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Influence Of Three Types Of Enamel Pre-Treatment Methods On The Shear Bond Strength And Surface Roughness Using Image Analysis And 3d Profiler-An In Vitro Study

Dr.Navaneetha Nambi
(Prof & Head, Madha Dental College) Chennai

Dr.Krishnaraj
(Professor Srm Dental College)

Dr.Sangeetha Duraiswamy
(Professor Srm Dental College)

Dr.Ravi
(Dean, Srm Dental College)

Dr.Dilip.S
(Professor Srm Dental College)

ABSTRACT:
Surface roughness is a component of surface texture. It is quantified by the deviations in the direction of the normal vector of a real surface from its ideal form. Roughness plays an important role in determining how a real object will interact with its environment. In orthodontics, the surface roughness requires to be rough enough to lodge a secure bonding and various techniques in literature can deliver it. Acid etching and sandblasting or air abrasion technique have been discussed both separately and in combination for over years.
The purpose of this study was to compare the shear bond strength of the brackets bonded after using three different types of enamel pre-treatment methods; acid etching, sandblasting, and combination of acid-etching with sandblasting and also to compare the degree of roughness created using image analyser and non-contact 3D profiler.
Keywords: *enamel conditioning, acid etching, sandblasting, air abrasion, SEM, 3D profiler, shear bond strength.*

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I. INTRODUCTION

Acid-etch bonding technology, initially introduced by Buonocore[1] in 1955, has significantly changed clinical practice in all fields of dentistry. Acid dissolution of the enamel surface creates micro porosities those results in a micromechanical bond[2].

In 1965, Newman[3] first used pre-treatment of enamel using phosphoric acid for bonding of orthodontic brackets. As the bonding of brackets is a day-to-day procedure in orthodontics, considerable researches have been devoted to bonding techniques. For optimal results, the bond strength must be high enough to prevent failure and at the same time should cause no damage to the enamel.

The usage of phosphoric acid provides good bond strength but also causes some amount of enamel loss; in varying degrees depending upon the exposure time and concentration of the acid used. The concentration and exposure time of phosphoric acid was decreased from 80% to 37% and application time from 60 seconds to 15 seconds[4]

Within the field of orthodontics, this technology has resulted in significant treatment improvements, including more esthetic and hygienic appliances, elimination of post treatment band spaces, easier caries detection and treatment, less soft tissue irritation, and decreased possibility of enamel decalcification.

Air-abrasion technology has been examined for potential applications within dentistry. This technology was introduced before acid-etch bonding by Dr. Robert Black in the 1940s[4]. Many investigators have been interested in the effects of sandblasting. Zacharrison and co-workers found that sandblasting improves the retention and increases the bond strength when bonding to gold, porcelain and amalgam. It was believed that sandblasting lower lingual retainer wires also improves the bond strength[5].

Acid pre-treatment of the enamel surface is clinically effective and reliable. However, there are several drawbacks associated with the bonding technique, namely, toxicity of acid to oral soft tissues and time required to obtain the desired dissolution. Air abrasion, on the other hand, possesses neither of these drawbacks, while having minimal effect on oral soft tissues, with typical tooth surface preparation times ranging from 0.5 to 3 seconds, without the additional step of rinsing[6].

Although some studies have evaluated the bond strength after sandblasting, evidence is generally lacking when it comes to comparison of shear bond strength with sandblasting and when used in combination with acid etching.

The purpose of this study was to compare the shear bond strength of the brackets bonded after using three different types of enamel pre-treatment methods; acid etching, sandblasting, and combination of acid-etching with sandblasting and also to compare the degree of roughness created using image analyser and non-contact 3D profiler.

II. MATERIALS AND METHODS

This study was performed on extracted premolars that did not have any caries or restorations. All teeth were stored in distilled water immediately after extraction and changed every week.

The sample consisted of 62 human premolars extracted for orthodontic purpose with intact buccal enamel without any hypoplastic spots, enamel cracks.

The total sample was divided into three groups, consisting 20 teeth in each group
Group A: Sandblasting group consisting of 20 teeth
Group B: Acid etching group consisting of 20 teeth
Group C: Combination group consisting of 20 teeth.
Two samples were used for surface roughness evaluation of untreated enamel.

Group A consisted of 20 premolar teeth subjected only to sandblasting with an intraoral sandblaster (DANVILLE-made in USA) with aluminium oxide particles 50µm in size, sandblasted for 5 seconds with the nozzle at an angle of 45^0 to the long axis of the tooth and kept 6mm away from the surface of teeth[4].

Fig 5: Intra oral sandblaster

Group B consisted of 20 premolar teeth subjected to acid etching with 37% orthophosphoric acid (3M UNITEK Monrovia California, USA), for 15 seconds per sample, then rinsed under water and air-dried.

Fig: 6 Acid etching liquid

Group C consisted of 20 premolar teeth subjected to sandblasting initially using the above method followed by acid etching for 15 seconds and then rinsed with water and air-dried.

III. SURFACE ROUGHNESS EVALUATION:

Surface roughness created by three types of pre-treatment methods and untreated enamel were evaluated and compared.

This quantification of the roughness was performed by ultra-precision benchtop 3D optical profiler made by TAYLOR HOBSON Precision- TALYSURF CCI (British make). This uses a non-contact way of evaluating the surface roughness created on the surface of the enamel. The TalySurf CCI is an advanced 3-dimensional non-contact optical metrology tool used for advanced surface characterisation.

These instruments have the ability to offer a true topographical representation of a surface with 0.01nm Z resolution over a full scan range plus a 0.4 nm lateral resolution, with over 1,000,000 data points. The Talysurf CCI Lite is an advanced type of measurement interferometer (a non-contact 3D Profiler). Talysurf CCI is an advanced type of measurement interferometer. It uses a patented correlation algorithm to find the coherence peak and phase position of an interference pattern produced by a selectable bandwidth light source.

This method provides both high resolution and excellent sensitivity to returning light. Versatility is one key benefit of the Talysurf CCI Lite non-contact 3D Profiler. Polished or rough, curved, flat or stepped surfaces with reflectivity between 0.3% and 100% can all be measured using one single algorithm, with no need to change mode for different surfaces and no concerns about the wrong mode being selected.

Samples from groups were scanned under the 3D profiler and a 3D view of the surface scanned was received with a graph and values Rp, Rv, Rz, Rc, Rt, Ra, Rq, Rsk, Rku for each sample.

Rp	Maximum peak height
Rv	Maximum valley depth
Rz	Peak-peak value
Rc	Mean summit curvature
Rt	Peak-peak
Ra	Average roughness
Rq	Root mean square
Rsk	Surface skweness
Rku	Surface kurtosis

Total 60 samples from group A,B and C were scanned under the 3D profiler and the surface roughness parameters were received by non-contact method.

Assessment using scanning electron microscope

Before subjecting the sample to scanning electron microscope, it was coated with a golden die under a chamber under high pressure. The SEM images were recorded each at 1000X optical zoom per sample.

The SEM images were later subjected to image analyser, IMAGE PRO-PLUS VERSION 6.3 for windows from media cybernetics. It was spatially caliberated. Using the measurement option, with an “irregular trace tool”, the measurements of the irregularities caused on the enamel surface were evaluated.

IV. SHEAR BOND STRENGTH EVALUATION:-

All the 60 samples treated with 3 types of enamel conditioning were bonded with labial premolar brackets from American Orthodontics Company, the adhesive used was TRANSBOND XT from 3MUnitek, Monrovia, California and light cured using halogen curing unit for 40 seconds each.

The bond strength was tested using INSTRON UNIVERSAL TESTING MACHINE maximum load of 50KN Cat #2716-020.

Samples were embedded in acrylic and mounted onto the jig used to align the labial surface of each tooth so that it was perpendicular to the bottom of the mold.

Samples were then mounted in the jig attached to the universal testing device. For shear testing, the specimens were secured in the lower jaw of the machine so that the bracket base of the sample paralleled the direction of the shear force.

The specimens were stressed in an occluso-gingival direction with a cross-head speed of 1 mm/min, as in previous studies[19,20]. The force required to dislodge the bracket was recorded in Newton.

The next criteria utilized was Adhesive Remnant Index (ARI). It was determined to evaluate whether the debonding has occurred at the adhesive-enamel interface or adhesive-bracket interface. The following criteria were utilized.

Score 0 = No adhesive left on the tooth.
Score 1 = Less than half of the adhesive left on the tooth.
Score 2 = More than half of the adhesive left on the tooth.
Score 3= All adhesive left on the tooth, with distinct impression of the bracket mesh.

V. RESULTS

Initially the surface roughness was assessed and quantified using scanning electron microscope and non-contact 3D profiler respectively. It was followed by the testing of bond strength of the samples using a universal instron machine.

SURFACE ROUGHNESS TESTING:-

The scanned images of untreated samples showed relatively smooth surface of enamel at both 100X and 1000X optical zoom under SEM. Certain irregularities were noted on the surface like scratches caused by forceps on the enamel during extraction of the tooth. The images of each group are shown below in the figures.

Group A (sandblasting), group B (acid etching) and group C (combination) samples were scanned under electron microscope and the images were subjected to image analysis using image pro-plus under irregular trace tool.

STATISTICAL ANALYSIS: (image analysis)

The statistical results of image analysis measurements of SEM images three groups. The descriptive analysis was performed by one way ANOVA (analysis of variance).

TABLE 6 : POST HOC DATA FOR IMAGE ANALYSIS

Multiple Comparisons

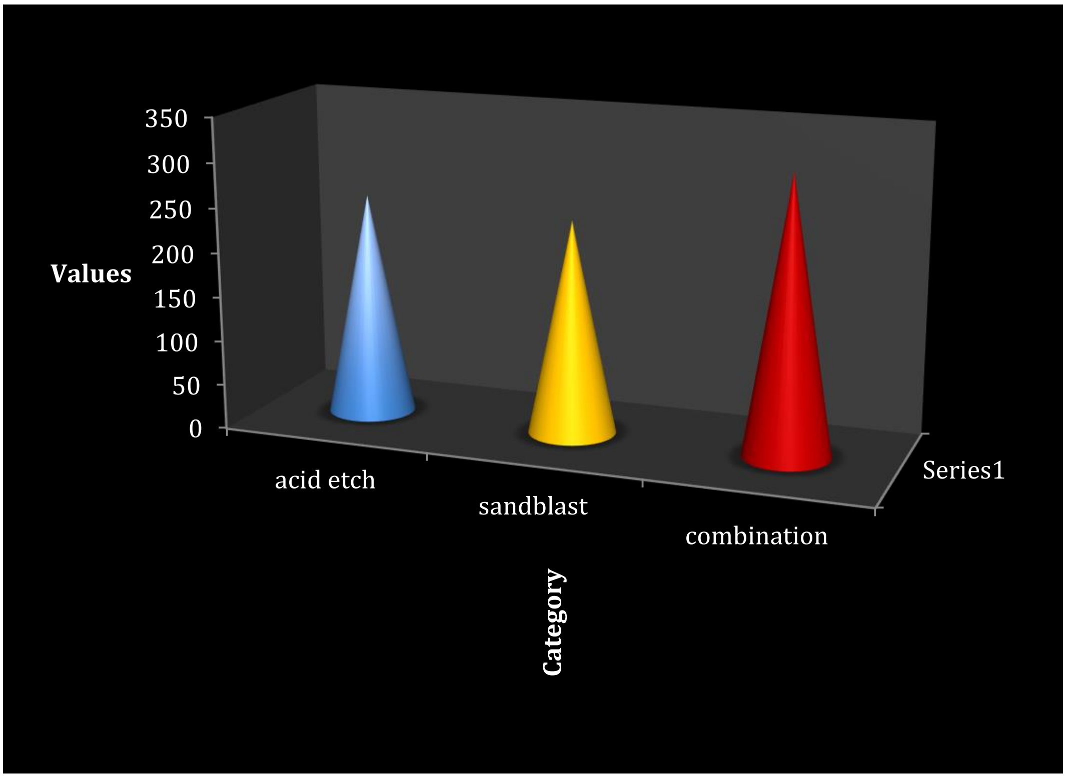
Dependent Variable: Image analysis
Tukey HSD

(I) GROUP	(J) GROUP	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval Lower Bound	95% Confidence Interval Upper Bound
Sandblast	Acid etching	-10.34731	11.54512	.647	-38.9725	18.2779
	Combination	-70.49541*	11.54512	.000	-99.1206	-41.8702
Acid etching	Sandblast	10.34731	11.54512	.647	-18.2779	38.9725
	Combination	-60.14810*	11.54512	.000	-88.7733	-31.5229
Combination	Sandblast	70.49541*	11.54512	.000	41.8702	99.1206
	Acid etching	60.14810*	11.54512	.000	31.5229	88.7733

*. The mean difference is significant at the .05 level.

Inference:-

According to the statistical analysis of the values obtained from the image analysis of SEM images, one way ANOVA test suggests that the F value (21.743) was greater than the F-critical value (3.3541) with a P value of 0.000 and thus null hypothesis was rejected. This test was followed by tukey test as the post HOC tests. Comparable amount of difference in the roughness was created between combination-acid etching and sandblasting-combination; with combination having more roughness in both the probabilities. But no significant difference in roughness measurements of acid etching-sandblasting was created.



Graph 1: Comparison of Measurements using Image analyser

These images scanned under SEM, and analysed under image pro-plus, though provide an accurate view of the enamel surface, still arbitrary in reaching a conclusion regarding the surface roughness created. To quantify the roughness created, the non-contact 3D profiler was utilized.

SURFACE ROUGHNESS EVALUATION USING 3D PROFILER

The statistical results of the quantification of surface roughness were evaluated. The descriptive analysis was performed by one way ANOVA (analysis of variance).

TABLE 13: POST HOC DATA FOR SURACE ROUGHNESS

Multiple Comparisons

Dependent Variable: SURFACE ROUGHNESS

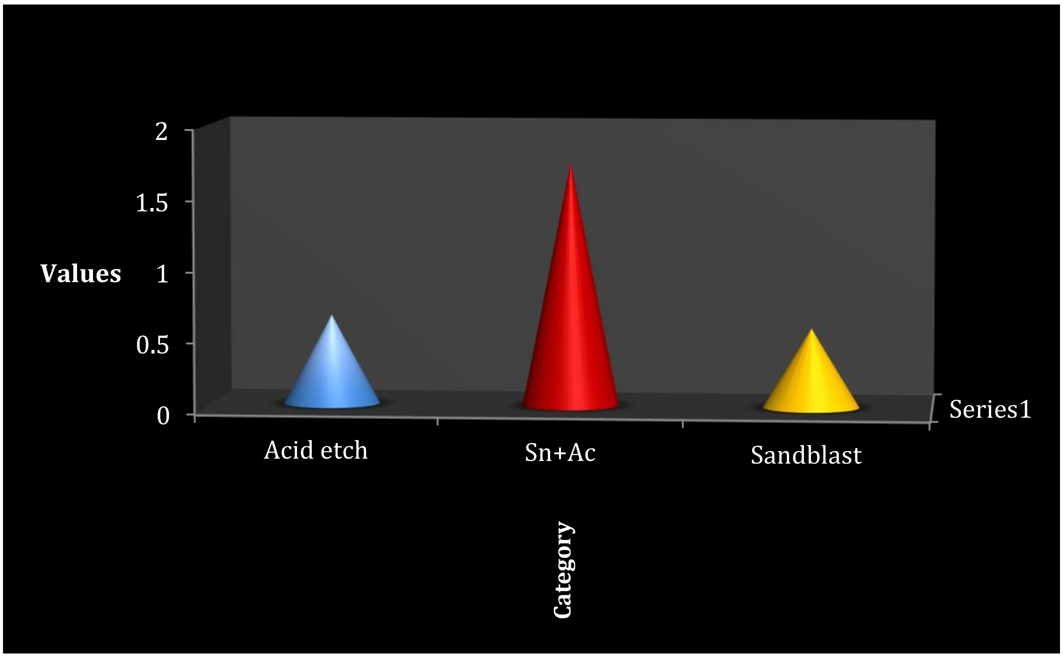
Tukey HSD

(I) Group	(J) Group	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
					Lower Bound	Upper Bound
Combination	Acid etching	1.218200*	.397657	.013	.23224	2.20416
	Sandblast	1.166600*	.397657	.018	.18064	2.15256
Acid etching	Combination	-1.218200*	.397657	.013	-2.20416	-.23224
	Sandblast	-.51600	.397657	.991	-1.03756	.93436
Sandblast	Combination	-1.166600*	.397657	.018	-2.15256	-.18064
	Acid etching	.051600	.397657	.991	-.93436	1.03756

***The mean difference is significant at the 0.05 Level**

Inference:-

According to the statistical analysis of the values obtained from the 3D non-contact profilometry, one way ANOVA test suggests that the F value (6.0027) was greater than the F-critical value (3.3541) with a P value of 0.000 and thus null hypothesis was rejected. This test was followed by tukey test and krushkal Wallis test as the post HOC tests. Comparable amount of difference in the surface roughness was created between combination-acid etching and sandblasting-combination; with combination having more roughness in both the probabilities. But no significant difference in surface roughness of acid etching-sandblasting was created.



Graph 2: Comparison of Surface Roughness

SHEAR BOND STRENGTH EVALUATION:-

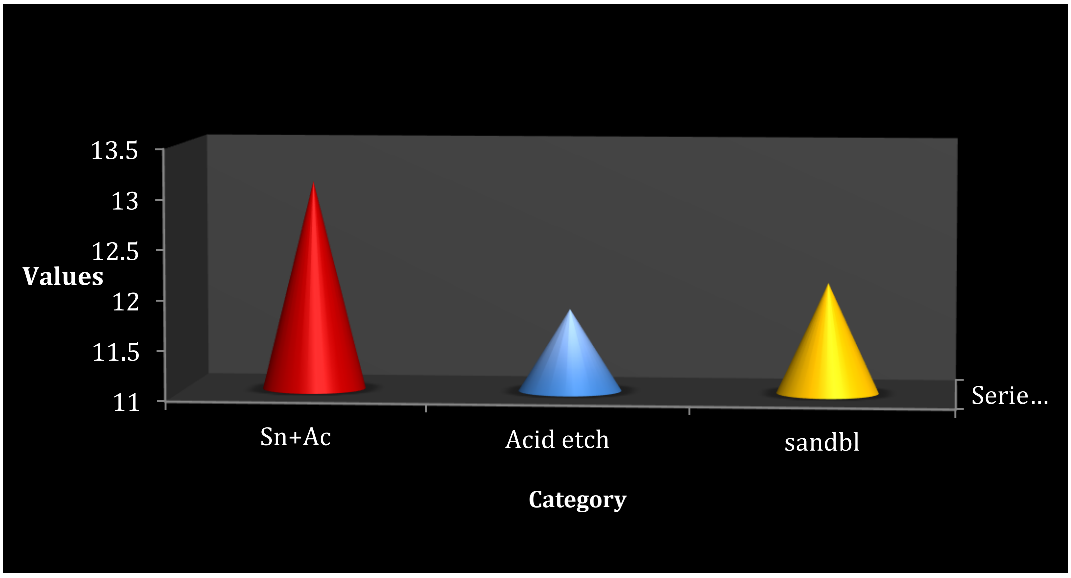
Statistical Analysis of shear bond strength evaluation using the descriptive statistics of bond strength testing was performed using one-way ANOVA followed by post HOC tests:-

TABLE 17: POST HOC DATA FOR SHEAR BOND STRENGTH

Post Hoc Tests

Multiple Comparisons						
Dependent Variable: SHEAR BOND STRENGTH Tukey HSD						
(I) Group	(J) Group	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval Lower Bound	Upper Bound
Combination	Acid etching	1.27650*	.09827	.000	1.0400	1.5130
	Sandblast	.99350*	.09827	.000	.7570	1.2300
Acid etching	Combination	-1.27650*	.09827	.000	-1.5130	-1.0400
	Sandblast	-.28300*	.09827	.015	-.5195	-.0465
Sandblast	Combination	-.99350*	.09827	.000	-1.2300	-.7570
	Acid etching	.28300*	.09827	.015	.0465	.5195

***The mean difference is significant at the 0.05 Level**



Graph 3: Comparison of Shear Bond Strength

Inference:-

The shear bond strength of all three groups was statistically significant in one way ANOVA. The F-value being (93.071) was greater than F-critical value (3.1588) the null hypothesis was rejected, the p-value being (0.0000).

Confidence Intervals for Group Means				
Group	Confidence Interval			□□□□□
Combination	13.107	±	0.1392	95%
Acid etching	11.8305	±	0.1392	95%
Sandblasting	12.1135	±	0.1392	95%

Post Hoc TUKEY test also suggests that combination group (group C) elicits more shear bond strength when compared to sandblasting group (group A) and Acid etching group (group B). Combination is significantly higher than the other two groups in their mean shear bond strength.

ARI ADHESIVE REMNANT INDEX:-

The ARI (ADHESIVE REMANENT INDEX) scores among the three groups were used as a more detailed means of evaluating the location of bond failures within the groups[5,11].

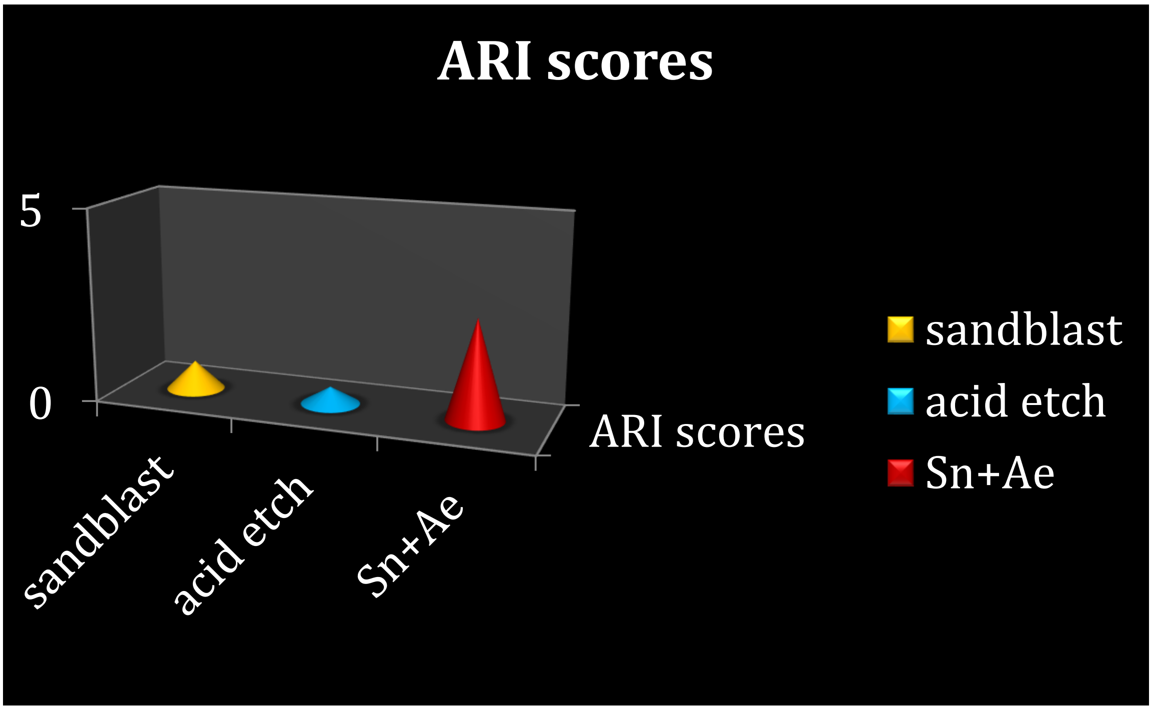
TABLE:20 POST HOC TEST FOR ADHESIVE REMNANT INDEX

Multiple Comparisons

Dependent Variable: ARI
Tukey HSD

(I) GROUP	(J) GROUP	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval Lower Bound	Upper Bound
Sandblast	Acid etching	.300	.194	.278	-.17	.77
	Combination	-1.850*	.194	.000	-2.32	-1.38
Acid etching	Sandblast	-.300	.194	.278	-.77	.17
	Combination	-2.150*	.194	.000	-2.62	-1.68
Combination	Sandblast	1.850*	.194	.000	1.38	2.32
	Acid etching	2.150*	.194	.000	1.68	2.62

*. The mean difference is significant at the .05 level.



Graph 4: Comparison of adhesive remnant index scores

The evaluation of the ARI scores indicated significant difference in bond-failure site between the two groups. These results showed that the combination Group C left more adhesive on the enamel than the group A and group B.

VI. DISCUSSION

With the introduction of the bonding techniques to attach orthodontic brackets to the enamel surface, different approaches have been suggested to condition the enamel surface. Acid etching of the enamel surface to create mechanical retention with phosphoric acid compounds is a commonly used approach.

Variations in the acid concentrations, as well as the duration of application, have been investigated to determine which combinations provide maximum bond strength with minimum loss of tooth surface[12,23,31]. Other approaches of enamel pre-treatment have also been recommended, including the use of intra oral sandblaster, which, instead of etching the enamel surface, creates macro irregularities thereby increasing the surface area of the enamel and reducing the surface energy[38, 57].

Sandblasting procedures were introduced to the dental profession to either clean or roughen various surfaces. As a result, attempts were made to use the procedure to condition the enamel surface for bonding purposes. Air-abrasion technology uses a high-speed stream of aluminum oxide particles, propelled by air pressure [8,26,]

The first sandblasting process was patented in the United States of America in 1870. Sandblasting is a general term used to describe the act of propelling very fine bits of material at high-velocity to clean or etch a surface. Sand used to be the most commonly used material, but since the lung disease silicosis is caused by extended inhalation of the dust created by sand, other materials are now used in its place.

Air-abrasion technology quickly gained favour within the dental community, due to several advantages, includes, elimination of pressure, vibration, bone-conducted noise, lack of heat generation, and reported increase in patient comfort[12, 47.]

The success of sandblasting techniques currently used in orthodontics, as well as in other areas of dentistry, suggests that sandblasting enamel directly may be a feasible technique, both for preparing teeth before bonding and for increasing bond strength [41,46,]

Many investigators have been interested in the effects of sandblasting. Zachrisson[21,27,30,36] found that sandblasting improves the retention and increases the bond strength when bonding to gold, porcelain, and amalgam. He also believed that sandblasting lower lingual retainer wires before bonding increases their bond strength. Several authors have independently found that sandblasting bracket bases greatly increases their retentive surface[41.]

The measurement of the texture of a surface is attributed to its roughness present. It is quantified by the vertical deviations of a real surface from its ideal form. If these deviations are large, the surface is rough. If the deviations are small, the surface is smooth.

Roughness is typically considered to be the high frequency, short wavelength component of a measured surface. Roughness plays an important role in determining how a real object will interact with its environment. Roughness is often a good predictor of the performance of a mechanical component and determines how well the adhesive will mechanically interlock with the enamel surface [17,19,33],

Surface roughening of enamel is a highly complex phenomenon. Many factors need to be considered, including the particle size, shape and hardness of the abrasive, the particle velocity, and the microstructure of the surface being abraded. Experimenting with high energy abrasion, White believed that it was difficult to predict precisely the roughness of surfaces prepared.

Etching otherwise known as “disambiguation” is the process of using strong acid or mordant to cut into the unprotected parts of a surface to create roughness[10]. Acid etching is a form of micro-etching, whereas sandblasting can be regarded as a form of macro-etching. Because the concept of sandblasting the enamel surface is unique, a conservative approach of only 5 seconds was taken to determine whether sandblasting is a viable alternative to acid etching[24,51].

Not many studies have evaluated the combination of sandblasting and acid-etching type of enamel pre-treatment on the surface roughness of enamel and their effect on shear bond strength of orthodontic brackets.

The purpose of this study was to evaluate the surface roughness created on the enamel due to the three types of pre-treatment methods; sandblasting (group A), acid etching (group B) and combination of both (group C); and comparison of their shear bond strength and adhesive remnant index scores.

A quantitative measurement of surface roughness was obtained using a non-contact 3D optical profiler manufactured by Taylor Hobson Talysurf. The root mean square roughness and peak-valley measurements suggest that combination group C with 1.735550µm mean value has the maximum surface roughness in comparison with groups A and B with values of 0.56890µm and 0.51730 µm respectively. The difference between the combination group and the other groups was found to be statistically significant but the difference between sandblasting and acid-etching was not statistically significant.

The results of the present study were in acceptance with a study done by **Karen Reisner**[36] who compared the surface roughness using profilometer after enamel preparation and concluded that combining sandblasting with acid etching increases the surface roughness significantly.

Wahidney[42] concluded in a study that the surface roughness was higher in samples where sandblasting was followed by acid etching, which is in concordance with the present study.

An image analysing software- *image pro-plus* with its "irregular tracing tool" was utilised to quantify the irregularities present in the SEM images. No studies have been done previously to evaluate the roughness after sandblasting, using this software.

The image analysis results indicate that group C with a mean value of 310.1384(μm) was higher in comparison with group B (acid etching) with a value of 249.9903(μm) and group A (sandblast) which has a mean value of 239.6430(μm). The image analyses show that the combination group shows higher roughness value compared to other two groups. This was found to be in accordance with the roughness evaluation using non-contact 3D profiler.

The comparison of shear bond strength between the three groups suggests that combination group (group C) with a value of 13.1070mpa shows relatively much higher bond strength in comparison with other two groups of sandblasting (group A) with a value of 12.1135mpa and acid-etching (group B) with a value of 11.8305mpa performed individually.

The results of this study were in concordance with a study evaluated by **Karen R. Reisner**[36] who compared the enamel preparation for orthodontic bonding and concluded that sandblasting followed by acid etching provides higher shear bond strength values.

Wahidney[42] concluded in a study that the shear bond strength was higher in samples where sandblasting was followed by acid etching, which is in concordance with the present study.

The present study was found to be in contradiction with a study done by **Marc E. Olsen**[13], who compared the shear bond strength and surface structure between conventional acid etching and air-abrasion of human enamel suggested that air-abrasion resulted in significantly lower bond strength compared with acid etching.

Hence correlating the values of the surface roughness evaluation and shear bond strength evaluation, it shows that increase in the surface roughness is directly proportional to increase in the shear bond strength values.

Adhesive remnant index in the present study infers that all the teeth prepared with the combination technique resulted in ARI scores of 2 to 3, indicating that significant amount of composite remained on the tooth surface.

This indicates that the bond between the enamel surface and adhesive was much stronger than that between the adhesive and the bracket base. On the other hand, in the acid-etch group, most (14/20) of the ARI scores were between 0 and 2, indicating that a significant amount of composite remained attached to the bracket base.

The group where sandblasting was used showed the ARI scores falling between 1 and 2. This would indicate a stronger bond between the bracket base and the adhesive. Differences in the enamel surface preparation, before bonding, may explain the significantly decreased bond strength values in the acid etched group.

Combination of both acid etching and sandblasting produced a synergistic effect of both micro-mechanical and macro-mechanical interlocking of the adhesive to enamel surface. We can safely assume that the combination group has acquired the positive effects of both the pre-treatment methods, thus resulting in a better bond strength.

The shear bond strength values obtained from the various groups in this study were found to be higher than the minimum bond strength adequate for clinical orthodontics as suggested by **Reynolds**[58]. The minimum bond strength of 6 to 8 MPa were considered to be able to withstand masticatory and orthodontic forces.

However, frequent debonding can lead to prolonged treatment time and patient burn out. High adhesive strength between bracket and tooth is an essential factor in any treatment concept, Also, increased bond strength are always necessary in certain clinical situations.

In recent years orthodontists deal with an ever-increasing number of adolescents and young adults who lack the seriousness of proper maintenance of fixed appliance in comparison with adults; the necessity for increasing the bond strength for such patients is beneficial.

In case of lingual orthodontics, bracket breakage and rebonding is a tedious and laborious process, where such combined enamel preparations of sandblasting followed by acid etching shall increase the bond strength to comfortable levels for both clinician and patient.

The enamel sandblasting combined with etching appears to be a useful procedure in orthodontics, and the shear bond strength indicates that the clinical performance shall be higher. High adhesive strength between bracket and tooth is important requirements for the successful integration of bonding in orthodontics into everyday practice, provided further studies prove beyond doubt that the sandblasting procedure does not produce excessive enamel loss.

However, surface roughening of enamel is a highly complex phenomenon. Many factors of enamel sandblasting have to be taken into consideration, i.e; inhalation of aluminium oxide particles, adjacent gingival tissue irritation, and protective eye wear for patient and clinician. In order to recommend large-scale use of this procedure, further clinical trials are required.

The risk versus benefit ratio of the intra-oral sandblasting procedure should be taken into consideration. They should be followed by randomized clinical trials before they are routinely inculcated into everyday clinical practice.

VII. SUMMARY AND CONCLUSION

The present study was performed to assess the degree of surface roughness created with three different types of enamel pre-treatment methods, sandblasting, acid etching and combination of sandblasting followed by acid etching.

The surface roughness was evaluated and compared using two methods; an image analysis of SEM images using a software and a non-contact 3D profiler. The shear bond strength was also evaluated and compared using Instron testing machine. The Adhesive remnant index scores were then evaluated for all the groups.

From the statistical analyses of the results obtained the following conclusions were drawn:-

1. The surface roughness was found to be increased in combination group compared to acid etching and sandblasting groups by both image analyses of SEM photomicrographs and non-contact 3D profiler. The difference between acid etching and sandblasting groups was not statistically significant.
2. The shear bond strength of the combination group was found to be higher in comparison with other two groups, and the difference was statistically significant.
3. In the present study the ARI scores reveal that more amount of adhesive was present at surface of enamel in combination group which indicates failure predominantly at the resin-bracket interface and for the acid etching and sandblasting groups' failures were predominantly at enamel-adhesive interface and the differences between combination group and other two groups were statistically significant.