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RESEARCH ARTICLE

EFFECT OF FINISHING AND POLISHING ON MECHANICAL PROPERTIES OF COMPOSITE.

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Abstract

Objective: To evaluate the effect of finishing/polishing systems on the surface roughness, micro-hardness, and modulus of elasticity of different types of composite-resins.

Materials and Methods:Specimens were made of four types of composite-resins that packed into special designed blocks, after that, they subjected to light cure. Aluminum-oxide discs (Sof-Lex, 3M ESPE) used to finish/polish half of the specimens immediately. Surface roughness (Ra, μm ; n=20), Vickers micro-hardness (200g; 15s; n=20) and Modulus of elasticity (E=FL3/4BH3d, n=20) were measured. The specimens tested before and after immediate finishing/polishing. Data were analyzed by ANOVA and Tukey post Hoc ($P<0.05$).

Result: Finishing/polishing system significantly influenced roughness, micro-hardness and modulus of elasticity ($P<0.05$). Group A1 [universal] produced significantly least surface roughness ($0.07\pm 0.03\text{Ra}, \mu\text{m}$) while Group A4 [nano-filled] exhibit the highest micro-hardness ($90.06 + 3.53\text{VHN}$) and modulus of elasticity ($7.17 + 0.45\text{ GPa}$) in comparison to others.

Conclusion: Finishing and polishing procedures have apparent effect on different mechanical properties of composite-resins, render them as critical steps to produce effective and efficient restoration.

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Introduction:-

Dental restorations require finishing and polishing procedures to fulfill the requirements of form and function and to promote aesthetics, longevity, and periodontal health [1, 2]. Different methods can be used for finishing and polishing, and the surface smoothness obtained is dependent on the composition of the composite, the presence of bubbles, and the instruments and procedures used [3].

Composite resins are considered one of the most suitable dental materials to make minimal invasive treatments due to their aesthetics, biocompatibility, easy handling and adhesive properties; in spite of that, it discolored easily after some time and have poor marginal sealing which is the main disadvantages of their use and directly related to their composition and mechanical properties as microhardness [4,5].

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Organic monomers or polymers, filler, bonding agents, and activator are the components of composite resins. According to the size of filler particles, composite resins can be classified as follows macro-fill, micro-fill, hybrid and nano-fill. [6]

Changes in matrix composition, the introduction of new monomers, filler content optimization, and variations in particle size, type, and morphology can all increase the surface roughness of composites [7] and can result in plaque accumulation, gingival inflammation, and surface staining [8]

The conversion rate of polymerization directly affects the hardness of composite resins depending on the distance of polymerization light [9], polymerization time, and irradiation power [10].

Moreover, the thickness of the stratification layers more than 2mm can partially be polymerized, and that will affect the hardness of the composite resins and increasing the fracture liability [9, 11].

The softer surface resins may retain the scratches created by the finishing procedures, which can affect the fatigue strength of restoration leading to premature failure [12].

One of the important mechanical property of restorative material is its surface hardness, which measures the material's strength to its surface plastic deformation. A material's hardness is the result of an interaction of the properties such as strength, ductility, malleability, resistance to cutting and abrasion. A decrease in the microhardness value may indicate a superficial degradation, and therefore a change in its roughness, which collaborates with the accumulation of plaque and consequently the deposition of lactic acid, hence jeopardizing the restoration's longevity [13,14]. There are several methods to measure this property and the Vickers microhardness test is one of them.

Both the surface roughness as well as the hardness of the composite resin may also be associated to its characteristics, such as the type of organic matrix, size, composition, and distribution of loading particulates [15], including the material's exposure to low pH food, drinks and mouth rinse solutions [16].

Modulus of elasticity was describing the rigidity of the material. Several authors have reported a significant correlation between the modulus of elasticity and the percentage of filler by volume (vol%)[17] or by weight (wt%)[18]. Sabbagh et al. (2002), evaluating the modulus of elasticity of several resin-based composites commercially available observed significantly different moduli, even for composites of the same category, indicating that compositional differences between composites from different manufacturers (the kind of monomer, the shape, and size of the inorganic filler) influence the mechanical behavior of the materials.

The present research is conducted with the aim to evaluate the effect of finishing and polishing systems on the surface roughness, hardness, and modulus of elasticity of different types of composite resins.

Objectives:-

The aim of this research is to evaluate the effect of finishing and polishing systems on the surface roughness, hardness, and modulus of elasticity of different types of composite resins.

Material and Methods:-

Experimental Design

The main factors evaluated in this in vitro study were finishing/polishing systems [aluminum oxide discs (Sof-Lex, 3M ESPE)].

The specimens were made of four different types of composite resins; the materials used in this study are listed in table (1) following a randomized complete block design. After that, the materials were light cured and tested before and after finishing/polishing. The dependent variables were mean surface roughness (R_a , μm) ($n=20$), Vickers microhardness ($n=20$), and modulus of elasticity ($n=20$)

Table 1:-The material and light cure units used in this study:

Material	Composition	Manufacture information	Batch Lot No
Filtek™ Z350 XT® (Universal)	Matrix: Bis-GMA, UDMA, TEGMA, PEGDMA, and bis-EMA. Fillers: silica (20nm), zirconia (4-11nm), and aggregated zirconia/silica clusters (20nm silica and 4-11nm zirconia). Mean size: 0.6 to 10µm (72.5%).	3M ESPE, St. Paul, USA	N870445
Te-Econom Plus® (Hybrid)	Matrix: Dimethacrylate and TEGMA (22wt%). Fillers: barium glass, ytterbium tri-fluoride, silicon dioxide and mixed oxide (76wt% or 60%vol). Mean size: 0.04 and 7µm, mean 850nm	Ivoclar, Vivadent, Schaan, Liechtenstein	U20279
Filtek™ Z350 XT® (Nanohybrid)	Matrix: : Bis-GMA, UDMA, TEGMA, PEGDMA, and bis-EMA Filler: zirconia/silica ≤ 3µm and 20nm silica Mean size : 82%	3M ESPE, St. Paul, USA	N706303
Tetric Evo ceram (Nanofilled composite)	The monomer matrix composed of dimethacrylates (17-18% weight). The inorganic filler contain Barium glass, Ytterbium tri-fluoride and mixed oxide. The content of particle size 79-80% weight or 60-61% volume. The particle size of inorganic filler 40nm and 3,000nm.	Ivoclar vivadent, Schaan, Liechtenstein.	K15489
Sof-Lex	Aluminum oxide (medium: 40 µm, fine: 24 µm, x-fine: 8 µm)	3 M/ESPE Dental Products, Seefeld, Bavaria, Germany	1202000341
Light cure unit [Light emitting diodes (LED)]	Mega-Phisk dental	Chromalux 75, 400-500 nm, Germany.	

Surface roughness

A two-part Teflon mold (diameter = 10 mm and high = 2 mm) (fig.1) was filled with the composite in a single increment over a glass slide, then another glass slide was positioned and pressed against it with an excess removal before polymerization. The composites were cured for 40 seconds in three consecutive points, producing a partial overlapping. Half of the specimens of each group randomly divided received finishing/polishing immediately after preparation.

Finishing/polishing procedure (Sof-Lex):

It is done by application of medium, fine, and superfine grain discs, sequentially, mounted on the handpiece. Each disc was applied 10 seconds for the specimen under constant cooling with a water jet. One disc sequence was used for each specimen.

After that, compressed air/water irrigation was performed for 10 seconds and cleaned (ultrasonic bath for 30 seconds in distilled water), and stored dry after using paper towels. A single operator performed all laboratory procedures in an air-conditioned environment at a temperature of 20±2 °C.

Surface roughness assessment:

A profilometer (Mitutoyo SJ-301 Surftest, Aurora, IL, USA) calibrated with a standard of known roughness was used. The arithmetic mean of the absolute distance of the roughness profile (R_a , μm) was recorded within a measuring length of 4 mm and with a cut-off of 0.8 mm. Four readings were taken for each specimen, one parallel, one perpendicular, and two diagonal in relation to the direction of the finishing/polishing instrument application. The mean of the four readings was obtained to represent each specimen.



Fig 1:-A photograph of non-assembled split Teflon mold used for Surface roughness test

Surface microhardness test:

Preparation of specimens:

Twenty specimens from each material were prepared in a split Teflon mold 4mm diameter and 3 mm height (Fig.2, 3). The mold was positioned over a glass slide and filled with the composite, which was inserted in a single increment. Another glass slide was positioned and pressed against it with an excess removal before polymerization. The composites were cured for 40 seconds in three consecutive points, producing a partial overlapping.

The specimens were removed from the Teflon mold 30 sec after illumination and stored in a tank filled with water at 37°C for 24 h; the tank was wrapped in Aluminum foil. Half of the specimens of each group randomly divided received finishing/polishing (similar procedures that are done for specimens of surface roughness) immediately after preparation.

Assessment of the surface microhardness:

Surface microhardness of the specimens was determined using Digital Display Vickers Microhardness Tester [Model HVS-50, Laizhou Huayin Testing Instrument Co., Ltd. China.] (Fig.4) with a Vickers diamond indenter and a 20X objective lens. A load of 200 gram was applied to the surface of the specimens for 15 sec. Three indentations were equally placed over a circle and not closer than 1 mm to the adjacent indentations or to the margin of the specimens were made on the surface of each specimen. The diagonal length of the indentations was measured by the built in scaled microscope (Fig.5).

Surface microhardness calculation:

Vickers microhardness was obtained using the following equation:

$$\text{VHN} = 1.854 \text{ L/d}^2$$

Where:

VHN: Vickers hardness in Kg/mm². L: Load in Kg.
d: Length of the diagonals in mm.



Fig 2:-A photograph of assembled split Teflon mold used for creates surface microhardness disc specimen.



Fig 3:-A photograph of non-assembled split Teflon mold used for creates surface microhardness disc specimen.\



Fig 4:-A photograph of Vickers microhardness tester.

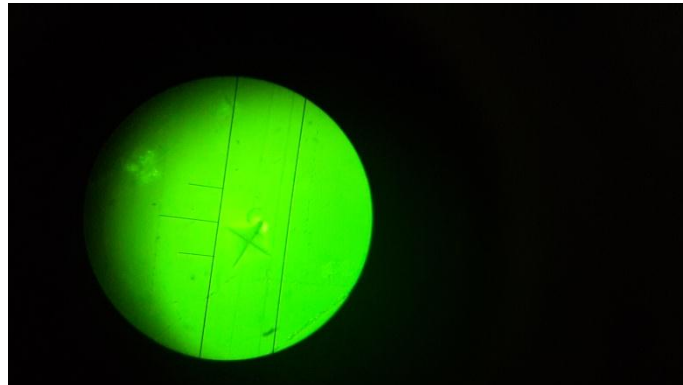


Fig 5:-A photograph of specimen under Vickers microhardness tester.

Modulus of elasticity

Twenty bar-shaped specimens were made of each composite resin types, using a metallic mold with the dimensions specified by the ISO 4049/2000 specification (25 mm x 2 mm x 2 mm).

The mold was positioned over a glass slide and filled with the composite, which was inserted in a single increment. Another glass slide was positioned and pressed against it with an excess removal before polymerization. The composites were cured for 40 seconds in three consecutive points, producing a partial overlapping. Half of the specimens of each group randomly divided received finishing/polishing (similar procedures that are done for specimens of surface roughness) immediately after preparation.

Afterward, they were submitted to a three point bend test with a universal testing machine (Model LRX-Plus; Lloyd Instruments Ltd., Fareham, UK) with a crosshead speed of 1 mm/min [10 specimens before polishing and 10 specimens after polishing] (Fig.6). The maximum loads were obtained and the modulus of elasticity (GPa) was determined as

$$E = FL^3/4BH^3d$$

Where F is the maximum load; L is the distance between the supports; B is the width of the specimen, H is the height of the specimen, and d is the deflection (in millimeters) corresponding to the load F.

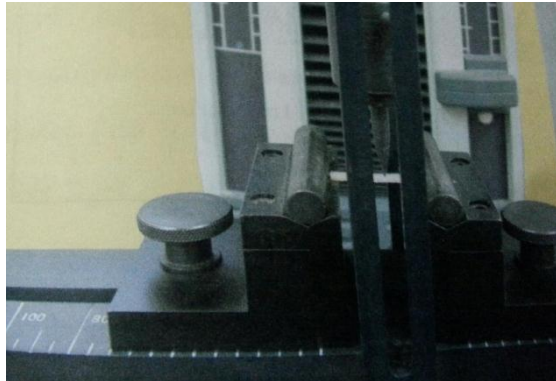


Fig 6:-A photograph of composite reins on universal testing machine

Statistical Analysis:

The recorded values were collected, tabulated and statistically analyzed. The effect of the finishing and polishing systems was analyzed using two-way Analysis of Variance (ANOVA) and Tukey post hoc test were used for testing the significance between the means of tested properties of all tested materials which statistically significant when the P value ≤ 0.05 .

Result:-

The statistical analysis pointed out significant differences between composites for surface roughness, Vickers microhardness, and modulus of elasticity and the data were presented as mean and standard deviation (SD) values of different groups.

Surface roughness:

Two-way ANOVA found a significant effect of finishing/polishing system on surface roughness $P \leq 0.05$. Group A1 [Universal] had significantly less surface roughness than the other types of polished surface as presented in table 1.

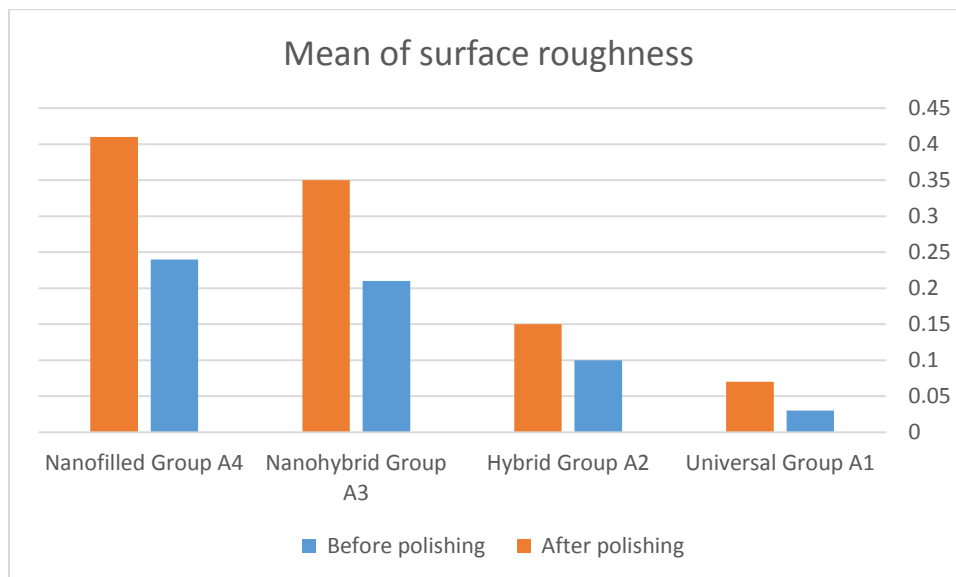


Table 2:-Comparison of roughness (Ra, μm) means (\pm standard deviation) for the finishing and polishing systems studied:

Groups	Before polishing Mean	SD	After polishing Mean	SD	P-value
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Universal Group A1	0.03	±0.01	0.07	±0.03	<0.001 *
Hybrid Group A2	0.10	±0.05	0.15	±0.1	
Nanohybrid Group A3	0.21	±0.05	0.35	±0.35	
Nanofilled Group A4	0.24	±0.1	0.41	±0.06	
Tukey post Hoc	A4 > A1		A4 > A1		

* Significant at $P \leq 0.05$,

Surface microhardness test:

The mean values of Vickers microhardness are summarized in Table 3. Two-way ANOVA showed a significant effect of finishing/polishing system on microhardness $P \leq 0.05$. Group A1 [Universal] had significantly lower microhardness before polishing than other group.

Tetric Evo Ceram (90.06 ±3.53VHN) exhibit the highest VHN (Harder) and group A1 [Universal] had lower microhardness (66.01±3.56VHN).

Table 3:-Comparison of Vickers microhardness means (± standard deviation) for each finishing and polishing systems studied:

Groups	Before polishing Mean	SD	After polishing Mean	SD	P-value
Universal Group A1	66.01	±3.56	69.52	±5.65	<0.001 *
Hybrid Group A2	75.64	±3.83	80.73	±4.98	
Nanohybrid Group A3	80.09	±1.65	85.62	±3.06	
Nanofilled Group A4	86.01	±4.2	90.06	±3.53	
Tukey post Hoc	A4 > A1, A4 > A2		A4 > A1, A4 > A2		

* Significant at $P \leq 0.05$,

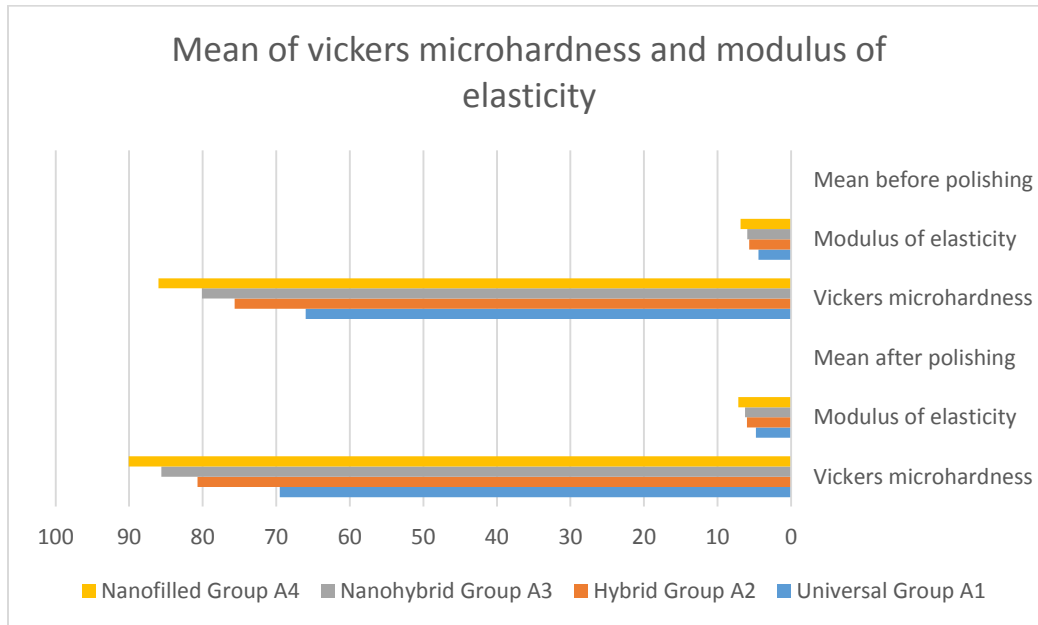
Modulus of elasticity

The mean values and standard deviation of modulus of elasticity are presented in table 4. Significant effect of finishing/polishing system on modulus of elasticity $P \leq 0.05$. Group A1 [Universal] produced significantly less modulus of elasticity than the other types of polished surface as presented in table 4. Nano-filled group A4 exhibit the highest modulus of elasticity (7.17 +0.45 GPa) and group A1 [Universal] had lower microhardness (4.41 ±0.84 GPa).

Table 4:-Mean of modulus of elasticity (GPa) for composite resins before and after polishing

Groups	Before polishing Mean	SD	After polishing Mean	SD	P-value
Universal Group A1	4.41	±0.84	4.78	±0.68	<0.001 *
Hybrid Group A2	5.70	±0.59	5.98	±0.60	
Nanohybrid Group A3	5.94	±0.84	6.24	±0.71	
Nanofilled Group A4	6.85	±0.72	7.17	±0.45	
Tukey post Hoc	A4 > A1		A4 > A1, A4 > A2		

* Significant at $P \leq 0.05$,



Discussion:-

Surface roughness:

Clinical use of composite resins increased due to new expansions in fixation systems and the higher aesthetic expectations of the patients [19]. One of the crucial steps that affect on the success of the restorative procedure, is the finishing and polishing procedures which applied to the surfaces of aesthetic restorative materials and it has noticeable effect on extending the life of the restoration, aesthetics, and in terms of oral health [20].

In aesthetic dentistry, the material used for restoration should resemble the natural appearance of the tooth [20]. Composite resin restoration, that most closely mimic the surrounding enamel surface, should not be obvious to the naked eye. Increased roughness of the surface will result in a decreased surface shine [21]. Moreover, smooth restoration reduces plaque accumulation, the patient discomfort felt by gingival irritation, and formation of secondary decay [22]. For that, it is a great importance clinically to determine the finishing and polishing techniques, which will produce the smoothest surface of composite resin [23]. As in previous articles, the smoothest surfaces in the current study were those finished with a clear band [20,21,23]. However, surfaces finished with a clear band are rich in organic fixatives. At the same time, removing the outermost resin with finishing and polishing procedures produces a surface that is harder, with higher resistance to wear, and aesthetically permanent [24].

Increased surface roughness of the restoration results in increased the degree of light reflection and consequently, there is a reduction in shine of the restoration. The clinical importance of surface roughness includes its direct effects on restoration aesthetics and the fact that it causes a surface discoloration over time. In previous clinical studies, rough surfaces of the restorations increased plaque accumulation and decreased the efficacy of oral hygiene applications [25,26,27]. The restorative materials used in the current study selected due to their frequent use in the posterior region. The surface roughness of the composite materials used in the posterior region in this study evaluated and the lowest to the highest values of roughness were Universal, Hybrid, Nano-hybrid and Nano-filled respectively

The surface texture properties of any material results from interactions of several factors [22,28]. Some of these are internal factors, as fillings (type, dimension, shape, and particle distribution), resin matrix type, the highest degree of polymerization, and effective fixation between the filling and the resin matrix [29]. In addition to that, external factors related to the finishing and polishing system, such as material elasticity in which the abrasives are embedded, abrasives hardness, and the geometry of the instrument used [22]. Several studies have reported that composite resins containing smaller dimensions fillings showed a smoother surface after polishing than that containing larger dimensions fillings [20,21,30]

In this study, four types of composite restorations were tested. The results showed that universal composites had smoother surface under all conditions of finishing and polishing than other types of composite. These results are in contrast with Koh et al. study [20] and the study of Rai and Gupta.[31] It may be because of the combination of nano-sized particles and the nano-cluster formulations for nano-filled composite. The nano-cluster filler particles consist of loosely bound agglomerates of nano-sized filler particles. During abrasion, the primary particles (nanometer sized), and not the clusters themselves, can be worn away, rather than be plucked out; thus, smooth finish and higher gloss is retained over time. In the hybrid and universal, the particle size is larger, leaving the surface rough due to pluck out of filler particles after wearing out of resin matrix during polishing.[32] Contrary to our study, Silikas et al.[33] compared the surface roughness of micro hybrid and nano-hybrid and found no difference in surface roughness.

Hardness

Hardness can be defined as the resistance of solid structures to permanent indentation or penetration. Changes in hardness may reflect the cure state of a material and the presence of either a continuous reaction or the maturity of the restorative material [34]. In general, increasing the particle size increases the resistance and surface hardness of the composite. Moreover, the type, morphology, distribution, and volume fraction of filler particles and the concentration of diluent monomers affect the hardness of the composite [35].

In the present study, surface hardness was increased after finishing and polishing of nano-composite when compared to other composite resin. The increase of hardness in finishing was significant in nano-filled composite. This difference may be because of the difference in matrix and filler component of resin. These results are in coincidence with the study Chinelatti *et al* [36]

Furthermore, another investigation proved that delayed finishing and polishing generally results in surface similar to or even harder than that obtained with immediate finishing and polishing.[37]

Modulus of elasticity

The elastic properties of the restorative materials, such as yield strength and elastic moduli, measure the ability of the materials to restore to their original shape when a load is applied and removed [38]. The modulus of elasticity is directly related to the amount of deformation when the material is subjected to external forces [39]. Hence, dental materials that are used in posterior restorations must possess an adequate modulus, strain, and yield ability to withstand the high forces during mastication [40]. In addition, the percentage of endurance combination, modulus of elasticity, and elastic recovery of the material used in the restoration of abfraction defects, which result from stress accumulation on the edge of tooth enamel-cement with the impact of occlusal forces, should be compatible with that of tooth tissue [41]. Materials with low elasticity modulus deform more under masticatory stresses and do not have sufficient resilience, which may cause catastrophic failure, whereas a high elastic modulus is required to withstand deformation and cuspal fracture [42].

The comparison between the composites showed a statistically significant difference in modulus of elasticity before and after polishing. The morphological characteristics of the fillers must also be considered, since they have been shown to be determining factors in both the filler loading [43] and the material strength. Smooth spherical shaped filler particles are related to an increased volume fraction of the filler due to the improved packing of the particles and also to higher fracture strength. This could explain the high modulus obtained with nano-filled composite, which is constituted by small round shaped particles.[44]

Conclusion:-

Evolutions in finishing and polishing systems are important to create ideal restorations and linked with the improved clinical success of dental practitioners. Further studies are needed to examine restorative materials and techniques capable of creating properties and appearances similar to the enamel in the complex surfaces of restorations in the clinical environment.

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