Laboratory evaluation of a compomer and a resin-modified glass ionomer cement for orthodontic bonding

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Abstract: The mean shear debonding force of stainless steel orthodontic brackets with microetched bases bonded with either a compomer or a resin-modified glass ionomer cement was assessed. In addition, the amount of cement remaining on the enamel surface following bracket removal was evaluated. Finally, survival time of orthodontic brackets bonded with these materials was assessed following simulated mechanical stress in a ball mill. Debonding force and survival time data were compared with those obtained for brackets bonded with a chemically cured resin adhesive, a light-cured resin adhesive, and a conventional glass ionomer cement. There were no significant differences in mean shear debonding force of brackets bonded with the compomer, resin-modified glass ionomer, chemically cured resin adhesive, or the light-cured resin adhesive. Brackets bonded with a conventional glass ionomer cement had a significantly lower mean shear debonding force than that recorded for the other materials. The Adhesive Remnant Index (ARI) mode score indicated that significantly less cement remained on the enamel following debonding of brackets cemented with resin-modified or conventional glass ionomers compared with other adhesives. The median survival time for brackets cemented with the compomer, resin-modified glass ionomer, chemically cured resin, or light-cured resin were significantly longer than for brackets cemented with conventional glass ionomer. The compomer and the resin-modified glass ionomer adhesive appear to offer viable alternatives to the more commonly used resin adhesives for bracket bonding.

Key Words: Compomer, Resin-modified glass ionomer, Ball mill

Following the introduction of acid etching of enamel by Buonocore[1] in 1955, the use of composite resins for direct bonding of orthodontic brackets to teeth[2] has become a routine part of fixed appliance therapy.[3-6] Modifications to adhesive formulations over the past 30 years have led to the current availability of two-paste systems,[7] no-mix adhesives,[8] light-activated direct bonding materials,[9,10] and brackets precoated with adhesive.[11,12] The use of composites for bracket attachment has, however, a number of disadvantages, including enamel loss that could occur during prophylaxis,[13] acid etching,[14] and debonding.[15] In addition, plaque accumulation around the bracket could lead insidiously to decalcification in individuals having poor oral hygiene.[16-18]

Glass ionomer cements, through a unique combination of properties, offer a potential means of addressing the shortcomings of composite resins. Adhesion to metal and enamel,[19] often without the need for acid etching,[20] less enamel damage at post-debond cleanup,[21] and the ability to release[22,23] and absorb[24,25] fluoride make these materials particularly attractive as orthodontic bonding agents. Although conventional glass ionomer cements have inferior bond strengths compared with composite resins,[26-28] newer hybrid materials comprising glass ionomer and composite components appear to offer greater potential for clinical performance.[20] Two of these materials are the light-activated products Dyract Orthodontic (De-Trey Dentsply, Kanstanz, Germany) and Fuji Ortho LC (GC America Inc, Chicago, Ill). Dyract Orthodontic belongs to a new class of materials called compomers,[29-31] which are formed by combining composite resin and fluoride silicate glass. Fuji Ortho LC is a resin-modified glass ionomer cement.[32,33] Although independent laboratory studies have evaluated the potential of Fuji Ortho LC[34] and Dyract Orthodontic[35] for bracket bonding, no study to date appears to have compared the bond strength of these materials under the same experimental conditions.

A recent laboratory investigation[34] emphasized that further attention should be given to the bracket-pad

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conditioning procedure to enhance bond strength with Fuji Ortho LC. Sandblasting the bracket base may improve bond strength, as shown by a previous study using Ketac-Cem,[36] but the effect of sandblasting on Fuji Ortho LC has not yet been assessed.

Fuji Ortho LC has performed well in uncontrolled prospective clinical trials,[32,33] and similar data on Dyract is awaited. At present, no reports of randomized clinical trials exist comparing either of these two new materials with conventional composite resins for bracket bonding. In the absence of such investigations, laboratory studies should subject specimens bonded with these new bonding agents to simulated mechanical stress in an attempt to predict their likely clinical performance and provide comparative data with conventional composite adhesive systems.

The aims of this study were to assess the mean shear debonding force of stainless steel brackets with microetched bases bonded with either the compomer material Dyract Orthodontic or the resin-modified glass ionomer cement Fuji Ortho LC. In addition, the amount of cement remaining on the enamel surface following debonding was evaluated. Finally, survival time of brackets bonded with each material was assessed following simulated mechanical stress in a ball mill. Comparisons were made between the newer materials and a chemically cured resin adhesive, a light-cured resin adhesive, and a conventional glass ionomer cement.

Materials and methods

To assess debonding force, 75 human premolars were collected and stored in distilled water following decontamination in 0.5% chloramine. They were divided into five groups, each comprising seven maxillary and eight mandibular premolars. Each tooth was notched in the apical one-third and mounted with the long axis vertical to below the amelocementum junction in a block of self-curing acrylic resin. The teeth were then cleaned with a pumice slurry, washed in distilled water, and dried with an air syringe. A stainless steel preadjusted edgewise bracket with microetched base (3M Unitek, Monrovia, Calif) was bonded to each premolar. Brackets were kept in the manufacturer's packaging until immediately prior to bonding and were handled at all times with bonding tweezers to avoid contamination of the bonding base. Fifteen brackets were bonded with each material. Five orthodontic bonding agents were investigated, and two—Dyract Orthodontic (De-Trey Dentsply, Kanstanz, Germany) and Fuji Ortho LC (GC America Inc, Chicago, Ill)—were chosen as the test materials.

Dyract is a single-component compomer resin formed by combining a composite resin and a glass ionomer cement. Supplied in sealed ampoules from which it is applied to the bracket base, it can be hardened only through photopolymerization. After its initial set, the material takes up water, initiating an ionic acid-base reaction, leading to the formation of hydrogels in the resin structure. Fuji Ortho LC is a powder-liquid–based resin-modified glass ionomer cement that is set using a tri-cure reaction. This comprises an acid base reaction of the glass ionomer components, a free radical addition polymerization reaction activated by visible blue light, and self-cure of the resin monomer.

A chemically cured resin adhesive (Right-On, TP, LaPorte, Ind), a light-cured resin adhesive (Transbond, 3M Unitek, Monrovia, Calif) and a conventional glass ionomer cement (Ketac-Cem, Espe, Oberbay, Germany) were chosen for comparison. Enamel etching for 15 seconds with 37% orthophosphoric acid gel was undertaken prior to bonding with Dyract Orthodontic, Right-On, or Transbond; the enamel surface was rubbed dry with a cotton wool roll prior to bonding with Ketac-Cem. Although an enamel conditioner is supplied by the manufacturer of Fuji Ortho LC, no enamel etching or drying was done prior to bonding with this cement because clinical performance of brackets bonded with Fuji Ortho LC has been shown to be adequate with no enamel pretreatment.[32] Otherwise, material mixing and light-curing of the cement (where appropriate) were performed according to the manufacturers' instructions.

Excess cement or adhesive was removed from around the bracket periphery immediately following bracket placement. For Dyract Orthodontic, Fuji Ortho LC, and Transbond, light-curing was undertaken for 5 seconds each from the mesial, distal, incisal, and gingival aspects of each bracket using an Ortholux light source (3M Unitek, Monrovia, Calif). When the cements were cured, they were transferred to a humidor and held at 37°C for 24 hours prior to measuring shear debonding force using a Nene N3000 testing machine with a crosshead speed of 1 mm/minute. A prebent piece of 0.8 mm stainless steel orthodontic wire was placed under the gingival tie-wings of each bracket[26] and connected to the upper arm of the Nene testing machine.

After each bonded bracket failed, the amount of adhesive remaining on the tooth surface was coded, using the criteria set out in the adhesive remnant index of Årtun and Berglund:[37]

0=no adhesive remains on the tooth surface

1=less than half the adhesive remains on the tooth surface

2=more than half the adhesive remains on the tooth surface

3=all the adhesive remains on the tooth surface

To assess survival time, another group of 50 human premolars was collected. These teeth were treated and stored in a manner identical to that used on the teeth to be debonded. They were divided into five groups, each with five mandibular and five maxillary premolars. The lingual or palatal enamel surfaces of the teeth in each group to be bonded with each material were coded with a diamond bur to facilitate identification later. Ten brackets were bonded with each material in accordance with the manufacturers' instructions, as outlined previously, and specimens were then stored in a humidor at 37°C for 24 hours.

Specimens were subjected to mechanical stress for 24 hours in a ball mill containing 470 g of ceramic spheres and 250 ml of distilled water at 37°C. After each hour of testing at 100 revolutions per minute, the failed specimens (debonded brackets) were removed from the mill. The distilled water was replaced with a fresh sample (37°C), and testing recommenced and continued for 100 hours.

The mean shear debonding force values for the materials tested were compared using ANOVA followed by a Tukey test. Weibull analysis[41] was used to calculate probability of failure at given values of applied force. The use of Weibull analysis may be more applicable to the evaluation of debonding force data[42] than the comparison of mean and standard deviation values for each material, since it takes due account of the debonding force values at the extremes of the distribution. A Weibull modulus value can then be generated for each specimen group, allowing numerical evaluation of the "dependability" of each material. Kruskal Wallis tests were used to compare mode ARI scores. Median survival time (MST) was determined for each material in the ball mill experiment using survival analysis[8,36,38] (BMDP IL, University of California). A log rank test (Wilcoxon/Breslow) was used to compare median survival times.

Table 1
Debonding force values for 15 brackets bonded with each material

Material	Mean shear debonding force (N)	Standard deviation	Weibull modulus	Characteristic debonding force (N)	Correlation coefficient
Dyract Orthodontic	51.1	20.2	2.6	55.1	0.95
Fuji Ortho LC	49.3	18.5	3.2	53.9	0.96
Right-On	46.9	15.3	2.6	53.6	0.94
Transbond	61.8	17.4	4.6	69.5	0.96
Ketac-Cem	22.5***	7.6	2.1	25.4	0.91

*** $p < 0.001$

Results

Debonding force data for each material are shown in Table 1. The mean shear debonding force for brackets cemented with Ketac-Cem (22.5 N) was significantly less than that for brackets bonded with any of the other materials. Weibull data are shown also in Table 1 and demonstrated graphically in Figure 1. The highest Weibull modulus was recorded with Transbond, indicating the greatest bond reliability was found with this adhesive. The high values of correlation coefficient of linearized least squares fit indicate that the data fit closely the Weibull distribution function. Figure 1 illustrates that for a given probability of failure, significantly less force would be required to dislodge a bracket bonded with Ketac-Cem compared with brackets bonded with any of the other materials. The mode ARI score for each debonded group is given in Table 2. There was a significant difference between the Fuji Ortho LC and Ketac-Cem groups compared with the other groups examined ($p<0.001$).

Median survival time (MST) plots for brackets cemented with each material are shown in Figure 2. The median survival time for brackets cemented with Ketac-Cem was 20.5 hours while MSTs for the other materials ranged from 37 hours and 50 hours with Right-On and Transbond, respectively, to 49 hours and 54 hours with Fuji Ortho LC and Dyract Orthodontic, respectively. The difference in MST between the Ketac-Cem group and the other groups was highly significant ($p<0.001$).

Table 2
Mode ARI scores recorded for 15 brackets bonded with each material

Material	Mode ARI scores
Dyract Orthodontic	3
Fuji Ortho LC***	0
Right-On	3
Transbond	3
Ketac-Cem***	1

*** $p < 0.001$

Discussion

This laboratory investigation evaluated the mean shear debonding force of stainless steel brackets with microetched bases bonded with a compomer material or a resin-modified glass ionomer cement; the results were compared with those obtained using a chemically cured resin adhesive, a light-cured resin adhesive, and a conventional glass ionomer cement. Premolar brackets with a curved microetched base were used for bonding because microetching has been shown to improve bond strength by about 20%.[36]

The mean shear debonding force of brackets bonded with Ketac-Cem was significantly less than that recorded with Transbond or Right-On, confirming the findings of other studies.[26,36] The higher bond strength recorded with light-cured glass ionomers compared with conventional glass ionomer cements is in agreement with the findings of some other laboratory investigations.[34,44] The highest bond strength recorded was with Transbond, followed by Dyract Orthodontic, Fuji Ortho LC, and Right-On. There was no significant difference, however, in debonding force between these materials. Only one other study has compared the mean shear bond strengths of brackets bonded with Dyract Orthodontic and Transbond.[35] Rock and Abdullah[35] found consistently higher mean shear bond strengths with Transbond than with the compomer material, confirming the findings of the present study. Interestingly, in the study reported here the compomer material and the resin-modified glass ionomer cement had very similar mean shear debonding forces, 51.1 N and 49.3 N, respectively. However, acid etching is required for bracket bonding with Dyract Orthodontic, while no enamel preparation is required prior to bonding with Fuji Ortho LC, thereby maintaining the integrity of the enamel surface.

The results of most studies on bracket retention have presented a mean debonding force or bond strength value and, in some cases, a standard deviation.[43] Using a mean value and a standard deviation assumes that the data are distributed normally. While the strength of a particular material is an important characteristic to establish in laboratory studies, it is often of greater significance to the clinician to establish whether this strength will be exhibited reliably.[45] Application of Weibull statistics will readily provide this type of information, the analysis remaining valid whether or not the data are normally distributed.[46] No previous study on the new brands of glass ionomer cement currently available for orthodontic bonding appears to have applied this form of statistical analysis to bond strength data, despite recommendations in the literature to do so.[46]

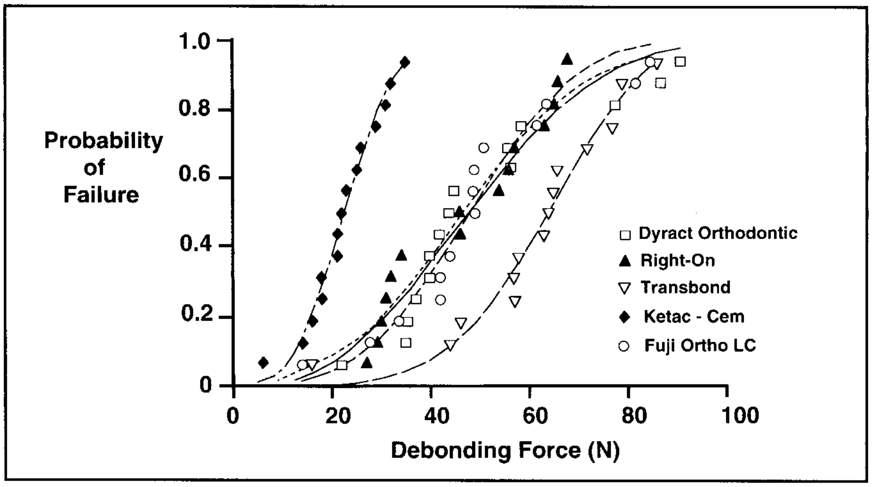

Figure 1

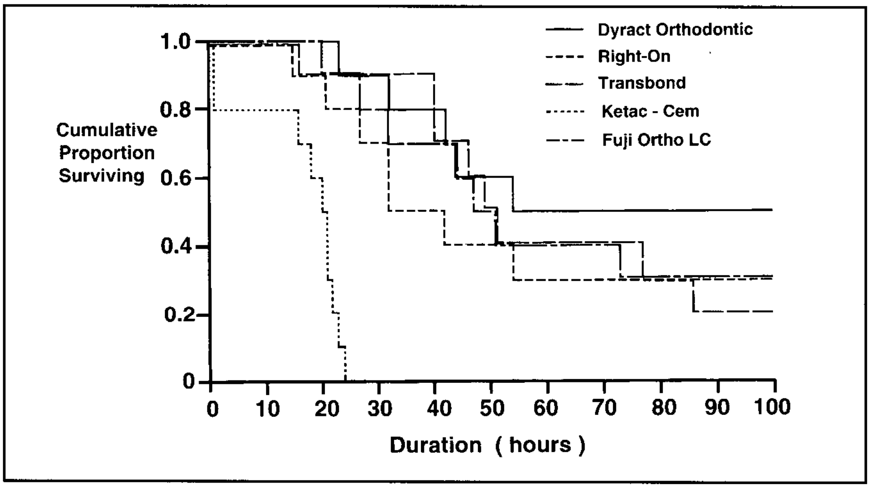

Figure 2

Application of Weibull analysis to the data obtained in the present study showed that if forces of the order of 30 N were chosen as representative of forces applied clinically, one would expect 76% of the brackets bonded with Ketac-Cem to fail. Eighteen percent of brackets bonded with the compomer Dyract Orthodontic or Fuji Ortho LC would be expected to fail at this force level, while only 11% of brackets bonded with Right-On and 2% of brackets bonded with Transbond would be expected to fail.

In the study reported here, there was also a significant difference between materials in the amount of adhesive remaining on the tooth surface following debonding. The conventional glass ionomer cement, Ketac-Cem, and the resin-modified glass ionomer cement, Fuji Ortho LC, had low ARI scores of 1 and 0, respectively, supporting in part the findings of a recent study by Komori and Ishikawa.[34] Those researchers also found that the most frequent ARI score for specimens bonded with Ketac-Cem 24 hours after shear debonding was 1, but the most frequent ARI score with Fuji Ortho LC at the same time point was 2. They used a different bracket base design (Mini-Diamond, Ormco, Glendora, Calif), which was not microetched; this may account in part for the differences in results of the two studies. Sandblasting of stainless steel bracket bases has been shown to promote bond failure at the enamel-cement interface.[36] Without sandblasting, more cement will be left on the enamel surface with Fuji Ortho LC after debonding. Komori and Ishikawa[34] recommended that further attention should be given to the bracket-pad conditioning procedure or to alteration of the bracket base design to enhance bond strength between Fuji Ortho LC and stainless steel brackets. The use of microetched bracket bases in the present study has shown clearly that the mode ARI score with Fuji Ortho LC will be 0 if such a bracket design is used for bonding.

The compomer material, Dyract Orthodontic, appears to behave more akin to a resin adhesive than to a glass ionomer cement having the same mode ARI score of 3 as Right-On and Transbond, confirming the finding of Rock and Abdullah.[35] Considerably more cleanup time would therefore be likely following debonding of brackets bonded with Dyract Orthodontic than with Fuji Ortho LC.

Although the results of bond strength tests and Weibull analysis on orthodontic bonding materials are of interest, specimen testing is usually carried out in environments that do not closely approach that of the clinical situation but, in many cases, are carefully controlled.[40] Although initial strength of a bonding material is an important characteristic for clinical function, material durability when subjected to oral stresses over time is equally relevant.[47] The cyclical nature of mechanical, thermal, and chemical processes in the mouth invariably induces material fatigue, which can lead to bond failure.[40] Studies conducted on bonded specimens have tended to subject them to thermal[34] insult, and only two studies[36,39] have exposed specimens to mechanical stress in a ball mill. The study reported here subjected 50 bonded specimens (10 bonded with each material) to such mechanical stresses. Brackets bonded with Dyract Orthodontic or Fuji Ortho LC survived almost 2.5 times longer than those bonded with Ketac-Cem. The median survival times for brackets bonded with either Dyract Orthodontic or Fuji Ortho LC (54 hours and 49 hours, respectively) were very similar to those recorded for brackets bonded with Transbond. Brackets bonded with Right-On or Ketac-Cem had shorter median survival times (37 hours and 20.5 hours, respectively). The longer survival times of the brackets bonded with light-cured materials compared with those bonded with conventional chemically cured materials may be related to the light-cured materials having greater protection from moisture contamination in the 24 hours prior to ball-milling by virtue of being command set.[48,49] The ball mill technique employs diverse forces of varying magnitude,[50,51] with bond failure likely occurring through a process of slow crack propagation generated within the bonding material by the force of impact and mechanical action of the ceramic spheres.[40]

No previous study has subjected brackets bonded with either a compomer or resin-modified glass ionomer material to mechanical stress in a ball mill and compared the results with those obtained using a conventional resin adhesive system or a conventional glass ionomer cement. The ball mill technique has proven useful in predicting the clinical performance of some orthodontic materials;[38,40] on this basis, one might expect brackets bonded with Dyract Orthodontic or Fuji Ortho LC to perform clinically in a manner comparable to brackets bonded with Transbond. This supports the findings of the Weibull analysis. To date, however, there are no results of randomized clinical trials comparing the performance of Dyract Orthodontic or Fuji Ortho LC with respect to Transbond, and these tests are required to further verify these findings.

Conclusions

1. There was no significant difference in mean shear debonding forces of brackets bonded with Dyract Orthodontic or Fuji Ortho LC and those bonded with conventional resin adhesive, but values were significantly greater for all materials compared with Ketac-Cem.

2. Weibull analysis indicated that, at a given force, the probability of bond failure is higher with Ketac-Cem. The values for Dyract Orthodontic, Fuji Ortho LC, and Right-On were very similar but less than those recorded for Transbond.

3. The Adhesive Remnant Index (ARI) mode value indicated that with Fuji Ortho LC, no cement was left on the tooth surface after debonding (mode score 0) while with Ketac-Cem, less than half the cement remained (mode score 1). With Dyract Orthodontic, Right-On, and Transbond most of the adhesive remained on the tooth after debonding.

4. Microetching of the bracket base is advisable with Fuji Ortho LC to minimize the amount of cement left on the tooth after debond.

5. The median survival time of brackets bonded with Dyract Orthodontic or Fuji Ortho LC was 2.5 times that of brackets bonded with Ketac-Cem.

6. Dyract Orthodontic, Fuji Ortho LC, Right-On, and Transbond are likely to perform similarly when used clinically for bracket bonding.

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Commentary: Laboratory evaluation of a compomer and a resin-modified glass ionomer cement for orthodontic bonding

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The use of conventional composite resins for the bonding of orthodontic brackets entails a potential risk of enamel decalcification. Therefore, there has been considerable interest in the development of bonding materials that would be more beneficial to the preservation of the dental enamel.

Glass ionomer cements, which possess many favorable characteristics, have historically been applied directly to the enamel without acid etching. However, results of both laboratory tests and clinical performance evaluations indicate that conventional glass ionomer cements are not recommended for clinical bonding of brackets due to their inferior bond strength. Currently, however, there is a consensus of opinion forming that favors the use of a new generation of hybrid cements that contain both resin and glass ionomer.

This new family of glass ionomer cements is now being introduced to the orthodontic specialty, but some confusion exists surrounding the exact formulation of the products. It is important to understand the performance of these materials during actual clinical application. Laboratory tests do play an important role in characterizing the bonding potential of these new systems. However, are the results of laboratory trials good predictors of clinical performance? How does the clinician interpret and evaluate the validity and practical utility of the results of laboratory and/or clinical studies? This present investigation makes an informative contribution in addressing these questions.

In the majority of laboratory studies, shear and/or tensile bond strengths are measured in order to evaluate the potential performance of the adhesive during clinical application. Many researchers have investigated one or more of the variables that can affect adhesive bond strength and contribute to bracket failure. However, even if the mean debonding forces and variables for bracket failure are known, the data obtained from laboratory experimental models are not derived from the demanding oral environment. Consequently, laboratory results cannot accurately predict the specific condition or location of the interface where bond failure might occur.

This paper is unique and sophisticated in terms of the research design; the investigators put an emphasis on reproducing the clinical environment. Bond strength and residual cement following debonding (ARI scores) were evaluated, and survival analysis was applied to calculate a cumulative probability of bracket failure during the experiment by simulating mechanical stress in a ball mill. With respect to the experimental design, it was very interesting to have the specimens subjected to thermal insult and mechanical stress in the ball mill. However, the mechanical stress generated by the force of impact and mechanical action of the ceramic spheres in the ball mill does not easily translate to active orthodontic clinical situations. Further explanation of this relatively unfamiliar apparatus might make it easier to interpret the experimental design and results.

One major concern that troubles clinicians, researchers, and manufacturers alike is the difficulty in comparing results from different reports. Since survival analysis has not been commonly applied in orthodontics, it is difficult to compare the results of this study with others. The cumulative probability of bracket failure at various times generated by survival analysis provides more useful and informative data for an indication of the average time of bracket failure. Future efforts might be directed toward not only standardizing laboratory testing, but also toward including survival analysis in research designs so that data can be easily compared and interpreted by clinicians.

This study may contribute to the development of a new generation of bonding materials and techniques that provide benefits to the dental enamel associated with bonding procedures. If the mechanical properties of the new generation of glass ionomer cements can be substantially improved, then the next critical step will be to evaluate the efficacy of these materials in preventing demineralization or enhancing the remineralization of enamel through the release and reuptake of fluoride.

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