Determination of Shear Bond Strength and Evaluation of Enamel Surface Changes Following Debonding of Different Ceramic Brackets: An-Vitro Study

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Abstract

Introduction: Ceramic brackets exhibit generally high bond strength and enamel surface damage after debonding. **Aim of the study:** To evaluate and compare shear bond strength and enamel surface changes while de-bonding different ceramic bracket systems. **Materials and methods:** Three types of ceramic brackets (polycrystalline Clarity; 3M Unitek, Monrovia, Calif; monocrystalline Inspire Ice; Ormco, Orange, Calif and Radiance; American orthodontics, USA) were bonded to extracted maxillary premolars, with Transbond XT light cure adhesive paste (3M Unitek). The sample consisted of 90 extracted maxillary premolar teeth. 15 bonded teeth of each type, were tested on UTM and 15 bonded teeth, were removed by pliers according to the manufacturers recommendations. After debonding with pliers ARI scores and SEM analysis of tooth surface and bracket base were evaluated under different magnifications (30X and 500X). **Results:** The mean SBS value of Inspire Ice, Radiance and clarity Advanced were 22.81 ± 2.02 MPa, 17.93 ± 1.63 MPa and 17.28 ± 1.45 MPa respectively. ARI score showed that most of the adhesive left on the tooth surface of monocrystalline brackets. SEM analysis showed that enamel surface changes in the form of open focal holes on tooth surface and globules were found on the corresponding bracket base. **Conclusion:** The highest SBS with minimum enamel surface damage observed on Inspire Ice.

Keywords: Ceramic bracket, Clarity, Inspire Ice, Radiance, SBS, SEM, ARI and enamel damage.

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INTRODUCTION

The In fixed orthodontics, earlier appliances were attached to the patients teeth by brackets and tubes with bands. After the introduction of etching technique by Michael G Buonocore bonding of attachment to enamel was started [1]. Newman introduced direct bonding technique as an alternative to banding in the field of Orthodontics [2]. In recent years adults are seeking esthetic orthodontic treatment. During early 1970's Plastic brackets were introduced in dentistry. These polycarbonate brackets had disadvantages of discoloration and slot distortion caused by water absorption [4, 17, 28]. To compensate disadvantages of polycarbonate brackets, high grade medical polyurethane brackets and polycarbonate brackets reinforced with ceramic and ceramic brackets have been recently introduced [3]. Ceramic brackets were made of

aluminium oxide and were available in Monocrystalline sapphire and polycrystalline ceramic brackets in orthodontics, since 1980's. This ceramic bracket has esthetically superior to plastic brackets. Ceramic brackets have certain advantages of color stability, high bond strength, and torque control than plastic brackets [6].

Monocrystalline brackets are more translucent than polycrystalline brackets [10]. Polycrystalline zirconia brackets (ZrO) have greatest toughness and cheaper but opaque and less aesthetic than monocrystalline brackets [11]. High bond strength of ceramic brackets may causes problems of enamel surface fracture during debonding[7]. It is mainly due to bond failure occurs at the enamel adhesive interface. To overcome this limitation, a second generation brackets with mechanical base was introduced in

1991(Transcend 2000, 3M Unitek, Monrovia, Calif). It has lower shear bond strength and causes less enamel surface fracture than the first generation, but It requires special debonding instruments [8]. In third generation (3M Unitek) collapsible bracket introduced in 1997 has a vertical slot, which help a consistent bracket failure mode during debonding, as in the same manner as metal brackets [9]. Bonding of ceramic brackets are done by three different methods consist of chemical, mechanical or combination of both. Mechanically retentive ceramic bracket are more desirable than chemically retentive brackets because second one shows higher bond strength. Higher bond strength causes more enamel surface damage after debonding [7]. So the manufacturers have continuously modified bracket base designs such as microcrystalline, mechanical ball, dove tail, dimpled, button etc and new debonding technique with different types of plier introduced in the market for their particular brand of brackets [22].

In this study consist of three ceramic brackets ; Clarity advanced poly crystalline ceramic brackets (3M Unitek, Monrovia, Calif) had microcrystalline mechanical base[13] and two monocrystalline ceramic brackets ; Inspire Ice (Ormco, Orange, Calif) and Radiance (American orthodontics, USA) are mechanically retained ceramic bracket with patented bead ball and patented quad matte respectively. Manual method of bonding of adhesive was done to the bracket base [14]. Enamel surface damage caused by debonding of ceramic brackets is more than that of metal brackets due to their higher bond strength [16]. The greater amount of enamel surface damage during debonding of ceramic bracket due to the presence of ceramic mesh, which has greater adhesion on enamel surface than other metal brackets [25].

Microscopic evaluation of tooth surfaces after debonding shows many scratches and rough surface. These surfaces provide potential site of plaque accumulation, stain and demineralization through microbial activity [24].

In recent years many types of ceramic bracket materials are available and it is necessary to determine the shear bond strength and intensity of enamel surface damage after debonding of various brackets.

This study was selected to determine the shear bond strength and intensity of surface damage when using these brackets in human teeth. For this study we used two monocrystalline bracket (Radiance and inspire Ice bracket) and one polycrystalline bracket (Clarity advanced) with mechanical base designs and to compare and measure the shear bond strength in universal testing machine and also determine enamel surface damage after debonding of these brackets with their corresponding pliers introduced by the manufacturer. Enamel surface and bracket base after debonding can be evaluated by SEM analysis. This

study help to assess which ceramic bracket exhibits highest bond strength and causes minimal damage to enamel after debonding of these brackets clarity advanced, Inspire Ice and radiance.

MATERIALS AND SUBJECTS

Ninety extracted maxillary premolars were extracted for orthodontic purpose used as sample for this study and stored for seven days in (0.1% wt/vol) thymol-water solution at room temperature, for asepsis and dehydration prevention [22]. After this period, the remaining soft tissues, calculi and root-adhered bone fragments were removed. Teeth were stored in distilled water at 4°C, which was replaced every seven days. All teeth had intact enamel surface with no caries and large restorations. Teeth selected were not pre-treated with chemical agents, such as hydrogen peroxide, formalin or fluoride. Prior to the start of the experiment, the teeth were rinsed and randomly assigned to three equal groups of 30 teeth in each group for three different bracket systems. A study by Hobson 2 *et al*. showed significant bond strength differences between upper and lower premolars. To obtain reliable results in enamel bond strength studies, the same tooth type from the maxillary or mandibular arch should be used and only maxillary premolars were included for this study.

Three types of Maxillary premolar ceramic brackets with 022" slot MBT series were selected : Clarity Advanced was manually pasted Poly crystalline AlO_2 ceramic bracket (U45, 6400-611) with microcrystalline mechanical base design having base area of 11.69mm^2 , Inspire Ice was clear monocrystalline AlO_2 ceramic twin bracket having base area of 11.50mm^2 with patented bead ball bracket base[22] and Radiance was clear monocrystalline AlO_2 ceramic twin bracket having base area of 15.1mm^2 with patented quad matte bracket base[31]. Identification of brackets is shown in (fig: 1 a-c).

Fig-1: Clarity advanced, b- Inspire Ice and c-Radiance

All teeth were scaled and given a thorough prophylaxis was done by water and pumice without fluoride with a rubber cup for 5 seconds under slow speed. Each rubber cup was replaced after 5 prophylactic procedures [27]. All teeth were rinsed and dried. Then bonding was done according to the manufacturer's instructions. The buccal enamel was

etched for 30 seconds with a 37 per cent phosphoric acid gel (ORTHO-TECH), rinsed with water spray for 20 seconds and air-dried with oil-free compressed air. At this point, each tooth had a chalky- white appearance. The bonding Primer (Transbond XT; 3M Unitek, St Paul, Minn) was placed on the etched area. The teeth were then dried with air. The adhesive (Transbond XT; 3M Unitek, Calif) was applied to the bracket base. Then the bracket was fixed on to the tooth with a constant force at the ideal occluso- gingival and mesio-distal position [15]. Each tooth was light cured for 10 seconds using a halogen curing light. All bonded specimens were placed in distilled water for 12 hours at 37°C after bonding [22]. The shear bond strength of the samples was tested on a Universal Testing Machine (Tinius Olsen). Then debonding of all samples was done as stated by the manufacturer for determining ARI index of bracket base at 10x magnification of optical stereomicroscope and SEM analysis of enamel surface and bracket base for determining enamel surface changes after debonding of brackets by using their respective pliers.

The sample consisted of 90 extracted maxillary premolar teeth were randomly assigned to 3 groups. 30 bonded clarity advanced brackets, 30 bonded Inspire Ice brackets and 30 bonded Radiance brackets. 15 of each bracket types were tested on a universal testing machine to determine shear bond strength and 15 of each bracket type, were removed by pliers according to the manufacturers recommendations to compare the enamel surface changes with the help of SEM analysis.

SHEAR TEST

The shear bond strength of the samples was tested on a Universal Testing Machine. (Tinius Olsen). The force required to shear off the bracket was recorded in Newton at a crosshead speed of 1mm/minute connected to a computer that recorded the results of each test. The specimen was held in lower jaw of the machine so that the bonded brackets base was parallel to the shear force direction. Force applying chisel was held in upper jaw and specimens was stressed in an occluso gingival direction at the bracket-tooth interface (fig-2). The force recorded in newton was converted in to Megapascals as a ratio of Newtons to surface area of brackets.

Fig-2: Sample mounted on UTM

Evaluation of adhesive remnant index on bracket base:

Clarity advanced brackets used in this study was debonded by conventional Weingart plier [22] (fig-3a) (Skodi, Made in India) by placing the beaks of the plier mesio-distally and applying constant pressure (Fig: 3b)

Fig-3a: Weingart plier for debonding clarity bracket

Fig-3b: Debonding clarity advanced bracket

Inspire Ice monocrystalline brackets used in this study were debonded by using ormco # 866-4020 debonding plier (fig-4b) by position the jaws of the instrument behind the gingival and occlusal tie-wings of the bracket. Squeeze the instrument handle to close the jaws around the bracket body. Continue squeezing the instrument handle to engage the wedge and advance it toward the bracket pad. As the wedge comes into contact with the tooth, it will peel the bracket from the tooth (fig: 4a).

Fig- 4a: Debonding of inspire ice bracket

Fig- 4b: ormco # 866-4020 debonding plier

Radiance brackets used in this study were debonded by using the recommended #001-017405, Radiance plus pliers (Fig-5b) by placing the opposing tips of the pliers occlusal and gingival under the tie wings of the bracket, while applying constant pressure to the handles (fig:5a).

Fig-5a: Debonding of radiance bracket

Fig-5b: #001-017405, Radiance plus pliers

After debonding all bracket base were examined by optical stereomicroscope of 10 times magnification, with the following classifications consist of 4-point scale from 0 to 3:

SCORE: 0 – No adhesive left on the bracket base;

SCORE: 1- Less than half of the adhesive left on the bracket base

SCORE: 2-More than half of the adhesive remained on the bracket base

SCORE: 3 – All adhesive was remained on the bracket base [23].

Scores were given by repeated checking of bracket base independently by 3 observers in oral pathology department and rechecked this score after 3 days by the same examiner. From this rechecked data more accurate and similar value were taken as score of each bracket base.

Sem analysis

Tooth surfaces and bracket base were examined by used to determine the site of the enamel surface and bracket base after debonding of bracket by the use of each group of brackets were debonded with their corresponding pliers recommended by their manufacturers such as #001-017405 debonding pliers

designed by American orthodontics for Radiance, #866-4020 debonding plier designed by Ormco for inspire ice and Weingart plier designed by SKODI, in India for clarity advanced bracket.

After ARI score evaluation, enamel surface damage was evaluated with the help of Scanning Electron Microscope (JEOL; MODEL-JSM6390) at increasing magnifications (30 and 500 x). The 30x magnification provide whole bracket base and tooth surface area [25]. SEM analysis provided only qualitative evaluation. In SEM analysis, initially the brackets were debonded, then the tooth surface and bracket base were mounted on aluminium stubs with their bases facing up, sputter coated with a 100Å⁰ layer of gold (Autofine coater JFC 1600, JEOL, Japan) and analysed using a high vacuum SEM (JSM 6390 LA, JEOL, Japan) that captured secondary electron images at 15kV using 12mm working distance. SEM of tooth surface image was a mirror image of SEM of bracket base image of same sample

STATISTICAL ANALYSIS

Data was analyzed using the statistical package SPSS 22.0 (SPSS Inc., Chicago, IL) and level of significance was set at $p < 0.05$. Descriptive statistics was performed to assess the mean and standard deviation of the respective groups. Normality of the data was assessed using Shapiro Wilkison test. Inferential statistics to find out the difference between the groups was done by one way ANOVA and Tukey's HSD posthoc test. ARI score comparison of proportion done using Chi square statistics.

RESULTS

Inspire Ice and Radiance bracket were used as experimental group and Clarity Advanced was used as control group. Shear bond strengths and debonding forces of these three ceramic brackets were evaluated by universal testing machine (Tinius Olsen) [22]. The SBS (MPa) value for all 15 samples in each of the three groups are displayed in (Table 1). The mean SBS for the Clarity advanced; Inspire ice and Radiance were 17.28, 22.81, and 17.93 MPa, respectively. The repeated-measures ANOVA found a significant difference between the groups and a P value < 0.05 . Result showed that (Table-2) there was statistically significant and higher SBS of Inspire Ice than Clarity advanced and Radiance ceramic brackets and also showed the clarity advanced and radiance had almost similar value, but slightly higher in Radiance bracket.

Table-1: Shear bond strength value

	Group A	Group B	Group C
	Clarity	Inspire Ice	Radiance
sample 1	14.81	22.64	19.11
sample 2	17.53	18.26	19.67
sample 3	17.95	23.61	15.27
sample 4	18.37	23.26	15.47
sample 5	19.51	20.17	16.44
sample 6	16.25	22.56	19.14
sample 7	16.39	24.86	19.81
sample 8	17.91	25.43	17.68
sample 9	18.79	22.35	16.58
sample 10	18.66	21.78	19.11
sample 11	16.22	22.86	19.29
sample 12	18.36	24.41	18.39
sample 13	17.54	20.62	16.68
sample 14	14.66	25.61	16.44
sample 15	16.25	23.82	19.87
MEAN	17.28	22.816	17.93
SD	1.451369	2.020671	1.639917
1 st quartile	16.25	22.065	16.51
3 rd quartile	18.365	24.115	19.215
IQR	2.115	2.05	2.705

Table-2: Oneway anova summary statistics

Source of variation	Sum of squares	df	Variance	F	P
Between Groups	274.0890	2	137.0445	46.5094	0.001*
Within Groups	123.7572	42	2.9466		
Total	397.8462	44			

One way Anova shows significant difference exist between the groups regarding shear bond strength ($p < 0.05$)

Table-3: Tukey's hsd poc hoc analysis

Group comparison	DIFFERENCE	95%CONFIDENCE INTERVAL	P VALUE
GROUP 1 vs GROUP 2	5.5300	4.0072 to 7.0528	0.0000*
GROUP 1 vs GROUP 3	0.6500	-0.8728 to 2.1728	0.558
GROUP 2 vs GROUP 3	-4.8800	-6.4028 to -3.3572	0.0000*

* $P < 0.05$ is statistically significant

Post hoc analysis using Tukey's HSD test shows the significant difference between Group 1vs 2 AND Group 2 vs 3

INTERPRETATION

The One way ANOVA followed by post hoc analysis test was used to find out the statistical significance between the groups. It is found out that

there is a significant difference exist between the groups ($p < 0.05$). Post hoc analysis of the pair wise groups also showed statistical significance $p < 0.05$) (Group A vs B, Group A vs C and Group B vs C). Highest and lowest bond strength observed in Group B and Group A respectively as shown in the table. The amount of adhesive remaining on the bracket base was evaluated using 4-point ARI score showed in table-4.

Table-4: Ari score of bracket base

Sample Number	Radiance	Inspire Ice	Clarity Advanced	Chi Square Value
0	4(26.6%)	7(46.6%)	2(13.3%)	0.04*(X ² =12.5)
1	7 (46.6%)	5(33.3%)	5(33.3%)	
2	3 (20%)	2(13.3%)	6(40%)	
3	1 (6.8%)	1(6.8%)	2(13.3%)	
Total	15	15	15	

SCORE: 0 – No adhesive remaining on the bracket base;
 SCORE: 1- Less than half of the adhesive on the bracket base
 SCORE: 2-More than half of the adhesive on the bracket base
 SCORE: 3 – All adhesive remaining on the bracket base [23]

ARI scores 0 showed that no adhesive remaining on the bracket base 4 Radiance, 7 Inspire Ice and 2 Clarity advanced brackets sample and Score 1 showed that less than half of composite only on bracket base of 7Radiance, 5 Inspire Ice and 5 Clarity advanced brackets sample. Only 1 specimen of each of the Radiance and Inspire Ice have all the residual adhesive remaining on their bracket base score 3. ARI score 2 showed that more than half of composite on bracket base of 3 Radiance, 2 Inspire Ice and 6 Clarity advanced brackets sample.

Tooth surface examination: There was no macroscopic evidence of enamel surface damage seen after debonding of brackets. When the tooth surfaces and bracket base undergo SEM analysis, there were small holes on the tooth surface adhesive remnants and small globules of enamel particle present on bracket base of the same sample. The open holes were large on clarity advanced tooth surface (fig:6a and 6c) and large globules on respective bracket surface (fig: 6b and 6d), Medium sized holes on radiance tooth surface (fig: 7a and 7b) and medium sized globules on bracket base (fig: 7c and 7d) and very small holes on inspire Ice tooth surfaces (fig: 8a and 8b) and small globules on bracket base (fig: 8c and 8d) at 30x and 500x magnification respectively.

Sem images at 30x and 500x magnifications

Fig-6a: Clarity tooth surface at 30x magnification shows holes

Fig-6b: Clarity bracket base at 30x magnification shows globules

Fig-6c: Clarity tooth surface at 500x magnification shows holes

Fig-6d: Clarity bracket base at 500x magnification shows globules

Fig- 7a: Radiance tooth surface at 30x magnification shows holes

Fig-7b: Radiance bracket base at 30x magnification shows globules

Fig- 7c: Radiance tooth surface at 500x magnification shows holes

Fig-7d: Radiance bracket base at 500x magnification shows globules

Fig- 8a: Inspire Ice tooth surface at 30x magnification shows holes

Fig-8b: Inspire Ice bracket base at 30x magnification shows globules

Fig-8c: Inspire Ice tooth surface at 500x magnification shows holes

Fig-8d: Inspire Ice bracket base at 500x magnification shows globules

DISCUSSION

Different types of ceramic brackets are available in recent days. In general, ceramic brackets are composed of aluminium oxide, which may be single crystal (monocrystalline) or polycrystalline. Among these monocrystalline brackets are more expensive and have more esthetics than polycrystalline brackets. Clarity is a collapsible polycrystalline bracket. Inspire Ice and Radiance is collapsible monocrystalline bracket, which has greater optical clarity. Ceramic bracket debonding causes considerable amount of enamel loss due to its high shear bond strength [16]. Several authors tried to reduce bond strengths by changing the adhesive paste, etchants, or the etching times and some manufacturer recommends different types of debonding plier. But no consistent method should not found to reduce the enamel fracture after debonding the brackets. The lack of ductility of ceramic brackets may generate stress in the adhesive–enamel interface that may produce enamel cracks after debonding. Ceramic brackets using chemical retention cause enamel damage more often than those using mechanical retention [17, 19, 20]. This damage occurs probably because the location of the bond breakage is at the enamel–adhesive interface rather than at the adhesive–bracket interface [17-20]. Microscopic evaluation of tooth surfaces shows many scratches and rough surface after debonding. These surfaces could potential site of plaque accumulation, stain and demineralization through microbial activity. Calcium loss from the enamel surface particularly can result in dental erosion [24]. All type of ceramic brackets have problems during debonding, mechanically retained brackets have adequate bond strength and cause minimal enamel damage [16, 30].

The purpose of this in vitro study was to compare the shear bond strength, Adhesive remnants index on bracket base and enamel surface damage after debonding of three ceramic brackets (Clarity advanced, Inspire Ice and Radiance). All these brackets selected for this study have mechanically retained base designs.

In present study, result showed that there was statistically significant and higher SBS of Inspire Ice than Clarity advanced and Radiance ceramic brackets. Park MG reported in their study that the bead base surface of Inspire Ice has many round monocrystalline beads, which is completely distributed over the base, there was small undercuts in between the beads, which helps in mechanical interlocking of the adhesive resin resulting in higher SBS than that of other brackets[33]. Result (table 1) showed that shear bond strength of clarity advanced and radiance had almost similar value, but slightly higher in Radiance bracket. Shear bond strength of monocrystalline brackets greater than that of polycrystalline brackets [32, 33]. Result showed that SBS of Inspire Ice was greater than that of Radiance. Lopez JL reported in his study that bond strength inversally proportional to the bonding area of bracket [34]. The average bracket-base areas of Radiance and Inspire Ice brackets were 15.1 and 11.50 mm² respectively [13, 22, 31].

In recent times to maintain the enamel structure in its pretreatment state and to reduce the iatrogenic damage, correct bonding and debracketing techniques with their respective pliers introduced by their manufacturers. The present study compared the debonding characteristics of a recently introduced debonding instrument designed to debond Inspire Ice and Radiance with clarity advanced bracket debonded using weingart pliers.

ARI scores represent the site of bond failure after debonding at the bracket adhesive interface or at the enamel adhesive interface. Macroscopic evaluation showed that cohesive failure occurs in the adhesive system. In the present study ARI score 0 indicating the adhesive failure at bracket-adhesive interface with distinct impression of the bracket mesh on enamel surface. ARI score 3 indicating the adhesive failure at enamel-adhesive interface. ARI score 1 and 2 indicating all the three types of bond failure. The cohesive adhesive failure occurs in 2 Radiance, 2 Inspire Ice and 4 Clarity advanced sample.

ARI scores (table 4) indicated and supported to the study of Liu J K et al that the two debonding pliers to leave most of the adhesive remaining on the enamel surface and small amount of composite only on bracket base[26]. ARI score 0 and 1 indicated to leave significant amount of the adhesive remaining on the tooth surface and fewer amounts on bracket base [26]. This result showed that with the new debonding instrument, left more residual adhesive on the enamel surface than the use of weingart pliers. Only 1 specimen of each of the Radiance and Inspire Ice have all the residual adhesive remaining on their bracket base. This result supported to the study of Suliman *et al.* and contradict ory to the study of Ostby *et al.* showed that the monocrystalline ceramic brackets had most of the adhesive remaining on the tooth surface with well-

defined outline but in case of polycrystalline ceramic bracket, less than 47% of sample showed most of the adhesive left on the tooth surface and in other half less than half of the adhesive left on the tooth surface[5].

On SEM analysis, in this study showed that ceramic brackets with low bond strength having clarity advanced brackets shows more enamel fracture than the other two brackets. These results supported to the study of Liu *et al.* and Chen *et al.* reported that debonding collapsible ceramic brackets with the pliers recommended by the manufacturers are safer[22,26]. Only 2 enamel fractures were noted when debonding the Inspire Ice brackets, 3 for Radiance and 6 for Clarity advanced brackets. The bond failure at the bracket-adhesive interface reduces the risk of enamel fracture. This result indicated that it is safe to debond the ceramic bracket with the pliers recommended by the manufacturers.

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CONCLUSION

The present study was done to evaluate and compare the shear bond strength and enamel surface damage after debonding of different ceramic brackets such as Clarity advanced, Radiance and Inspire Ice. The study led to the following conclusions:

- 1) The shear bond strength of Clarity advanced, Radiance and Inspire Ice was 17.28MPa, 17.93MPa and 22.816 MPa respectively. The repeated-measures ANOVA found a significant difference between the groups and a P value 0.001. A Tukey's post hoc test found that there was no significant difference between the clarity advanced group and the Radiance.
- 2) The amount of adhesive remaining on the bracket base was evaluated using 4-point ARI score showed that more than 75% of Radiance and Inspire Ice brackets have ARI scores of 0 and 1, but Clarity advanced only below 50% of these scores. That means most of the adhesive left on the tooth surface indicated that the bond failure occurs at the bracket-adhesive interface reduces the risk of enamel fracture with the help of pliers recommended by the manufacturers.
- 3) In this study SEM analysis showed that Only 2 enamel fracture were noted when debonding the Inspire Ice brackets, 3 for Radiance and 6 for Clarity advanced brackets. This result indicated that it is safe to debond the ceramic bracket with the help of pliers recommended by the manufacturers.

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