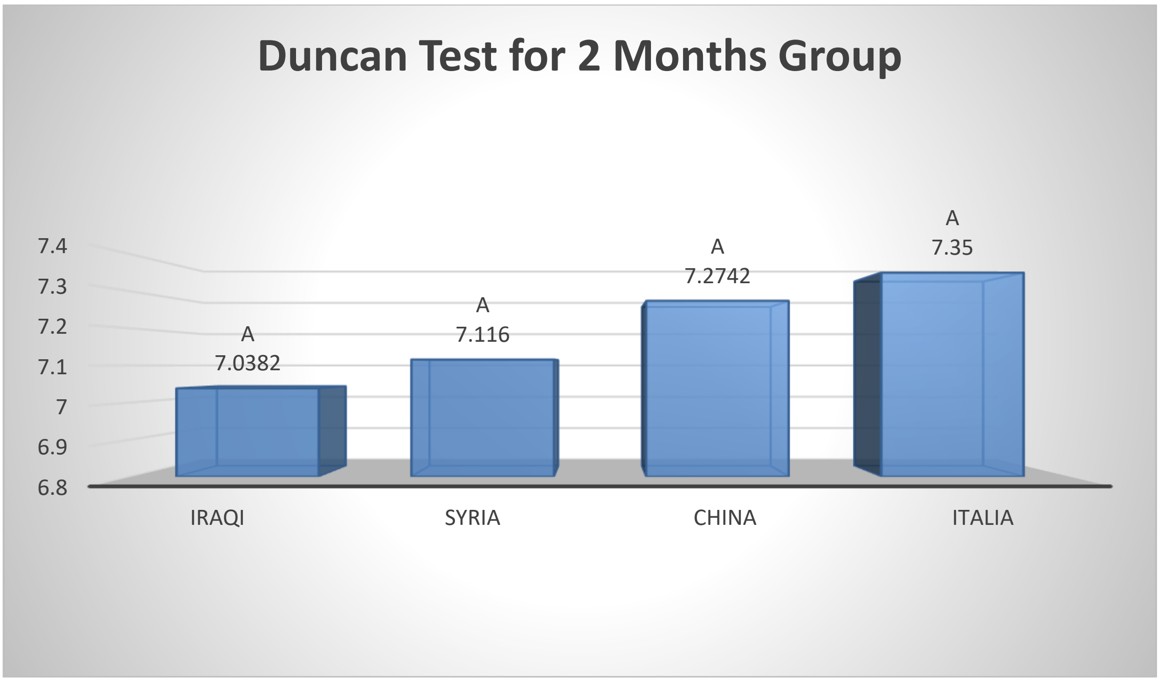

Figure (8): Duncan Test between subgroups (Iraq, Syria, China, and Italy), for a month group. Shear bond strength for four tested types of teeth after three cycles of thermal cycling and control without thermal cycling between acrylic denture base materials and artificial acrylic teeth.

ANOVA analysis in Table (1) also demonstrated that there was a statistically significant difference in the shear bond strength between the thermally cycled group and the control group for all tooth type manufacturers except with one week group, where there was no statistically significant difference with the control group.

The result in Table 2 demonstrated that the shear bond strength decline following thermal cycling was mitigated as the duration of thermal cycling was extended from one week to two months for all tooth types. In locations where the effect on shear bond strength would be lessened, the length of the thermal cycling was increased from one week to two months. ANOVA analysis in Table (2) and Figures (9,10,11 and 12) revealed that, when comparing the shear bond strength of these groups across the different thermal cycles (70, 300, and 900 cycles) used in this study to that without thermal cycling, there was a statistically significant difference (at $p<0.05$), these consideration is obtained by the effect of thermal cycling on the shear bond strength of the control and thermal cycling groups.

Table (2): Shear bond strength between acrylic denture base materials and artificial acrylic teeth was tested during three different thermal cycling cycles and without thermal cycling.

Time	Source of variance	Sum of squares	DF	Mean square	F-value	P value
Iraqi	Between groups	171.1508	3	57.0503	3726.33	0.0001**
	Within groups	0.2450	16	0.0153		
	Total	171.3958	19			
Syria	Between groups	167.2432	3	55.7477	2994.38	0.0001**
	Within groups	0.298	16	0.019		
	Total	167.541	19			
China	Between groups	168.62	16	56.2065	1544.08	0.0001**
	Within groups	0.5824	19	0.0364		
	Total	169.2020	3			
Italia	Between groups	169.437	3	56.479	831.615	0.0001**
	Within groups	1.087	16	0.068		
	Total	170.524	19			

DF: degree of freedom, P**: Means are highly statistically significant different at $p \le 0.01$

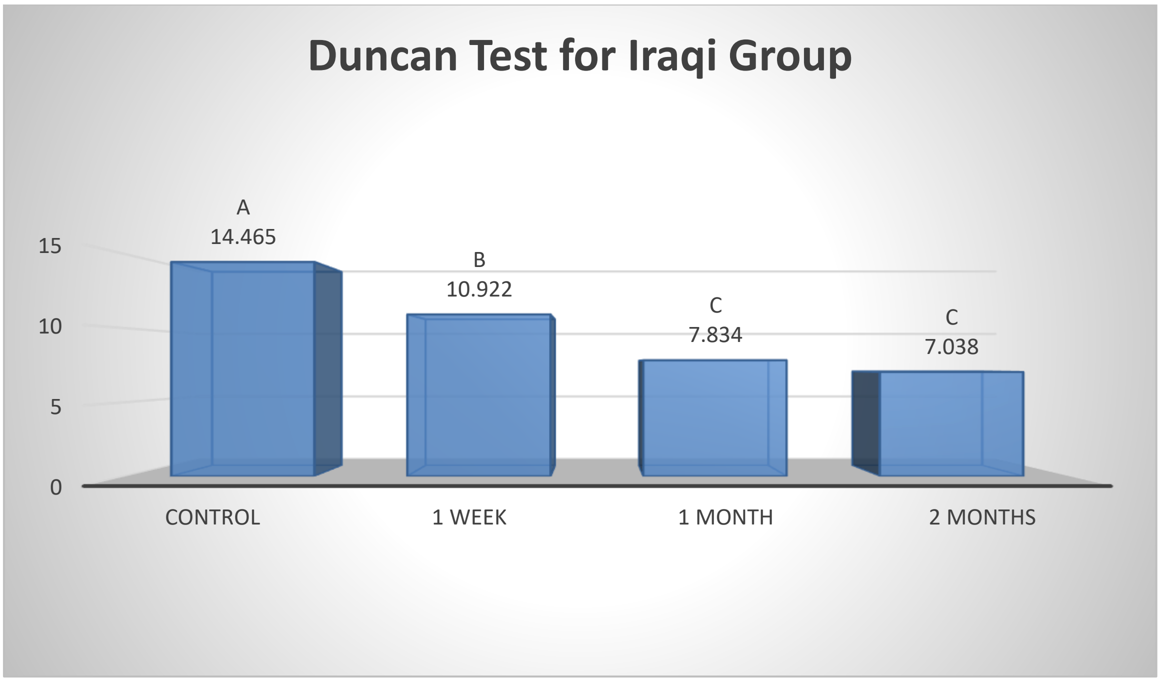

Figure (9): Duncan Test between Subgroups (Control, 1 Week, 1 Month, and 2 Months) for Iraqi Group, Shear bond Strength between artificial acrylic teeth and acrylic denture base materials after three cycles of thermal cycling and control without thermal cycling.

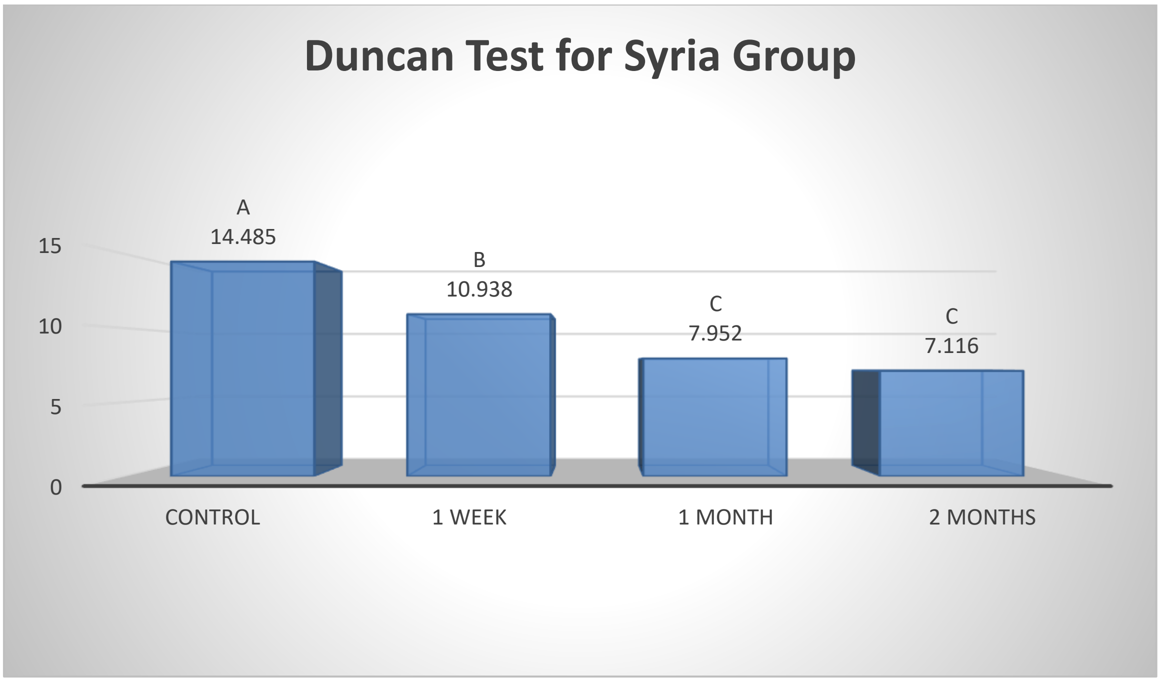

Figure (10): Duncan Test between Subgroups (Control, 1 Week, 1 Month, and 2 Months) Syria Group, Shear bond Strength between artificial acrylic teeth and acrylic denture base materials after three cycles of thermal cycling and control without thermal cycling.

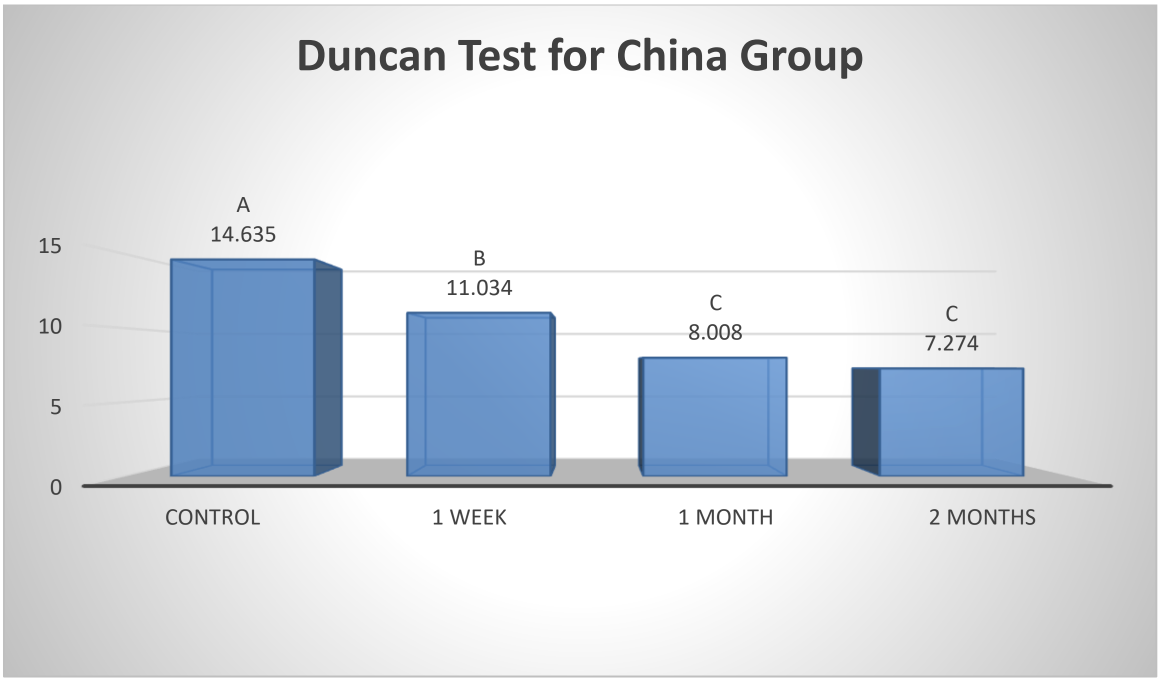

Figure (11): Duncan Test between Subgroups (Control, 1 Week, 1 Month, and 2 Months) China Group, Shear bond Strength between artificial acrylic teeth and acrylic denture base materials after three cycles of thermal cycling and control without thermal cycling.

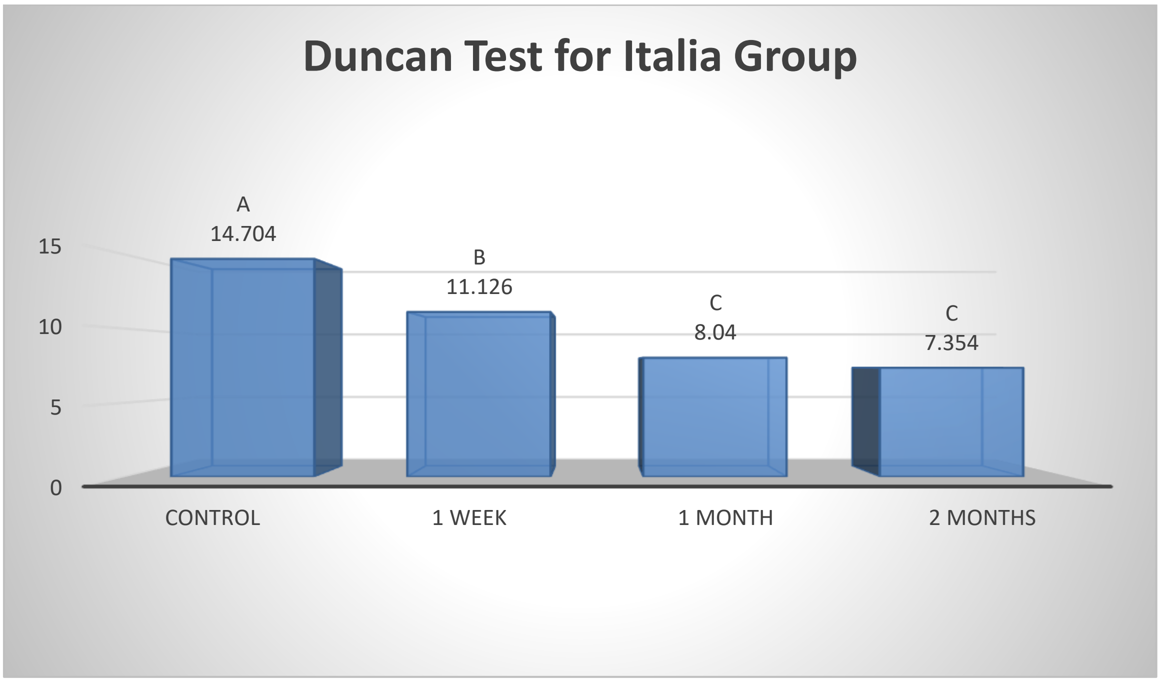

Figure (12): Duncan Test between Subgroups (Control, 1 Week, 1 Month, and 2 Months) Italia Group, Shear bond Strength between artificial acrylic teeth and acrylic denture base materials after three cycles of thermal cycling and control without thermal cycling.

DMRT analysis in Figures (5,6,7, and 8) revealed that the shear bond strength of the control group varied statistically only before cycling; no statistically significant differences were observed for all other varieties of teeth during the thermal cycling process.

DMRT analysis in Figures (9,10,11 and 12) revealed a statistically significant difference for all the mean values of the shear bond strength of control and thermal cycling samples among the different thermal cycles (70,300,900 cycles) that were used in this study as compared to those without thermal cycling, except between China and Italia groups where was no statistically significant differences between them after three cycles of thermal cycling.

DISCUSSION

Consuming hot or cold food and liquids, and using warm or hot water to clean the prosthesis [29,30], had the greatest impact on a dental prosthesis's temperature, which can vary significantly in a clinical setting. The most common clinical problem is bond failures at the area where the denture base resin and artificial teeth meet [31]. Several elements, including the ridge lap surface of the tooth's chemical and mechanical preparation and the existence of contaminants near the tooth/denture base contact as a result of subpar laboratory techniques, can affect this bonding.

The results in Table (1) and DMRT analysis in Figures (5,6,7, and 8) showed that when aging (thermal cycling) was applied to groups, the shear strength decreased in comparison to the same period (time) when no aging was applied. In the thermal cycling group, all teeth showed the greatest strength of shear bonds value after one week of thermal cycling, while all tooth types showed the lowest value after two months, and this can be illustrated by considering that the material experiences fatigue or stress due to the cumulative effect of shrinkage and expansion brought on by temperature variations [14] thereby decreasing its shear bond strength.

The control group's shear bond strength was found to differ statistically only before thermal cycling, except for one one-week group, as indicated by the ANOVA test in Table 1, and the DMRT shear bond strength. However, no statistically significant differences were found for other periods of thermal cycling for any of the tooth types (Iraqi, Syrian, Chinese, and Italian). The theory was that the kind of denture teeth could also have an impact on acrylic teeth's capacity to adhere to denture base resins [18].

In regard to the effect of periods of aging(thermal cycling), the result could be explained by factors such as high solubility in water and high water sorption, which reduce mechanical properties like hardness, bond strength, and fatigue limit and these

factors would increase with increasing period of thermal cycling[32], the solute concentration in the dissolution medium influences this solubility more than immersion time [33] and can transmit stress factors to the microscopic or molecular level, where they induce modifications to the polymer chain or network[34].
Additionally, the various commercial varieties of acrylic resin display notable variations in water absorption, residual monomer, and ratios of water sorption and solubility, all of which have the potential to change how well the denture base and artificial teeth bond and adapt [35].

Another explanation that the (control) group had the smaller shear bond strength relative to the thermal cycling group could be that molecular mobility increases with temperature [36] which, along with the continuous polymerization reaction that occurs after thermal cycling, where residual monomer molecules are gradually consumed, may help to explain why samples of acrylic resin became more soluble and why the thermal cycling group's shear bond strength decreased in comparison to the control group that did not receive thermal cycling leading to more complete polymerization[37]. Chemical degradation is usually caused by oxidation and hydrolysis, which are processes that require the presence of water. Acrylic resin is affected by sorption and solubility because of its composition. When a solvent enters the polymer network, it causes an expansion of the structure, facilitates the extraction of monomers that did not react, and promotes the dissolution of linear polymer chains [38]. This expansion is facilitated when the density of crosslinks is low. Thus, polymers with a high density of crosslinks are more resistant to degradation due to the greater limitation of space and possible paths for the diffusion of permanents in the polymer structure. Such water sorption may contribute to the failure of adhesive-dentin bonds [39]; therefore, ageing is used to evaluate the bonding durability of the adhesive interface against thermal stress.

The findings presented in Table 2) DMRT analysis in figures (9,10,11, and 12) demonstrated that all types of tooth manufacturers (Iraqi, Syrian, Chinese, and Italian) experienced a decrease in shear force as the duration of thermal cycling increased from one week to two months. Similarly, the effect of ageing on shear strength would also decrease as the duration of thermal cycling increased from one week to two months, these can be explained in that the temperature variations may be the cause of the biodegradation of acrylic resin denture material, which results in the release of unbound or uncured monomers or resin from the polymer network and as a result of complete polymerization, these uncured bonds will decrease as thermal cycling periods increase[40,41], and these will lead to the decline in shear strength after cycling this agrees with *Marra et al.2004* who concluded that the storage conditions (dry vs.

thermocycler) had a significant impact on the bond strength. Additionally, they observed that the shear bond strength between resin teeth and a heat-polymerized denture base acrylic resin significantly decreased with ageing [42,43].

An ANOVA test in Table (2) and DMRT analysis in Figures (9,10,11, and 12) found that there was a statistically significant difference for the shear bond strength between the control and thermal cycling samples' mean values used in this study. This difference can be attributed to the release of residual stress caused by variations in the thermal coefficient of expansion (caused by cooling and heating) of various types of acrylic teeth[44-46]. Polymerization shrinkage of resin material and the release of internal stress attributed to thermal expansion of denture base in addition to the tendency of cooling shrinkage[7,47-50], which causes space to open up between the study's artificial teeth and the acrylic resin foundation, and these causes or factors may be the main reason why Italian teeth are had better and greater adhesion strength at different times than the other teeth used in this study.

Finally, the ANOVA test in Table (2) and DMRT analysis in figures (9,10,11, and 12) also found that there were no statistically significant differences between the China and Italy groups after three cycles of thermal cycling. This difference can be attributed to that the residual monomer reduces the mechanical properties of the acrylic resins, adversely affecting. The water uptake and the monomer release are time-dependent processes. Henceforth, the number of molecules within the denture base resin changes over the time and the denture polymer strength at a given time after water immersion is also affected by the amount of the molecules present, but this continued polymerization of the residual monomer in its active sites after the initial reaction counteracts the reduction in the mechanical properties, thereby these factors lead to the stability of mechanical property of acrylic resins on long-term aging between one to two month (51).

CONCLUSIONS

Within the limitations of the current study, thermal cycling(ageing), which involves subjecting samples to three cycles, had a detrimental effect on the shear bond strength of artificial acrylic teeth to the acrylic resin denture base. The shear bond strength of the control samples is higher than the samples subjected to heat cycling. With an increase in thermal cycling time, the shear strength falls. Italian teeth have a higher shear bond than teeth from other manufacturers in the study before they are heated.

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Authors' Contribution

Al-takai IF, Al-Neema HS, Al-Tahoo OZ contributed to conceptualization, validation, and writing the original draft. Al-takai IF, Al-Neema HS, Al-Tahoo OZ were responsible for formal analysis, methodology, and project administration. Al-takai IF, Al-Neema HS, Al-Tahoo OZ for supervision, review & and editing of the manuscript. Al-takai IF, Al-Neema HS, Al-Tahoo OZ contributed to the investigation, software development, validation, and visualization. Ihssan F. Al-takai IF, Al-Neema HS, Al-Tahoo OZ were involved in data curation, resources, and review & editing. All authors have read and approved the final manuscript.

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Conflict of interest

The authors declare that there are no conflicts of interest regarding the publication of this manuscript.

Availability of data and materials: Data is available at the request of the corresponding author.

Declaration of Generative AI and AI-assisted technologies

No artificial intelligence tools were used. The authors reviewed and edited the content as needed and take full responsibility for the content of the publication.

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قوة الارتباط القصي للأسنان الأكريلية الاصطناعية المختلفة بقاعدة طقم الأسنان الأكريلي بعد التدوير الحراري

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الملخص

الأهداف: تهدف الدراسة الحالية إلى التأكد من مدى تأثير ثلاث مرات مختلفة لدورة الحرارة على قوة رابطة القص لأسنان الأكريليك بقاعدة طقم الأسنان الأكريليك، **المواد وطرائق العمل:** بلغ عدد العينات (80) قسمت إلى أربع مجموعات حسب الشركات المصنعة المختلفة للأسنان الاصطناعية المصنوعة من الأكريليك وهي: المجموعة (I) أسنان عراقية، المجموعة (II) أسنان سورية، المجموعة (III) أسنان صينية والمجموعة (IV) الإيطالية. تم تقسيم هذه المجموعات أيضًا إلى أربع مجموعات بناءً على المدة التي سمح لها فيها بالدورة الحرارية - أسبوع واحد، وشهر واحد، وشهرين في الماء المقطر، حيث تحتوي كل مجموعة مقسمة على خمس عينات. تم إجراء اختبار القص باستخدام آلة اختبار عالمية بعد دورات حرارية مختلفة (70، 300، و600 دورة) بمعدل يومي من عشر دورات مع دورات حرارية متناوبة بين 5 درجة ± 2 درجة مئوية و55 درجة ± 2 درجة مئوية بواسطة استخدام آلة الدراجات الحرارية اليدوية. **النتائج:** اظهرت النتائج أن مجموعة السيطرة حصلت على أعلى قيمة لمقاومة القص مقارنة بمجموعات التدوير الحراري الأخرى وكانت قيمة قوة القص هي الأعلى بعد أسبوع من التدوير الحراري. كما كانت هناك فروق ذات دلالة إحصائية بين المجموعات الأربع قيد الدراسة وكذلك في جميع الفترات. **الاستنتاجات:** تتأثر قوة القص لأسنان الأكريليك الاصطناعية سلبًا بالتدوير الحراري عند مقارنتها بقواعد أطقم الأسنان الأكريليك للتحكم والعينات التي تم تسخينها لمدة ثلاث فترات زمنية مختلفة. بالمقارنة مع العينات التي تم تسخينها إلى درجة حرارة ثابتة، كانت عينات التحكم لديها رابطة قص أقوى. تقل قوة رابطة القص مع زيادة فترة الدورة الحرارية. قبل دورة الحرارة، كانت الأسنان المصنوعة في إيطاليا تتمتع برابطة قص أعلى من تلك المصنوعة من قبل الشركات المصنعة الأخرى في الدراسة.

الكلمات المفتاحية: مادة قاعدة طقم الأسنان الأكريليك، رابطة القص، الأسنان الاصطناعية، التدوير الحراري