

Correlation between surface roughness and fracture toughness of dental porcelain treated with different polishing materials and glazing techniques⁺

العلاقة بين الخشونة السطحية والصلادة الكسرية لخزف الاسنان المعالج بمختلف مواد وطرق التلميع والصقل

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Abstract :

The purpose of this study was to measure the correlation between surface roughness and fracture toughness of porcelain restorations, after treated with different polishing materials and glazing techniques. Seventy metal-ceramic specimens were fabricated and divided into seven groups according to the type of surface treatment of porcelain.

The surface roughness averages "Ra" of the specimens have been determined using the Profilometer device. The fracture toughness (K_{Ic}) of each specimen was measured using a Macro- Hardness Vickers Tester device supplied with a 9.8 N load indenter applied for (15 sec.) followed by measuring half diagonal of the fracture porcelain area and cracks length.

Statistical analysis indicated high significant differences among the test groups. The study concluded that, Polishing and glazing of porcelain is necessary for porcelain restorations, and the surface roughness correlated the strength of porcelain materials. Polished porcelain with (rubber wheel and polishing paste) can be considered a good alternative to applied glaze of porcelain restorations which is characterized by time consuming and sensitive technique.

Moreover, autoglazing porcelain followed by polishing or without polishing, proved to be disadvantageous since it increased surface roughness and lowered the fracture toughness of porcelain. Polishing +applied glaze can be used to get best surface smoothness and the best fracture toughness.

الخلاصة

أن الهدف من هذه الدراسة هو قياس العلاقة بين معدل الخشونة والصلادة الكسرية لتعويضات خزف الاسنان. حيث تم تحضير سبعون عينة مربعة من المعدن المغطاة بمادة الخزف السنية، وزعت العينات الى سبع مجاميع حسب نوع التلميع و الصقل لأسطح الخزف. عينت معدلات الخشونة لسطح العينات بواسطة مقياس الخشونة (البروفيلوميتر)، بعد ذلك تم فحص الصلادة الكسرية لكل عينة بواسطة مقياس الصلادة الكسرية الدقيق (فكرز) بتسليط ٩،٨ نيوتن لمدة ١٥ ثانية بواسطة المخرز ثم تم قياس نصف قطر الجزء المعيني المكسور من الخزف و قياس أطوال التشوهات الممتدة منه.

أظهر التحليل الأحصائي للنتائج أن التنعيم و الصقل لمادة السيراميك المستعملة في صناعة الأسنان هو ضروري جداً حيث انه يرفع من كفاءة هذه المادة و يطيل من فترة بقائها و أن هناك علاقة ما بين الخشونة السطحية لمادة

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الخشونة والصلادة الكسرية لها . أن الأستنتاجات المستنبطة من هذه الدراسة تبين أن تلميع الخزف بمسحوق الصقل الرملي ثم التلميع بالقرص المطاطي يليه أستعمال معجون التلميع بديل جيد للصقل الحراري المضاف ، و من جهة أخرى نجد أن صقل الخزف بالتزجيج الحراري الطبيعي (سواء أجراء بعد التلميع أو بدون تلميع) غير مفيد لأنه يزيد من خشونة السطح و يقتل من الصلادة الكسرية للخزف.

Introduction :

Dental porcelains have been modified to a state of near perfection but still they exhibit certain disadvantages. The most serious is their tendency to abrade all structure against which it occludes including natural teeth and various types of non-porcelain restorative systems [1].

This could be a direct result of creating rough porcelain surfaces especially following final cementation due to occlusal adjustments intraorally. Reports indicated that the retention of the glazed surface could be unguaranteed and could be removed under masticatory function in a short period of time [2,3,4]. Polishing unglazed porcelain surface have long evoked as an alternative to glazing [5]. Despite the aesthetic advantages of polished porcelain, there is concern as to whether the strength of a polished restoration might be reduced or its abrasiveness increased. Glazing has been cited as strengthening a dental porcelain restoration presumably because it causes a reduction of the flaws that initiate porcelain fracture and polishing also was described to reduce flaws [6].

Materials and Methods:

Seventy square piece of modeling base plate wax {1cm in length, 1cm in width and 1.5mm thickness} [2, 7] were cut using wax cutter then the wax sprued, invested and casting with Ni-Cr alloy (Super bond, American Dent-All, USA), the metal pieces were devested then the sprues were sectioned after that the metal pieces were finishing with stone bur, in order to standardize the flat metal surface, each sample was sand papered (220 grit) manually (1 cycle/sec.), fig (1) to receive porcelain material so that, thickness of metal pieces was 1.5 mm. measured by metal caliper device (Germany) . All samples were oxidized according to manufacturer's instructions, and the oxide layer on each metal sample was formed by heating it inside a computerized ceramic furnace at (960°C) for (6 min.) without vacuum. To control the thickness of the oxide layer, a sandblasting machine was used with sandblast powder of (50µm) aluminum oxide [8], the opaque and body porcelain (Vita 68, Germany) was fired according to manufacturer's instructions under vacuum. The excess thickness of porcelain was removed using a 50µm diamond disc, using one disc for each sample mounted on the straight hand piece at a speed of (30.000 rpm), while each sample was held by the artery forceps on the surveyor stage [9]. A drop of water was added by plastic syringe to the cutting area to decrease the frictional heat which generated during cutting procedure [5, 9,10,11,12].



Fig.1: The shape of the sample

The seventy samples were randomly divided into 7 groups according to the type of polishing and glazing techniques used. Numbering samples bases were done, then, surface roughness was measured for each sample before treatments by using a surface roughness measuring device (profilometer machine) [13], each 10 samples represented group, *Group I*: Unglazed porcelain (control group). *Group II*: Samples were sandblasted with (50 μ m aluminum oxide) at (3 bars) pressure for (30 sec.), after that the samples were cleaned ultrasonically in a bath of distilled water. Autoglazing was done by a computerized ceramic furnace according to manufacturer instructions at (940°C) for (1min.) without vacuum.

Group III: Samples were sandblasted with (50 μ m aluminum oxide) at (3 bars) pressure for (30 sec.) , and then applied the glaze solution on the porcelain using a dental porcelain bristle brush and fired according to manufacturer's instructions to (930°C) with holding time of (1 min.) without vacuum, *Group IV*: Samples were sandblasted using (50 μ m aluminum oxide) and then cleaned ultrasonically with distilled water after that all the samples treated with porcelain rubber wheel mounted on a straight hand piece at (30,000rpm) speed for (10 sec.) using one disc for each sample, while each sample hold by the artery forceps on the surveyor stage , *Group V*: The samples treated as same as group IV and then polished with porcelain polishing paste incorporating with polishing bristle brush and cloth brush mounted on a straight hand piece at (30,000rpm) speed for (10 sec.), while each sample held by artery forceps on the surveyor stage. *Group VI*: The samples were treated as same as group V and then autoglazing was done by a computerized ceramic furnace at (940°C) for (1min.) without vacuum. *Group VII*: The samples treated as same as group V and then the glazing technique was performed by applying the glaze solution on the porcelain and fired to (930°C) with holding time of (1 min.) without vacuum. After complete all these procedures, the handles were cut with carbundum disc mounted on a straight hand piece (35000 rpm) with water cooling and then, porcelain samples were placed in an oven at (600°C) for (30 min.) to relieve residual stresses that may have developed because of handle cutting procedures[9]. All samples were stored separately in air at room temperature until the final test was done.

Surface Roughness Test:

The surface roughness was expressed as a roughness average (Ra); this is calculated by first setting up a center line so the sum of the surface profile areas above the line is equal to those below, The (Ra) values for all specimens have been recorded using profilometer (Talysurf 4, Taylor-Hobson, England). For each specimen four readings were recorded and the mean was calculated.

Fracture Toughness Test:

This test will be performed using a Macro-Hardness Vickers tester device (Germany); the samples must be placed on a block of resin (polymathyle-methacrylate or epoxy) which was provided a support for the samples during test [14,15]. The Vickers indenter was then lowered, at a low speed, till it touched the porcelain surface that will be covered with a drop of oil prior to indentation to see the crack clearly.

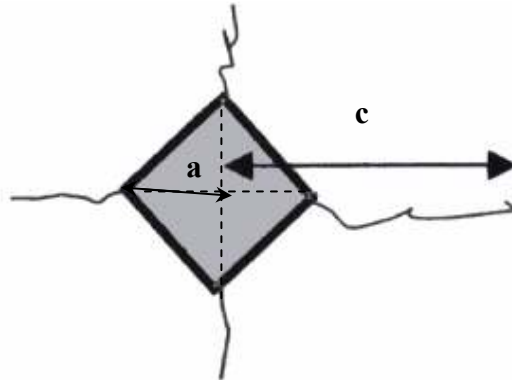
The fracture toughness was determined by indentation technique. One indentation was made on each sample with a load of (9.8 N) for (15 sec.) [14,15,16]. The load was automatically relived, the indented porcelain surface was viewed using the device eyepiece (400X magnification) supplied with a light source emitting from it, crack length measurements were made within (1 min.) to limit slow crack growth [15,16]. The fracture toughness calculated according to the following formula [17]:

$$K_{Ic} = 0.016 (E/H)^{1/2} (P/c^{3/2})$$

, where;

K_{Ic} = Fracture toughness in ($MN/m^{-3/2}$). C = Crack length (measured from the center of the indentation) in (μm). E = Elastic modulus (57.3 Gpa). H = Vickers hardness = $\{(0.47 p/a^2)$ in ($N/\mu m$). p = Indenter load (9.8 N). a = Half diagonal of the indentation} (measured from its center to the end of its corner) in (μm).

The crack length and the half diagonal distance were measured from the center of the indentation (Fig.2) by the micrometer pointer of the eyepiece of the Macro-Hardness Vickers Tester. All cracks radiating from the corners of the indentation were measured 4 times for each porcelain specimen and their means were calculated. The elastic modulus (E) for VMK 86 Vita porcelain was derived from [14].



a =half diagonal of the indentation. c = crack length.

Figure (2) Vickers indenter impression in a porcelain surface. The cracks appeared to emanate from each of the corners of the indentation [18].

Results:

Surface Roughness

From table (1), group VII scored the lowest mean value followed by group III and group V, while group I (control group) scored the highest mean value. Statistical analysis of (R_a) mean values of different groups using (ANOVA) test revealed that there was highly statistical significant differences at level ($P < 0.01$) among group means.

Table (1) Descriptive statistics for surface roughness test.

Studied groups	N	Mean Ra	Stander Deviation	Stander Error	Minimum	Maximum	ANOVA (F-test)
Unglazed-I	10	2.576	0.595	0.1882	1.68	4.03	0.00 Highly Sig. ($P < 0.01$)
auto glaze-II	10	0.735	0.062	0.019	0.62	0.81	
adding glaze-III	10	0.247	0.037	0.011	0.19	0.31	
Rubber wheel-IV	10	0.452	0.045	0.014	0.37	0.52	
Polished-V	10	0.355	0.054	0.017	0.26	0.44	
Polishing + auto glaze-VI	10	0.453	0.050	0.015	0.37	0.53	
Polishing + adding glaze-VII	10	0.129	0.029	0.009	0.10	0.20	
Total	70						

Fracture Toughness:

In general, the highest mean of (K_{Ic}) value was recorded in group VII which represented the toughest group followed by group V and then group III. On the other hand, group IV exhibited fracture toughness mean value close to group III, V, while lowest mean value was represented by group I (control). Statistical analysis of the (K_{Ic}) mean values of the different groups using (ANOVA) test indicated high statistical differences at level ($P < 0.01$) among group means as shown in table (2).

Table (2) Descriptive statistics for fracture toughness test.

Studied groups	N	Mean Ra	Stander Deviation	Stander Error	Minimum	Maximum	ANOVA (F-test)
Unglazed-I	10	0.460	0.291	0.092	0.126	0.880	0.00 Highly Sig. (P<0.01)
auto glaze-II	10	0.804	0.116	0.036	0.625	0.979	
adding glaze-III	10	1.469	0.212	0.067	1.230	1.849	
Rubber wheel-IV	10	1.345	0.180	0.056	1.120	1.710	
Polished-V	10	1.489	0.442	0.139	0.937	2.221	
Polishing + auto glaze-VI	10	1.125	0.148	0.046	0.825	1.341	
Polishing + adding glaze-VII	10	1.543	0.257	0.081	1.234	1.995	
Total	70						

The data documented in table (3) and figure (3) prove that there are negative relationship (correlation) between unglazed group (surface roughness test and fracture toughness test) with Pearson correlation coefficient (r) = -0.548 and non significant differences between them with $P > 0.101$.

Table (3) Correlation of unglazed group (Control) of roughness & fracture toughness.

Groups I	Pearson Correlation (r)	P-value	Sig.
unglazed Roughness	-0.548	0.101	Non Sig. (P>0.05)
unglazed Fracture toughness			
N	10		

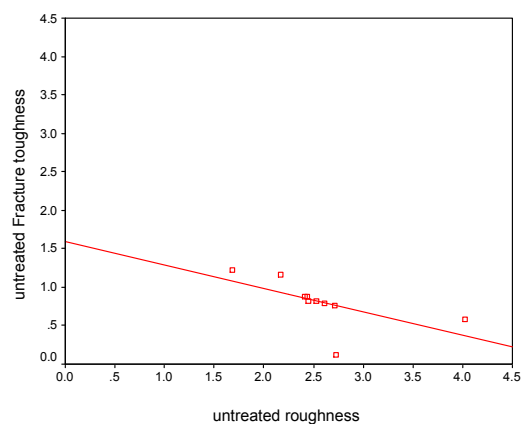


Figure (3) Correlation of unglazed group (Control) of roughness & fracture toughness.

Also, data present in the table (4) and

figure (4), shows that there are negative relationship (adverse relation) between autoglazed group (surface roughness and fracture toughness tests) with Pearson correlation coefficient (r) = -0.446 with non significant differences between them ($P > 0.197$).

Table (4) Correlation of autoglaze group of roughness & fracture toughness

Groups II	Pearson Correlation (r)	P-value	Sig.
autoglaze roughness	-0.446	0.197	Non Sig. ($P > 0.05$)
autoglaze fracture toughness			
N	10		

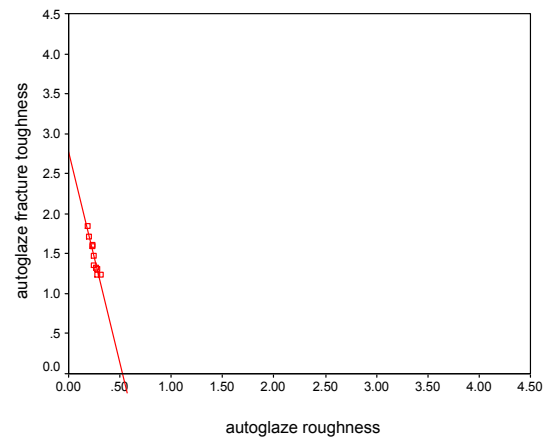


Figure (4) Correlation of auto glaze group of roughness & fracture toughness.

While table (5) and figure (5), table (6) and figure (6) show that there are strong negative relationship (correlation) between adding glaze groups, also between rubber wheel groups in (surface roughness and fracture toughness tests), the Pearson correlation coefficient (r) = -0.937, -0.965 respectively, and high significant differences between the tests $P > 0.00$.

Table (5) Correlation of adding glaze group of roughness & fracture toughness.

Groups III	Pearson Correlation (r)	P-value	Sig.
Adding glaze roughness	-0.937	0.00	Highly Sig. ($P < 0.01$)
Adding glaze fracture toughness			
N	10		

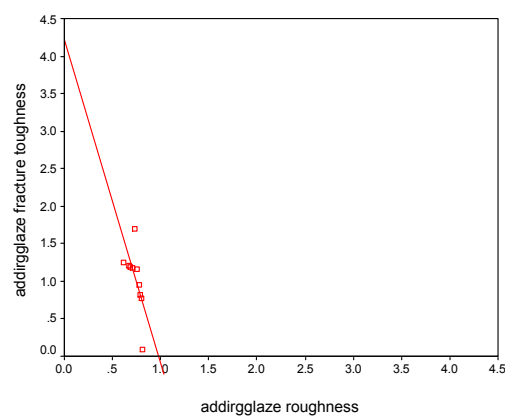


Figure (5) Correlation of adding glaze group of roughness & fracture toughness.

Table (6) Correlation of Rubber wheel group of roughness & fracture toughness.

Groups IV	Pearson Correlation (r)	P-value	Sig.
Rubber wheel roughness	-0.965	0.00	Highly Sig. (P<0.01)
Rubber wheel fracture toughness			
N	10		

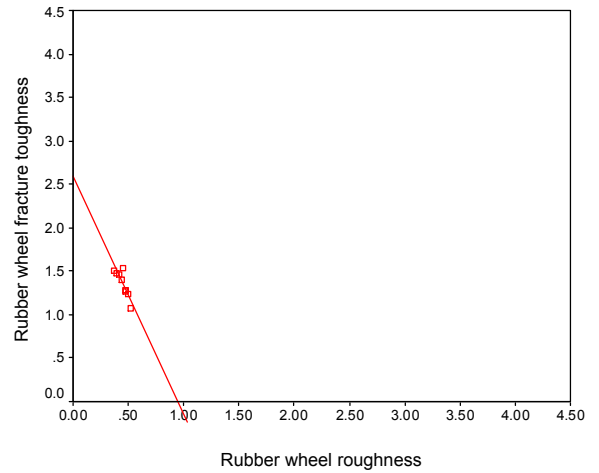


Figure (6) Correlation of Rubber wheel group of roughness & fracture toughness

In table (7) and figure (7), there are significant differences between polished group (between surface roughness and fracture toughness tests) with $P < 0.05$, and the Pearson correlation coefficient $(r) = -0.635$ that mean there are negative relationship (correlation) between two tests

Table (7) Correlation of polishing group of roughness & fracture toughness.

Groups V	Pearson Correlation (r)	P-value	Sig.
Polished roughness	-0.635	0.049	Sig. (P<0.05)
Polished fracture toughness			
N	10		

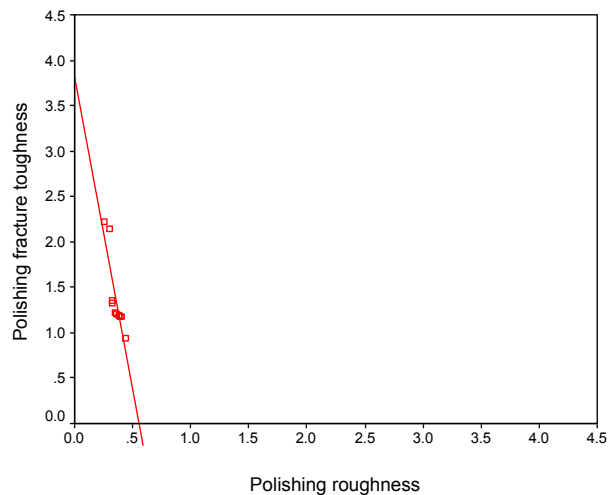
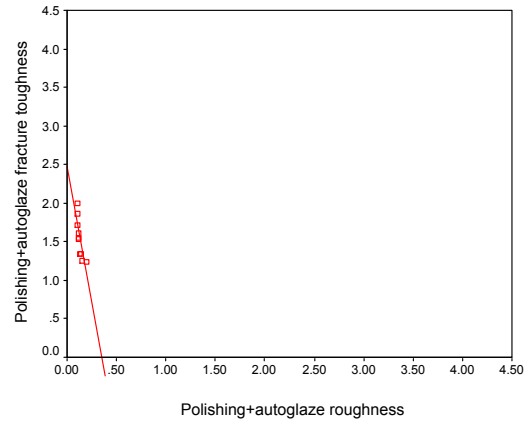


Figure (7) Correlation of polishing group of roughness & fracture toughness.

Again, in table (8) and figure (8), the correlation between surface roughness and fracture toughness tests for polished with autoglaized group show there are negative relationship (correlation) with Pearson correlation coefficient $(r) = -0.703$, also, there are significant differences between the tests $P < 0.05$.

Table (8) Correlation of Polishing+ auto glaze group of roughness & fracture toughness.

Groups VI	Pearson Correlation (r)	P- value	Sig.
Polishing+ auto glaze roughness	-0.703	0.023	Sig. (P<0.05)
Polishing+ auto glaze fracture toughness			
N	10		



. Figure (8) Correlation of Polishing+ auto glaze group of roughness & fracture toughness

Finally, table (9) and figure (9) indicate that there are strong negative relationship (correlation) between polished with adding glaze (in surface roughness and fracture toughness tests) with Pearson correlation coefficient (r) = -0.824, while P < 0.01 that mean there are highly significant differences between these tests.

Table (9) Correlation of Polishing + adding glaze group of roughness & fracture toughness.

Groups VII	Pearson Correlation (r)	P- value	Sig.
Polishing + adding glaze roughness	-0.824	0.003	Highly Sig. (P<0.01)
Polishing + adding glaze fracture toughness			
N	10		

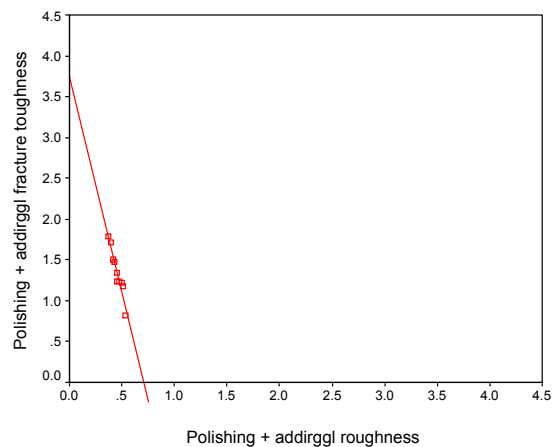


Figure (9) Correlation of Polishing + adding glaze group of roughness & fracture toughness.

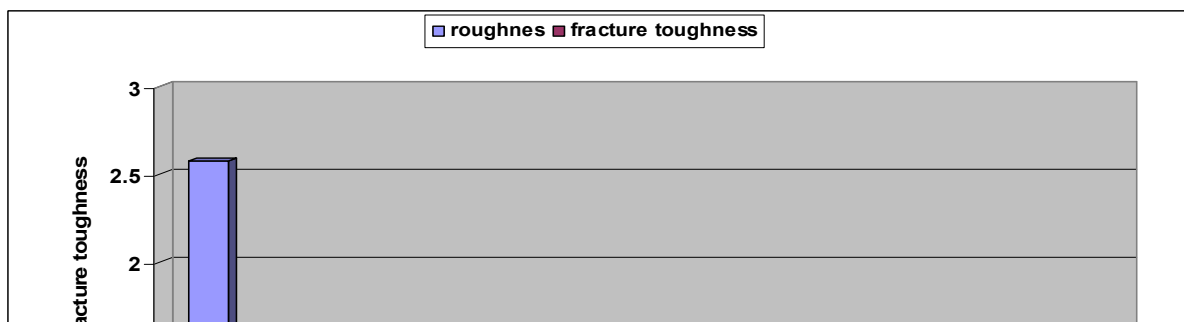


Figure (10) Distribution of surface roughness & fracture toughness according to studied groups.

Discussion:

From figure (10) appeared that the control group had high surface roughness and lowest fracture toughness. This might be due to the irregular particles and voids which were probably brought about by the removal of superficial grain during grinding. While group II is smoother and tougher than group I, but it was still the higher degree of roughness and lower fracture toughness in compared with rest groups. Because porcelain had the ability to glaze itself; autoglazed feldspathic porcelain produced superfine voids but its smoother than unglazed porcelain and found to be much stronger than unglazed porcelain, particularly if the surface was rough because the glaze is effective in reducing crack propagation [12,19,20].

Group III showed that improvement of (Ra) and (K_{Ic}) values and it was the second smooth surface in this study; this might be applied glaze lead to seal microscopic pitting present on the porcelain surface that produced glossy and a satisfactory surface for porcelain restoration [5,9]. Applied glaze reduced the depth and/or sharpness of the critical flaws, acted as a sealant and could flow in to the surface flaws on the porcelain surfaces and prevent them from reaching the initial point of fracture when the porcelain was stressed. While group IV had shown a moderately smooth surface this might be due to porcelain rubber wheel lead to exposure to the large bubbles in the surface. A finding concurred with study which reported that polishing feldspathic porcelain tended to be smoother than self glazed porcelain [12]. Group V showed high significant improvement in the (Ra) and (K_{Ic}) values in compared with the other groups because of the roughness presented by rubber wheel might be improved by porcelain polishing paste, this might be lead to make this group was second toughest group in this study. Because of that encouraged the use of polishing as alternative to glaze ceramic restoration these result agreed with the study which was found that polished unglazed porcelain were tougher than polished glazed surface [21]. Bar chart (13) showed an improvement (Ra) and (K_{Ic}) values for group VI than control group and increased in (Ra) value and decreased in (K_{Ic}) value than group III and group VII, a finding agreed with the study of which concluded that polishing followed by self glazing porcelain produced fine surface crack [9,22]. The rough surface resulting from the surface cracks and subsequent

porcelain chipping might be caused wear of the opposing occlusal surface, so that natural glaze after polishing procedure was not satisfactory for porcelain restoration . Group VII showed very high significant improvement in (Ra) values and scored the first surface smoothness among the tested groups. It was the toughest group in this study, these results supported by investigation which discovered that an optimum method of producing the smoothest surface in the shortest time has not been established yet. It's logical to assume that, fine polishing of a roughened surface followed by glazing produces smoother surfaces than polishing alone. The application of a surface glaze as a final finish could be the best method of increasing the strength of feldspathic porcelain and inhibiting crack propagation from the surface through the body of porcelain [12,20,23,24].

The reason that applied glaze following polishing porcelain with rubber wheels and polishing paste scored higher (K_{Ic}) values than polished porcelain (group IV and group V) can be attributed to that, the polishing procedure may have removed certain defects created during fabrication, but at the same time has produced surface compressive stresses due to heat generation as a result of friction between the polishing wheel and the ceramic surface. Such overheating can assist in producing plastic deformation, and also generate thermal mismatch between the outer and inner layers of the ceramic specimens that may lead to the development of tensile stresses in the inner layer [25].

It is noteworthy to verify that a significant correlation was found between the roughness of porcelain surface and the biaxial strength being that the smoother the surface, the stronger the samples [26].

Finally, these differences in biaxial strength could be attributed to the stress concentration of an applied load due to the roughness of the porcelain surface which could be caused by mechanical finishing or chemical action. If the strength of any porcelain was not affected by different surface treatment, this could be due to the size of the leucite particles, which apparently induce more stress concentration than the surface flaws and the roughness of the surface.

Their conclusion was that surface roughness determined the strength of porcelain material.

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