Research Article

In Vitro Evaluation of the Flexural Strength of Different Temporary Crown Materials, After Thermocycling

Georges El Najjar[1,3]*, Halal R[2], Daou M[3] and Zebouni E[1]

[1]*Department of Fixed Prosthetics, Saint-Joseph University, Lebanon*

[2]*Private Practice, Lebanon*

[3]*Department of Pediatric Dentistry, Saint-Joseph University, Lebanon*

*Corresponding Author: Georges El Najjar, Research Assistant, Department of Fixed Prosthetics, Saint-Joseph University, Lebanon.

Abstract

Objective of this Study: To study the variation of flexural strength as a function of time during an interval simulating a time span of a year in the mouth and determine whether the mechanical performance of the materials in question remains acceptable.

Materials and Methods: Three types of materials are used: bis-acrylic resin (Tempsmart® and Cooltemp®), conventional PMMA (Unifast III®) and composite resin (Revoteck LC®). The flexural strength is evaluated. The samples undergo thermal cycling up to 10 000 cycles and are evaluated at different points in time.

Results: The bis-acrylic and conventional PMMA showed acceptable results throughout this study. The bis-acrylic material Tempsmart® showed the best values. The composite material Revoteck LC® has shown to be inadequate.

Conclusion: Among the tested materials, Tempsmart® is the most suited for long-term temporary restorations.

Keywords: Flexural Strength; Temporary Restoration; Bis-Acrylic Resin; Composite Resin; Conventional PMMA

Abbreviations

b: Width in Millimeters; Bis-GMA: Bisphenol A-Glycidyl Dimethacrylate; F: Maximum Load in Newton; h: Height in Millimeters; ISO: International Organization for Standardization; l: The Length in Millimeters; mm: Millimeter; MPa: Megapascal; nm: Nanometer; PEMA: Polyethymethacrylate; PMMA: Polymethymethacrylate; UDMA: Urethane dimethacrylate; µm: Micrometer; σ: Flexural Strength in MPa

Introduction

A full prosthetic treatment includes many phases (laboratory fabrication, periodontal preparation …) according to the Academy of Fixed Prosthodontics and is done over a mid to a long period of time [1]. This fact has made provisional restorations a key element to the success of the definitive restoration and the treatment overall.

The requirements for a successful temporary restoration, though downplayed at times, are very close to those of a definitive restoration [2]. According to Shillinburg, these requirements are pulpal protection, positional stability, occlusal function, ease of cleaning, non-impinging margin, strength, retention, and esthetics [3].

Several complications may arise during the phase of temporary treatment. The most prominent being marginal inaccuracies, frac-

tures, and non-integrity of the external contour [4]. While the failure of the provisionals may occur at any point during the lifespan of a temporary restoration (fabrication, insertion, disinsertion, and function) it is important to note that when it does, it can negatively affect the remaining dental tissue, the health of the peridontium, and the functional and psychological well-being of the patient.

Fractures are a mechanical failure, a result of the propagation of a crack inside the material wrought on originally by surface flaw [1], a void in the material, inadequate thickness at the level of the connector or the preparation. Even in ideal manufacturing conditions, resin-based materials are by nature brittle, the fracture risk is always significant, hence it is important to always consider the flexural strength of the material [5].

The duration of use of temporary crowns may in some cases extend to 6 months, one year or even further, especially in cases of Vertical Dimension Alteration, Temporomandibular Joint Disorders, Orthodontics, Interim Implant Restorations and Bone Grafts. Most experimental studies limit the artificial ageing of the materials to a period of 6 months, which is insufficient to determine whether these materials' mechanical properties are adequate to fulfill their roles to the fullest extent in the complex cases mentioned beforehand.

Objective of the Study

The objective of this research is to study the variation of flexural strength as a function of time during an interval simulating a time span of a year in the mouth and determine whether the mechanical performance of the materials in question remains acceptable.

Clinical Significance

This study will allow the clinical practitioner to choose the most appropriate temporization material and determine a time period when the selected material's properties become inadequate and in need of replacing thus preventing complications.

Materials and Methods
List of materials and tools required

- A self-curing methyl methacrylate-based material (Unifast III by GC®)
- Two bis-acrylic resin-based materials (Tempsmart by GC® and Cooltemp by Coltene®)
- A composite-based material (Revotek LC by GC®)

- A curing light source (the Kerr Demiplus LED curing)
- Stainless steel mold
- 2 glass plates
- A thermocycler: Mechatronik SD thermocycler
- A universal testing machine: YLE universal testing machine.

Experimental procedure
Preparation of the specimen

Specimen preparation: A Stainless-Steel mold is prepared in order to produce the specimen in the form of bar (25 x 2 x 2 mm) according to EN ISO 4049;2009 (Figure 1).

Inclusion criteria:

- 25 x 2 x 2 mm bars
- No visible defects stemming from a lack of material (bubbles)
- Polished surface.
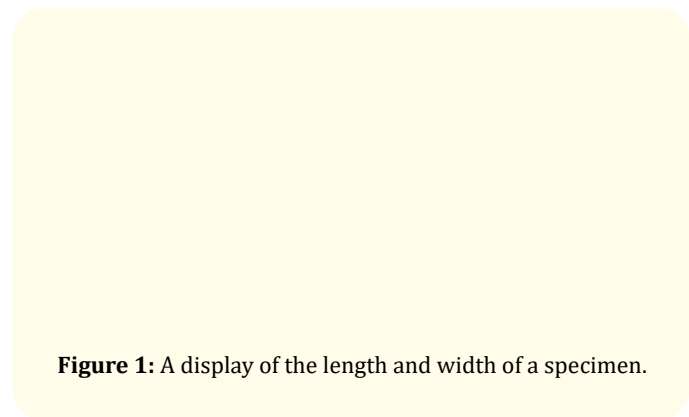
Figure 1: A display of the length and width of a specimen.

Exclusion criteria

- Visible defects as cracks or bubbles.
- Significant dimensional variations (The specimen were verified by a second operator).

Polymethymethacrylate samples

Before the preparation of the methyl methacrylate samples, the amount of powder (2 mg) is measured using a precision cup provided by the manufacturer and the acrylic liquid is dosed using a pipette (0.5 mL capacity, 1 mL in total per 2 mg of powder) (Figure 4). The stainless-steel mold is placed on the first glass plate.
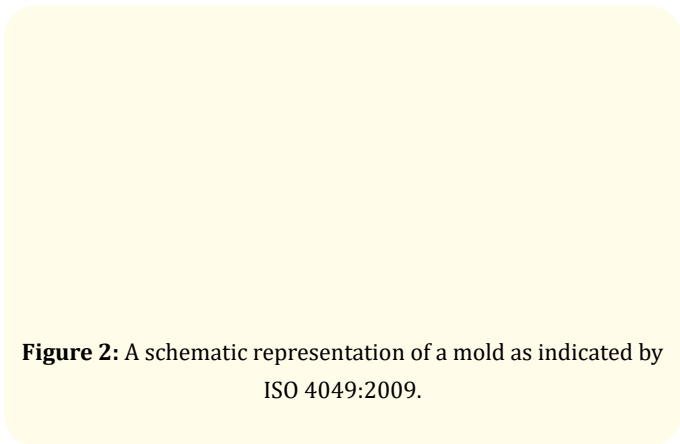
Figure 2: A schematic representation of a mold as indicated by ISO 4049:2009.

Figure 4: The acrylic resin Unifast III®, the powder (left) and the liquid (right).

Figure 3: The mold used in this study.

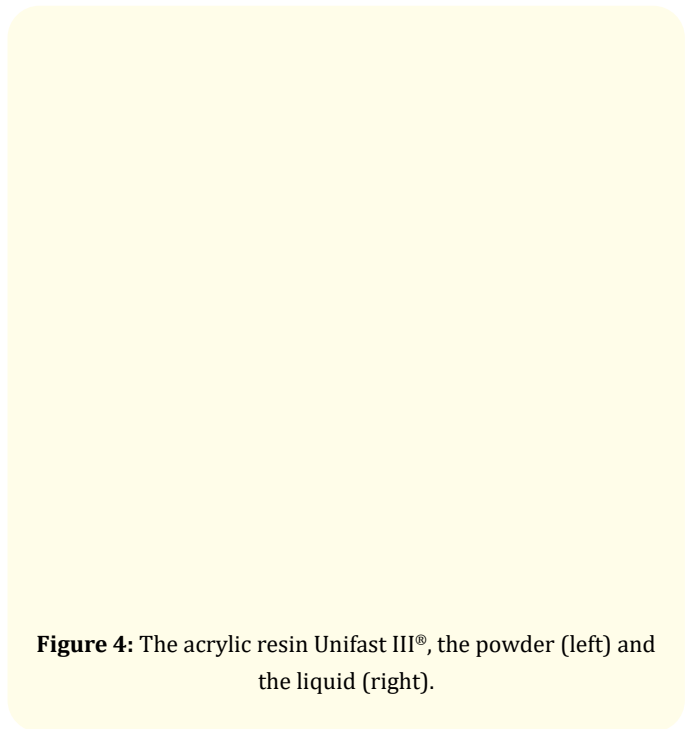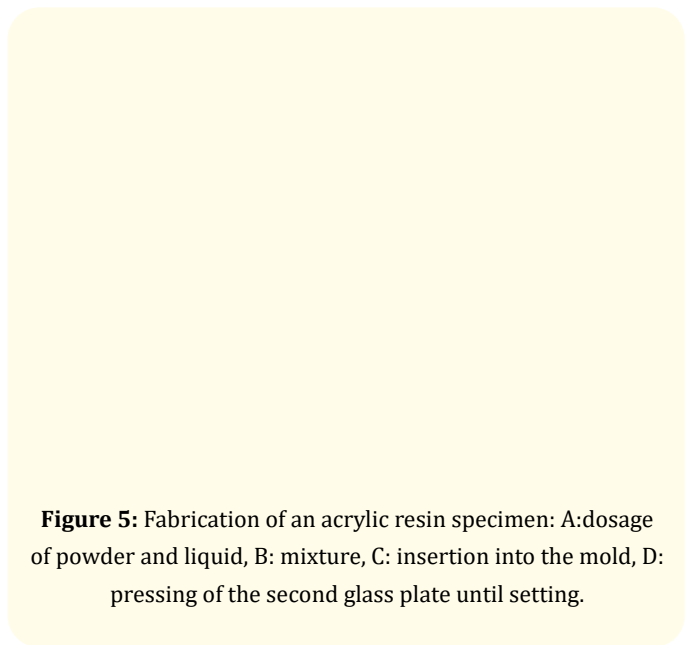The mixture is made by hand using a metal mixing spatula in a silicone cup. The mixture is inserted into the open pat of the mold. The larger quantity of excess is eliminated immediately by spatula, then the open part of the mold is covered with a glass plate, and the contraption is pressured and held together until the setting time is over (Figure 5). Following this, the specimen was polished using sandpaper (2400 grit).

Figure 5: Fabrication of an acrylic resin specimen: A:dosage of powder and liquid, B: mixture, C: insertion into the mold, D: pressing of the second glass plate until setting.

Bis-acryl samples

The stainless-steel mold is placed on the first glass plate. The bis-acryl material (Figure 6) is mixed and inserted into the mold with the Ramitec syringe (3M). The larger quantity of excess is eliminated immediately by spatula, then the open part of the mold is covered with a glass plate, and the contraption is pressured, held together and exposed to the curing light for 20 seconds each side

using the Kerr Demiplus LED curing. After removal from the mold, the specimens are also exposed to 20 seconds of the curing light each side (Figure 7). Following this, the specimen was polished using sandpaper (2400 grit).

Figure 6: The Bis-acrylic materials Tempsmart® (left) and Cooltemp (right)®.

Figure 7: Fabrication of a bis-acrylic specimen : A: insertion of the mixing tip in the mold, B: mixture inside the mixing tip, C: insertion of the mixed resin into the mold, D: removal of excess, E: pressing of the second glass plate and photopolymerization, E: end result.

Composite samples

The stainless-steel mold is placed on the first glass plate. The composite (Figure 8) is cut using a spatula, then inserted into the mold. The second piece of glass is pressed against the mold, then set aside to remove all obvious excess using the spatula. The glass is pressed again by hand while using the Kerr® Demiplus LED curing light for 10 seconds, then 20 seconds as per the manufacturer's

recommendations. Following this, the specimen is polished using sandpaper.

Figure 8: Fabrication of a composite specimen: A: the composite Revoteck LC®, B: extraction of a small portion of composite, C: insertion of the composite into the mold, D: pressing of the second glass plate, E: Light-curing, F: end result.

The procedure of artificial ageing

The thermalcycling procedure consisted of a number of thermal cycles that the samples have to undergo. Each cycle consisted of alternating dipping in two containers at 5°C and 55°C for 30 seconds with a dwell time of 10 seconds in between using the Mechatronik® SD thermal cycler (Figure 9). The samples undergo artificial ageing by Thermo-cycling according to the following table.
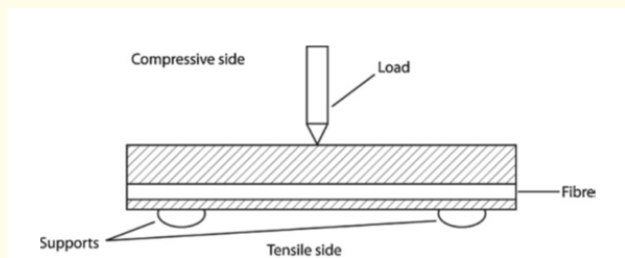
Flexural strength test

Excess materials are eliminated by scraping on sandpaper (grit 2400). The dimensions of the bars are examined by magnifying glass and a precision gauge. The "YLE Universal Testing Machine" (Figure 10 and 11) employed for the testing procedure. The speed of the crosshead is set to 1 mm/min.

	0 cycles	2500 cycles	5000 cycles	7500 cycles	10,000 cycles
Tempsmart	A1	A2	A3	A4	A5
Cooltemp	B1	B2	B3	B4	B5
Unifast III	C1	C2	C3	C4	C5
Revoteck LC	D1	D2	D3	D4	D5

Table 1: The materials divided by testing groups.

Figure 9: The different groups undergoing the aging process in the thermocycler.

Figure 10: Schematic representation of the testing apparatus.

Figure 11: YLE universal testing machine, flexural test mode.

Treatment of the results

The flexural strength is calculated in MPa as part of the following equations: $\sigma = \frac{3Fl}{2bh^2}$

Where: σ is the flexural strength in MPa

F is the maximum load in Newton.

l is the length, in millimeters.

b is the width in millimeters.

h is the height in millimeters.

Hypothesis

The flexural strength of the different materials remains acceptable throughout the period of the study (80 MPa according to ISO 4049;2009).

Statistical analysis

The statistical analyses were performed using IBM SPSS Statistics (version 25.0). The level of significance was set at -p-value ≤ 0.05. The primary outcome variable of this study was the flexural strength in MPa.

Kolmogorov-Smirnov tests and Shapiro-Wilk were used to assess the normal distribution of quantitative variables.

Two-way analysis of variance with two factors (First factor: four provisional materials; second factor: five cycles) was executed to compare the mean flexural strength among groups. Due to statistical interaction, this test was followed by univariate analyses and Bonferroni multiple comparisons tests.

Results
Normality distribution of primary outcome variable

The normality distribution of the flexural strength in each group and subgroup is displayed in the following table. The results have shown that the flexural strength is normally distributed for the majority of groups. Parametric tests were therefore used for the statistical comparisons.

Comparison of the mean flexural strength among groups

The mean, standard-deviation, minimum and maximum values of the flexural strength in different groups are presented in the following table.

Comparison between cycles

Our findings revealed that:

- The mean flexural strength of Temp Smart was not signifi-

Groups	Cycles	Kolmogorov-Smirnov			Shapiro-Wilk		
		Statistic	df	p-value	Statistic	df	p-value
Temp Smart	Baseline	0.213	10	0.200	0.948	10	0.670
	2500 cycles	0.224	10	0.170	0.894	10	0.189
	5000 cycles	0.119	10	0.200	0.959	10	0.769
	7500 cycles	0.174	10	0.200	0.918	10	0.341
	10000 cycles	0.197	10	0.200	0.885	10	0.148
Cool Temp	Baseline	0.186	10	0.200	0.920	10	0.360
	2500 cycles	0.240	10	0.106	0.897	10	0.202
	5000 cycles	0.238	10	0.115	0.915	10	0.338
	7500 cycles	0.169	10	0.200	0.899	10	0.215
	10000 cycles	0.218	10	0.195	0.945	10	0.612
Unifast III	Baseline	0.111	10	0.200	0.950	10	0.672
	2500 cycles	0.220	10	0.185	0.892	10	0.177
	5000 cycles	0.176	10	0.200	0.929	10	0.433
	7500 cycles	0.256	10	0.062	0.916	10	0.327
	10000 cycles	0.260	10	0.053	0.850	10	0.059
Revoteck LC	Baseline	0.323	10	0.004	0.781	10	0.008
	2500 cycles	0.162	10	0.200	0.955	10	0.732
	5000 cycles	0.152	10	0.200	0.936	10	0.508
	7500 cycles	0.202	10	0.200	0.878	10	0.124
	10000 cycles	0.144	10	0.200	0.959	10	0.778

Table 2: Normality distribution of the flexural strength.

df: Degree of Freedom.

	N	Minimum	Maximum	Mean	Std. Deviation	p-value
Temp Smart						
Baseline	10	103.1	182.8	126.094	23.432	0.637
2500 cycles	10	95.5	147.9	119.894	20.260	
5000 cycles	10	89.1	145.8	116.618	19.541	
7500 cycles	10	82.3	151.4	113.580	25.513	
10000 cycles	10	64.8	149.8	109.734	32.363	
Cool Temp						
Baseline	10	98.4	135.9	116.250	13.035	0.617
2500 cycles	10	59.9	140.9	109.880	27.471	
5000 cycles	10	70.3	117.2	106.406	14.831	
7500 cycles	10	74.0	162.0	103.893	25.786	

10000 cycles	10	48.6	145.8	101.231	26.927	
Unifast III						
Baseline	10	70.3	164.1	118.125	32.760	0.223
2500 cycles	10	68.8	170.1	106.090	29.062	
5000 cycles	10	56.7	129.6	98.611	24.830	
7500 cycles	10	45.8	137.3	95.088	26.302	
10000 cycles	10	64.8	129.6	91.108	24.464	
Revoteck LC						
Baseline	10	37.5	84.4	69.375[c]	16.358	0.000
2500 cycles	10	32.8	79.7	52.500[b]	13.221	
5000 cycles	10	35.2	63.4	46.840[a,b]	8.793	
7500 cycles	10	35.2	45.8	41.205[a,b]	4.084	
10000 cycles	10	12.1	52.6	36.443[a]	12.371	

Table 3: Mean flexural strength in different groups.

[a,b,c]: Different letters indicate the presence of a significant difference according to multiple comparisons tests.
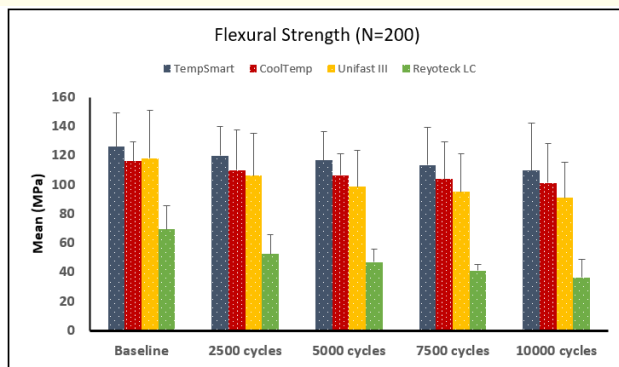
Figure 12: Mean flexural strength among groups.

cantly different among cycles (-p-value = 0.637).

- The mean flexural strength of Cool Temp was not significantly different among cycles (-p-value = 0.617).

- The mean flexural strength of Unifast III has decreased among cycles but the decline was not statistically significant (-p-value = 0.223).

- However, the mean flexural strength of Revoteck LC was significantly different among cycles (-p-value < 0.001); it de-creased significantly between Baseline and 2500 cycles (-p-value = 0.020). It also decreased significantly and gradually between 2500 cycles and 10000 cycles (-p-value = 0.029). Baseline > 2500 cycles > 5000 cycles = 7500 cycles > 10000 cycles.

Comparison between provisional materials

Our study showed:

- At baseline, the mean flexural strength was significantly different among materials groups (-p-value < 0.001); it was significantly smaller with Revoteck LC (-p-value < 0.001) and the difference was not significant between Temp Smart, Cool Smart and Unifast III (-p-value = 1.000).

- After 2500 cycles, the mean flexural strength was significantly different among materials groups (-p-value < 0.001); it was significantly smaller with Revoteck LC (-p-value < 0.001) however, we did not find a significant difference between Temp Smart, Cool Smart and Unifast III (-p-value = 1.000).

- After 5000 cycles, the mean flexural strength was significantly different among materials groups (-p-value < 0.001); it was significantly smaller with Revoteck LC (-p-value < 0.001) but the difference was not significant between Temp

Group	(I) Cycles	(J) Cycles	Mean Difference (I-J)	p-value	95% Confidence Interval for Difference	
					Lower Bound	Upper Bound
Revoteck LC	Baseline	2500 cycles	16.875	.020	1.954	31.796
		5000 cycles	22.535	.001	7.614	37.457
		7500 cycles	28.170	.000	13.249	43.091
		10000 cycles	32.932	.000	18.011	47.853
	2500 cycles	Baseline	-16.875	.020	-31.796	-1.954
		5000 cycles	5.660	.817	-9.261	20.582
		7500 cycles	11.295	.217	-3.626	26.216
		10000 cycles	16.057	.029	1.136	30.978
	5000 cycles	Baseline	-22.535	.001	-37.457	-7.614
		2500 cycles	-5.660	.817	-20.582	9.261
		7500 cycles	5.635	.819	-9.286	20.556
		10000 cycles	10.397	.292	-4.525	25.318
	7500 cycles	Baseline	-28.170	.000	-43.091	-13.249
		2500 cycles	-11.295	.217	-26.216	3.626
		5000 cycles	-5.635	.819	-20.556	9.286
		10000 cycles	4.762	.893	-10.160	19.683
	10000 cycles	Baseline	-32.932	.000	-47.853	-18.011
		2500 cycles	-16.057	.029	-30.978	-1.136
		5000 cycles	-10.397	.292	-25.318	4.525
		7500 cycles	-4.762	.893	-19.683	10.160

Table 4: Multiple comparisons tests of the flexural strength between cycles in Revoteck LC group.

Groups		Sum of Squares	Df	Mean Square	F	-p-value
Temp Smart	Contrast	1555.319	4	388.830	0.640	0.637
	Error	27357.071	45	607.935		
Cool Temp	Contrast	1357.301	4	339.325	0.669	0.617
	Error	22811.096	45	506.913		
Unifast III	Contrast	4544.469	4	1136.117	1.485	0.223
	Error	34421.533	45	764.923		
Revoteck LC	Contrast	6501.235	4	1625.309	11.788	0.000
	Error	6204.621	45	137.880		

The F tests the effect of Cycles. This test is based on the linearly independent pairwise comparisons among the estimated marginal means.

Table 5: Univariate analyses of the comparison between cycles in each group.

Smart, Cool Smart and Unifast III (-p-value > 0.05).

- After 7500 cycles, the mean flexural strength was significantly different among materials groups (-p-value < 0.001); it was significantly smaller with Revoteck LC (-p-value < 0.001) and the difference was not significant between Temp Smart, Cool Smart and Unifast III (-p-value > 0.05).

- After 10000 cycles, the mean flexural strength was significantly different among materials groups (-p-value < 0.001); it was significantly less important with Revoteck LC (-p-value < 0.001) and the difference was not significant between Temp Smart, Cool Smart and Unifast III (-p-value > 0.05).

Discussion

The crucial role of the physical properties of dental materials in achieving the overall goal of temporary restorations was long stated by Donovan., *et al*.

Cycles		Sum of Squares	Df	Mean Square	F	-p-value
Base-line	Contrast	19886.902	3	6628.967	12.873	.000
	Error	18538.330	36	514.954		
2500 cycles	Contrast	27528.691	3	9176.230	16.802	.000
	Error	19660.772	36	546.133		
5000 cycles	Contrast	28966.874	3	9655.625	29.810	.000
	Error	11660.731	36	323.909		
7500 cycles	Contrast	31461.718	3	10487.239	20.722	.000
	Error	18219.007	36	506.084		
10000 cycles	Contrast	32697.570	3	10899.190	17.273	.000
	Error	22715.482	36	630.986		

Table 6: Univariate analyses of the comparison of the flexural strength between materials for each cycle.

The flexural strength test remains one of the most preferred testing methods, as it proves advantageous by measuring a wide range of mechanical stresses including tensile and compressive stresses. Contrary to fracture toughness, flexural strength has a strong correlation to the clinical aspect of material wear and is a reliable indicator of it.

The ISO 4049:2009, according to which this study was conducted, provides the extensive and necessary guidelines to allow this type of testing to be conducted in a simple and reproducible manner.

The characteristics of the material

Bis-acrylic temporary restorative materials have been able to surpass the mechanical capacities of the conventional polymer-based temporary materials. The filler content influences the mechanical performance, specifically the flexural strength and the properties related to it. According to Wool., *et al.* simply adding

Cycles	(I) Groups	(J) Groups	Mean Difference	-p-value	95% Confidence Interval for Difference	
					Lower Bound	Upper Bound
Baseline	Temp Smart	Cool Temp	9.844	1.000	-18.490	38.178
		Unifast III	7.969	1.000	-20.365	36.303
		Revoteck LC	56.719	.000	28.385	85.053
	Cool Temp	Temp Smart	-9.844	1.000	-38.178	18.490
		Unifast III	-1.875	1.000	-30.209	26.459
		Revoteck LC	46.875	.000	18.541	75.209
	Unifast III	Temp Smart	-7.969	1.000	-36.303	20.365
		Cool Temp	1.875	1.000	-26.459	30.209
		Revoteck LC	48.750	.000	20.416	77.084
2500 cycles	Temp Smart	Cool Temp	10.014	1.000	-19.165	39.194
		Unifast III	13.804	1.000	-15.375	42.983
		Revoteck LC	67.394	.000	38.215	96.573
	Cool Temp	Temp Smart	-10.014	1.000	-39.194	19.165
		Unifast III	3.790	1.000	-25.390	32.969
		Revoteck LC	57.380	.000	28.200	86.559
	Unifast III	Temp Smart	-13.804	1.000	-42.983	15.375
		Cool Temp	-3.790	1.000	-32.969	25.390
		Revoteck LC	53.590	.000	24.411	82.769

5000 cycles	Temp Smart	Cool Temp	10.212	1.000	-12.260	32.684
		Unifast III	18.007	.189	-4.465	40.479
		Revoteck LC	69.778	.000	47.307	92.250
	Cool Temp	Temp Smart	-10.212	1.000	-32.684	12.260
		Unifast III	7.795	1.000	-14.677	30.267
		Revoteck LC	59.566	.000	37.095	82.038
	Unifast III	Temp Smart	-18.007	.189	-40.479	4.465
		Cool Temp	-7.795	1.000	-30.267	14.677
		Revoteck LC	51.771	.000	29.300	74.243
7500 cycles	Temp Smart	Cool Temp	9.687	1.000	-18.402	37.777
		Unifast III	18.492	.446	-9.597	46.581
		Revoteck LC	72.375	.000	44.286	100.464
	Cool Temp	Temp Smart	-9.687	1.000	-37.777	18.402
		Unifast III	8.804	1.000	-19.285	36.894
		Revoteck LC	62.688	.000	34.599	90.777
	Unifast III	Temp Smart	-18.492	.446	-46.581	9.597
		Cool Temp	-8.804	1.000	-36.894	19.285
		Revoteck LC	53.883	.000	25.794	81.972
10000 cycles	Temp Smart	Cool Temp	8.503	1.000	-22.861	39.868
		Unifast III	18.626	.636	-12.738	49.991
		Revoteck LC	73.291	.000	41.927	104.656
	Cool Temp	Temp Smart	-8.503	1.000	-39.868	22.861
		Unifast III	10.123	1.000	-21.241	41.487
		Revoteck LC	64.788	.000	33.424	96.152
	Unifast III	Temp Smart	-18.626	.636	-49.991	12.738
		Cool Temp	-10.123	1.000	-41.487	21.241
		Revoteck LC	54.665	.000	23.300	86.029

Table 7: Multiple comparisons tests of the flexural strength between materials for each cycle.

fillers to a polymer matrix system will improve significantly the mechanical performance of a material.

According to Kundie., *et al.* nanofillers (10 - 40 μm) improve the flexural strength of a polymer-based material when compared to microfillers (20 - 50 nm). The increase of flexural strength can be directly attributed to the following reasons:

1. The nanoparticles help grab monomer and polymer segments.

2. The fillers-matrix chemical bond is strong. The silane coupling agent, present at the surface of the filler, is the key element for the formation of this bond.

3. The small particle size of the fillers (10 - 40 μm) is responsible for the optimal and homogeneous stress transfer from the soft resin to the nanofillers, through enhanced interfacial adhesion between matrix and nanofiller and the fact that the stress will be shared by a larger number of particles.

4. The increased rigidity and the decreased ductility.

5. The prevention of crack propagation through uniform dispersion.

The main component

Bis-acryl is a term that can generally mean all the dual-polymerizable temporary crown material. At the molecular level, this term indicates that the chemical composition of the main component is either Bis-GMA or UDMA. In both cases, the component, alone, offers superior mechanical properties than conventional polymethyl methacrylate-based compositions. This is largely due to the higher attainable length of the polymer after polymerization [6].

While Bis-GMA-based temporary materials have emerged first and still occupy an important percentage of the commercially available products, UDMA-based materials, since their inception, have had better results especially while under mechanical testing [7].

In order to simulate the tough conditions a material will have to withstand in the oral cavity, and study more vigorously its properties, several procedures were conducted, putting those materials to the test.

The first element of the process is the aging of the material.

Aging process

The aging process constitutes a significant part of the study design, as it is meant to simulate the desired intra oral aging process for the predetermined testing period. The most prominent aging techniques are aging by storage and aging by thermocycling (Table of references).

Aging by storage consists of storing the specimens in a fluid (usually distilled water, or artificial saliva) for a predetermined period at 37°C. The stress is generated when water penetrates the polymer matrix and cause its degradation through the process of hydrolysis [8]. This procedure is time consuming, as it is supposed to match the time window determined in the study design. For example, if the aim of the study is to evaluate the flexural strength of a certain material after 12 months of usage, the specimen would have to be stored in the water or artificial saliva for the same period of 12 months.

Aging by thermocycling, The ISO TR 11450, consists of a determined number of cycles during which the specimens are placed in a high temperature (55°C) container then a low temperature container (5°C) for a predetermined number of cycles. This technique presents many advantages over the simple storage technique. First,

it is far less time consuming as 10 000 cycles, which amounts to about a year *in vivo*, take approximately 2 weeks to complete. Second, two types of stress are generated: 1) stress by water sorption, and unlike in the case of water storage, the hydrolysis occurs faster and more intensely in the high temperature container, 2) the thermal stress caused by the alternation between the high temperature and the low temperature containers is mirrored by cycles of contraction/expansion stresses in the material at the internal level [9]. Thus, the process of aging by thermocycling offers an alternative to aging by storage that is more potent, quicker and with a higher degree of resemblance to reality.

Aging by occlusal loading (mechanical loading by a chewing simulator), while closely mirroring the chewing forces, only find their usefulness when studying dynamic phenomena in a controlled environment, for example the phenomenon of crack initiation and propagation [10].

Polymerization procedure

Another factor influencing the mechanical performance, the polymerization method.

Bis-acryl is the only class of material that possesses the dual-curing feature when compared to the conventional acrylic resin is auto-curing, and the resin composite is light-curing. In the most recent experimental study on the subject, the author Akiba, concluded that the specimens have significantly superior flexural strength when a dual-cure approach is applied (chemical curing coupled with light curing) when compared with the self-curing specimens [11].

This is further explained by the evaluation of the degree of conversion, while under the dual curing mode, the resin-based materials have a significantly higher degree of conversion. The higher degree of conversion leads to better structural state of the polymer matrix which evidently results in better physical and mechanical characteristics and a better mechanical performance of the materials.

Results analysis

In this study, the bis-acrylic products and the conventional PMMA, Tempsmart®, Cooltemp® and Unifast III®, have performed in a similar way with no significant difference between the results at the baseline or after the aging process. However, the compos-

ite resin, Revoteck LC®, have shown lower flexural strength values at the baseline, with significant decrease over the many periods of the cycles. The null hypothesis that the flexural strength of the materials will remain acceptable after thermocycling is accepted for the bis-acrylic materials (Tempsmart® and Cooltemp®) and the conventional PMMA (Unifast III®) and rejected for the composite material (Revoteck® LC).

Reliability and reproducibility of the study

Other studies evaluating and implementing similar experimental procedures and conditions have yielded similar results. Thus, providing further evidence surrounding the reproducibility and credibility of the previously established methods.

The mechanical performance of composite-based temporary crown material, Revoteck® LC, was the subject of several studies. The results found in these studies, at the baseline, (58 and 70.37 MPA) [12,13] and after 2500 cycles of thermocycling (60 MPA) [14] are consistent with the values obtained in the present study.

One study conducted the flexural strength test 24 hours after the fabrication process, the mean flexural strength in this case was about 118.1 MPA [15], a slightly lower value than the 126.09 MPA obtained at the baseline. The second study included a more intensive aging process, measuring the flexural strength 24 hours after fabrication, after 5000 and 10 000 cycles in the thermocycler, generating respectively the following values: 116.7 MPa, 107.7 MPa and 108.2 MPa [11] which are close values to the ones obtained in the study: 126.09 MPa, 116.6 MPa, and 109.73 MPa.

The second bis-acrylic material, CoolTemp®, has not been the subject of any recent studies surrounding the flexural strength, therefore this study proves to be useful for future comparative studies.

The PMMA product, Unifast III®, in this study, has a mean flexural strength of 106.09 MPa at 2500 cycles, significantly different to the results of other studies, coming at 68 MPa [16] and 70 MPa [15] at 2500 cycles. This could be explained by a slight difference in the manipulation of the material during the fabrication of the specimens. Here, the glass plates were compressed by hand for the entire duration of the setting period unlike the other studies where they were held together with a clamp. This difference in pressure during the setting period might have had an influence on the struc-

tural integrity of the resin and thus have influenced the outcome of the flexural strength test.

Management of deficiencies

While the mechanical performance of the materials used in provisional restorations have improved, deficiencies still do occur and often require the practitioner's intervention either through repairing or the making of a new restoration altogether [4].

When using conventional acrylic resin, the procedures of repairing and rebasing can be done through the addition of a small quantity of acrylic resin or a selective addition of flowable composite [17].

The situation differs when it comes to the bis-acrylic resin material. While at first it was thought that repairing a bis-acrylic restoration would result in a less than desirable mechanical performance [18]. However, later studies proved that repairing the fractured bis-acrylic provisional with a flowable composite delivered higher mechanical strength to the point that, while under load, the fracture would most probably occur in the body of the bis-acrylic resin and not in the repaired area [19]. This is where Tempsmart®'s composition proves to be remarkably advantageous. This material can be repaired and rebased with the same material, a compatible flowable composite and a conventional polymethyl methacrylate resin.

Strong points of the study

The design of this study contains several strong points. First, the experimental procedure was largely executed by following closely the standards set by the ISO.

The sample size is significantly large, especially when compared to similar studies.

The aging process is longer than those of all the previous studies. The testing was done after several aging periods. The testing was more frequently than any study on the subject.

The results are in accordance with the findings of similar studies.

Shortcomings of the study

While the study is focused on materials used in direct technique, it might have been useful to add a heat-cured resin as this

material has always been one of the first choice materials in long term provisional restoration [1].

The flexural modulus is a second property that could have been explored to add a different level of understanding of the mechanical properties of the tested materials, however, the specific testing machine does not have the proper operating system capable of generating the stress-strain curve. The curve is crucial as its slope is used to calculate the flexural modulus [20].

Conclusion

Within the limitations of this *in vitro* study, the bis-acrylic resin materials have displayed the best flexural strength values among the tested materials. The bis-acrylic and polymethylmethacrylate resin materials were adequate all throughout the testing periods while the composite material presented flexural strength values that were insufficient for it to fulfill its purpose as temporary crown material.

The filler content and the long chain formation has given Tempsmart® an advantage from a mechanical point of view over all the other products. And its compatibility with different materials when it comes to repair and modification makes Tempsmart® the most suitable product for clinical applications.

Future studies may complete this experimental study with a broader and larger material to compare and may also test the strength of Tempsmart® when repaired with the wide array of materials it is compatible with.

Bibliography

1. Burns DR., *et al*. "A review of selected dental literature on contemporary provisional fixed prosthodontic treatment: report of the Committee on Research in Fixed Prosthodontics of the Academy of Fixed Prosthodontics". *Journal of Prosthetic Dentistry* 90.5 (2003): 474-497.

2. Luthardt RG., *et al*. "Clinical performance and periodontal outcome of temporary crowns and fixed partial dentures: A randomized clinical trial". *Journal of Prosthetic Dentistry* 83.1 (2000): 32-39.

3. Donaldson KJ. "Fundamentals of fixed prosthodontics, fourth edition". *The British Dental Journal* 213.8 (2012): 427-427.

4. Patras M., *et al*. "Management of provisional restorations' deficiencies: a literature review". *Journal of Esthetic and Restorative Dentistry* 24.1 (2012): 26-38.

5. Lang R., *et al*. "Fracture resistance of PMMA and resin matrix composite-based interim FPD materials". *The International Journal of Prosthodontics* 16.4 (2003): 381-384.

6. Ogliari FA., *et al*. "Influence of chain extender length of aromatic dimethacrylates on polymer network development". *Dental Materials* 24.2 (2008): 165-171.

7. Kerby RE., *et al*. "Mechanical properties of urethane and bis-acryl interim resin materials". *Journal of Prosthetic Dentistry* 110.1 (2013): 21-28.

8. Guo J-H., *et al*. "Influence of Physical Aging on Mechanical Properties of Polymer Free Films: The Prediction of Long-Term Aging Effects on the Water Permeability and Dissolution Rate of Polymer Film-Coated Tablets". *Pharmaceutical Research* 8.12 (1991): 1500-1504.

9. Gale MS and Darvell BW. "Thermal cycling procedures for laboratory testing of dental restorations". *Journal of Dentistry* 27.2 (1999): 89-99.

10. De Munck J., *et al*. "A critical review of the durability of adhesion to tooth tissue: methods and results". *Journal of Dental Research* 84.2 (2005): 118-132.

11. Akiba S., *et al*. "Influence of different curing modes on flexural properties, fracture toughness, and wear behavior of dual-cure provisional resin-based composites". *Dental Materials Journal* 38.5 (2019): 728-737.

12. Jo LJ., *et al*. "Flexural strength and hardness of resins for interim fixed partial dentures". *Indian Journal of Dental Research Off Publ Indian Journal of Dental Research* 22.1 (2011): 71-76.

13. Poonacha V., *et al*. "In vitro comparison of flexural strength and elastic modulus of three provisional crown materials used in fixed prosthodontics". *Journal of Clinical and Experimental Dentistry* 5.5 (2013): e212-217.

14. Mehrpour H., *et al*. "Evaluation of the Flexural Strength of Interim Restorative Materials in Fixed Prosthodontics". *Journal of Dentistry* 17.3 (2016): 201-206.

15. Shibasaki S., *et al*. "Influence of Different Curing Modes on Polymerization Behavior and Mechanical Properties of Dual-Cured Provisional Resins". *Operative Dentistry* 42.5 (2017): 526-536.

16. Takamizawa T., *et al*. "Mechanical Properties and Simulated Wear of Provisional Resin Materials". *Operative Dentistry* 40.6 (2015): 603-613.

17. Wassell RW., *et al*. "Crowns and other extra-coronal restorations: provisional restorations". *The British Dental Journal* 192.11 (2002): 619-622.

18. Koumjian JH and Nimmo A. "Evaluation of fracture resistance of resins used for provisional restorations". *Journal of Prosthetic Dentistry* 64.6 (1990): 654-657.

19. Hagge MS., *et al*. "Shear bond strength of bis-acryl composite provisional material repaired with flowable composite". *Journal of Esthetic and Restorative Dentistry American Academy of Cosmetic Dentistry* 14.1 (2002): 47-52.

20. Zweben C., *et al*. "Test Methods for Fiber Tensile Strength, Composite Flexural Modulus, and Properties of Fabric-Reinforced Laminates". In: Tsai S, editor. Composite Materials: Testing and Design (Fifth Conference). West Conshohocken, PA: ASTM International (1979): 228-262.

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