Shear bond strength of rebonded brackets after removal of adhesives with Er,Cr:YSGG laser

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Abstract

This study was conducted to examine the bond strength of rebonded orthodontic brackets after adhesive residuals on the surface of the bracket bases were removed by Er,Cr:YSGG lasers. Seventy-six brackets bonded to premolars with a self-etching primer adhesive system were equally divided into four groups after the first debonding with the bracket bases (Group 1) untreated, and treated by (Group 2) Er,Cr:YSGG laser, (Group 3) sandblaster, and (Group 4) Er,Cr:YSGG laser/sandblaster. The treated brackets were rebonded to the new premolars in the same manner as the first-stage experiment. The shear bond strengths were measured, with the bonding/debonding procedures repeated once after the first debonding, and the bracket/adhesive failure modes were evaluated after each debonding. The treated bracket base surfaces were observed under a scanning electron microscopy (SEM). The mean rebond strengths were significantly lower in group 1 than in other groups, and that there were no significant differences between the other groups. The mean initial bond strength was significantly higher than the mean rebond strength in group 1 but there was no

significant difference between the two in the other three groups. Failures at the bracket-adhesive interface occurred frequently at second debonding in group 1. Under the SEM, residual adhesive was removed from the bracket bases by Er,Cr:YSGG laser, while adhesive remnant was seen underneath the meshwork of the bracket bases and microroughness appeared on the meshwork after sandblasting. Er,Cr:YSGG laser certainly could serve the purpose of promoting the use of recycled orthodontic brackets.

Introduction

In orthodontic practice, lasers are used for dental enamel etching,[1] removal of adhesive residues on the surface of dental enamel after debonding,[2] reduction of the risk of enamel damage when a ceramic bracket is debonded,[3] alleviation of pain at the time of tooth movement[4] and acceleration of tooth movement velocity,[5] among others. For these purposes, Er,Cr:YSGG,[1] Er:YAG,[2] CO_2,[3] and Ga/Al/As diode[4,5] laser systems are available. Er,Cr:YSGG lasers perform cutting dental hard tissue with water accelerated by the laser beam, so that a report says that impact on pulpal tissue and change in dental hard tissue composition can be held down to the minimum.[6]

In orthodontic treatment, brackets sometimes have to be rebonded because of their falling and the need to correct their positions.[7] Factors affecting the shear bond strength of recycled brackets include bracket base design,[8] microscopic damage to bracket bases,[9] the amount of adhesive left on the surface of the bracket bases[8,10] and the method of removing these leftovers.[8,9,11,12] It has been usual practice to remove adhesives on the surface of the bracket base with green stone,[11] gas torch[11], and sandblasters.[8,9,11,12] As regards the effect of sandblasting, all the previous studies have come up with conflicting findings: some authors held that the bond strength of rebonded brackets decreased significantly from the initial bond strength, [8,12] some others asserted it increased significantly, [8] and still others said it stayed unchanged. [8,11]

As of June 2010, no studies were found in Pub Med on the rebond strength of brackets after adhesive remnants were cleared off from the bracket bases by lasers.

Reynolds [13] were of the view that 6 - 8MPa was the minimum bond strength of brackets needed to endure occlusal and orthodontic forces. Most previous studies used 6MPa as a threshold for bond failure. [14,15]

The purpose of this study was to examine the bond strength of rebonded orthodontic brackets after adhesive residuals on the surface of the bracket bases were removed by Er,Cr:YSGG laser.

Materials and methods

The protocol (ECNG-H-37) was approved by the Committee of Ethics of The Nippon Dental University School of Life Dentistry at Niigata. Informed consent was obtained from all participants.

A total of 160 premolars were collected and stored in a solution of 0.1% (wt/vol) thymol at 4°C for a maximum of 3 months before testing. The criteria for tooth selection included intact buccal enamel with no pretreatment chemical agents, no cracks incidental to extraction and no caries.

Before bonding, 84 in 160 premolars were cleaned with a mixture of water and nonfluoride pumice paste (Pressage, Shofu, Kyoto, Japan), rinsed with a water spray and dried with an oil-free air stream.

A total of 84 brackets used in this study were of a metal premolar standard edgewise type with an 0.018-inch slot (Victory series, 3M Unitek, Monrovia, CA, USA). The average bracket base area was 9.94 square millimeters. The brackets were bonded by one operator.

For bonding the brackets, a self-etching primer adhesive system was used. Transbond Plus self-etching primer (3M Unitek) was rubbed onto the dry surface of the enamel for 3 seconds and subsequently ventilated with oil-free compressed air. After priming, Transbond XT adhesive (3M Unitek) was applied to the bracket base. The bracket was put on the buccal surface of each tooth and pressed firmly into place to express adhesive from the rim of the bracket base. Excess adhesive was removed with an explorer without disturbing bracket positions. Then, the bracket was light-cured with an Ortholux LED curing light (3M Unitek) for a total of 20 seconds (10 seconds mesially and another 10 seconds distally on each tooth).

The root of each tooth-bonded bracket was cut off with a separating disk (Separate disk, Shofu). The tooth crown was embedded in the specimen holder ring with a chemically activated acrylic resin, so that the buccal enamel surface was parallel to, and projected above, the brim of the cylindrical specimen holder ring. All specimen holder rings with the embedded teeth were stored in artificial saliva at 37°C for 24 hours. Eighty-four teeth, each with a bracket bonded, were randomly divided into four groups of 21 teeth each. From each group, 19 teeth were subjected to shear bond strength tests.

A universal testing machine (EZ Test, Shimadzu, Kyoto, Japan) was used to determine the shear bond strength. The specimen holder rings were arranged in this machine so that a load was applied to the occlusal bracket wings with a force in the occlusogingival direction parallel to the buccal enamel surface. The force required to shear off the bracket was recorded in Newtons (N) at a crosshead speed of 1.0 mm per minute. The shear bond strength (MPa) was then calculated by dividing the shear force by the bracket base area.

After bond failure, the bracket bases and the enamel surfaces were examined by the same operator under a stereomicroscope at 20 X magnification. The adhesive remnant index (ARI) was used to assess the amount of adhesive left on the enamel surface. [16] Two months later, the ARI scores were recorded for a second time by the same investigator. Kappa statistics showed that intra-rater reliability was very good (0.91). [17]

Adhesive residues on the bracket bases after debonding in each group were treated differently from group to group.

Group 1: Adhesive left on the bracket bases was not removed.

Group 2: Adhesive remnants were removed by Er,Cr:YSGG laser (Waterlase MD, Biolase Technology Inc, CA, USA). The operating conditions used were: a power output of 3.75W, a wave length of 2.78 μm, a pulse duration of 140 μs, a frequency of 20 Hz and air and water levels, each 50%.

Group 3: A sandblaster (Jet Blast III, J Morita, Tokyo, Japan) was used for the removal of adhesive remnants on the bracket bases. Sandblasting was carried out using 50 μm aluminum oxide particles under a pressure of 0.45 MPa The distance between the surface of the bracket base and the tip of the sandblasting hand piece was 10 mm. [11,18]

Group 4: After adhesive remnants were removed by Er,Cr:YSGG laser as in group 2, sandblasting was done for 3 seconds.

To remove abrasive grit adhered to the bracket bases in groups 3 and 4, an air compressor was used for 2 seconds and then a ultrasound cleaner (PIEZO-1, Yoshida, Tokyo, Japan) for 15 minutes. Whether the adhesive remnants were thoroughly gotten rid of was confirmed with the naked eye after drying the laser irradiated bracket bases with a moisture-free air stream in groups 2 and 4 and after the application of compressed air in group 3.

Two new unused brackets, and the base surfaces of those remaining two brackets in each group, which had not been tested for shear bond strength were sputter-coated with palladium and platinum, and examined under a scanning electron microscope (SEM, S-800, Hitachi Ltd, Tokyo, Japan) at 200 X magnification. An accelerating voltage was 15 kV.

Rebonding of the 76 treated brackets in groups 1 to 4 (19 brackets in each group) was done with the use of the remaining 76 premolars in the same manner as described earlier for the first-stage experiment using 84 premoars. Bonding strengths and ARI scores were measured as were done in the first-stage experiment. By numbering the first- and second-stage specimens, the rebond strengths were compared with the initial bond strengths.

Statistical analysis

Statistical analyses were performed using the SPSS for Mac version 17.0J (SPSS Japan Inc, Tokyo, Japan) and Excel-Toukei 2006 for Windows (SSRI, Tokyo, Japan). The mean bond strength, standard deviation, and range were calculated for each of the four groups. A two-way analysis of variance (ANOVA) was used to test the main effects of bonding/debonding sequences and reconditioning treatments on the mean shear bond strength. If the two-way ANOVA showed a significant interaction between these variables, a one-way ANOVA and the Scheffe test were used to compare the mean bond strengths between groups at each debonding. Paired t-test was used to compare the mean bond strengths between first and second debondings in each group. The Kurskal-Wallis test and the Steel-Dwass test were used in order to compare the ratios of the numbers of brackets showing less than 6MPa among the four groups, and the distribution of ARI scores among the eight groups. All the statistical tests were performed at a $P<.05$ level of significance.

Results

The two-way ANOVA showed significant differences in the mean shear bond strength between bonding/debonding sequences (F=60.37, P=.001, power=1.00) and between reconditioning treatments (F=14.16, P=.001, power=1.00), and significant interaction between two variables (F=16.33, P=.001, power=1.00).

The one-way ANOVA showed no significant differences in the mean initial bond strength among the four groups (F=.08, P=.972). The one-way ANOVA showed significant differences in the mean rebond strength among the four groups (F=32.33, P<.001) and the Scheffe post-hoc test showed that the mean rebond strengths were significantly lower in group 1 than in other groups (P<.001 in each comparison), and that there were no significant differences between the groups excluding group 1 (Group 2 vs Group 3, P=.716; Group 2 vs Group 4, P=.929; Group 3 vs Group 4, P=.970). Paired t-test revealed that the mean initial bond strength value was significantly higher than the mean rebond strength value in group 1 (P<.001) but that there was no significant difference between the two in the other three groups (Group 2, P=.425; Group 3, P=.123; Group 4, P=.180) (Table 1). In the initial bond strength tests, all the brackets had more than 6MPa. In the rebond strength tests, the numbers of brackets below 6MPa were 17 (89.5%) in group 1, one (5.3%) in groups 2 and 4, and two (10.5%) in group 3. The Kruskal-Wallis test (P<.001) and the Steel-Dwass test found a significant difference in the ratio between group 1 and the other groups (P<.001 in each comparison) but no significant difference between groups 2, 3, and 4 (Group 2 vs Group 3, P=.934; Group 2 vs Group 4, P=1.000; Group 3 vs Group 4, P=.934).

Figure 1 presents typical SEM photographs of bracket bases before initial bonding and after surface treatment. In group 1, the bracket base was covered entirely with adhesive remnants as shown in Fig. 1-A. In group 2, no adhesive remnants were observed underneath the meshwork, whose surface (Fig. 1-B) looked smoother than that of any one of the unused brackets (Fig. 1-E). In group 3, microroughness appeared on the surface of the meshwork and adhesive remnants were seen underneath the meshwork (Fig. 1-C). In group 4, microroughness was recognized on the surface of the meshwork but adhesive remnants were not (Fig. 1-D).

The Kruskal-Wallis test and the Steel-Dwass test showed that there was a significant difference in the distribution of ARI scores between group 1 at second debonding and the other seven groups ($P<.001$ in each comparison), but not any significant difference among the other seven groups (Table 2). Failures occurred at the bracket-adhesive interface in many samples assigned to group 1 at second debonding. By contrast, in the other seven groups, the most common failure occurred at the enamel-adhesive interface.

Discussion

Our study found that the shear bond strength values of all the samples at first debonding measured up to 6MPa, which was the bond strength required for successful orthodontic treatment.[13] Our study showed that there was no significant difference in the mean initial bond strength and the distribution of ARI scores between four groups. This could be interpreted as a fair indication that the random division of 76 bracket-bonded premolars with brackets into four groups was adequate.

In our study, the mean rebond strength value for group 1 was significantly lower than that for any other three groups. Moreover, it was significantly lower than the mean initial bond strength. As Fig. 1-A demonstrates, the decreased rebond strengths were attributable to the fact that adhesive remnants reduced the area of contact between the bracket mesh and the adhesive used for rebonding. This view was congruent with the observation of Rosenstein et al. [10] that the adhesive left at the bracket bases was responsible for a reduction in rebond strength.

In our study, no significant difference was noted in the mean rebond strength among three groups other than group 1. Furthermore, the mean rebond strength was not significantly different from the mean initial bond strength in three groups other than group 1. In group 2, the mean rebond strength was on a par with the mean initial bond strength. As Fig. 1-B shows, this was presumably because residual adhesive was completely removed from the bracket bases by Er,Cr:YSGG laser. In some specimens in group 2, the surface of the meshwork of the bracket base partly got smooth (Fig.1-B). This was possibly due to the melting by heat. As suggested by De Moor et al. [6] in their report, presumably the surface of the meshwork must have been melt by dint of the interaction between the output power of Er,Cr:YSGG laser and air/water percentage.

In group 3, traces of adhesive were left at the bracket bases at the time of second bonding, but the rebond strength was comparable with that in groups 2 and 4. This was presumably due to the microroughness caused by aluminum particles on the surface of the bracket base as shown in Fig. 1-C. The presumption was perhaps supported by the observations of Willems et al. [8] that the microroughness on the surface of the bracket base increased its shear bond strength as the surface area for bonding increased. Our observations that sandblasting served to enhance the mean rebond strength value to almost the same level with the mean initial bond strength value tallied with the studies by Basudan et al. [11] However, Chung et al. [12] contended that sandblasting only served to lower bond strength. We thought that these different findings regarding the bond strength of rebonded brackets might have arisen from the differences in morphological changes of the bracket bases. This conjecture was based on the findings of Millett et al. [18] and Arici et al. [19] that adequate sandblasting time increased bond strength, and that longer sandblasting time and larger aluminum particles distorted the meshwork of the bracket bases, resulting in a decrease in bond strength.

Our finding that the mean rebond strength value in group 4 was almost equal to the mean initial bond strength was considered due to a multiplier effect of Er,Cr:YSGG laser and sandblast treatment as shown in Fig. 1-D.

From our finding that there were no significant differences in mean rebond strength among the three groups in which remaining adhesive was removed, we thought that the application of Er,Cr:YSGG laser as well as sandblasting was appropriate when recycled brackets are used.

The ratio of the number of brackets with bond strengths of less than 6MPa to the total in our *in vitro* study is corresponding to the bond failure rate in *in vivo* studies. [20]

Campoy et al. [21] reported a bond failure rate of 6.08% in their study using new brackets, Transbond Plus self-etching primer and Transbond XT adhesive. Using other types of adhesive systems, Linklater et al. [22] in their *in vivo* study put the failure rate at 6.34%; and Sunna et al., [23] 6.6%. These bond failure rates were lower than our ratio of rebonded brackets with bond strengths below 6MPa in group 1 (89.5%) and in close proximity to the ratios in groups 2 (5.3%), 3 (10.5%), and 4 (5.3%). This fact suggested that the ratio of brackets below rebond strength of 6MPa in groups 2, 3, and 4 should be acceptable clinically.

In the present study, bond failures occurred at the bracket-adhesive interface in many specimens in group 1 at second debonding and at the enamel-adhesive interface in the other seven groups. These phenomena suggested the possibility that the mechanical interlock between bracket base and adhesive becomes almost the same, whichever you might use, new brackets or recycled brackets, sandblasted or irradiated with Er,Cr:YSGG laser for removing adhesive remnants.

In our study, the sandblasting treatment was followed by ultrasonic cleaning to remove loose particles. This sequence of steps was decided to take based on the findings of

Kern et al. [24] that ultrasound had an edge over a gentle air stream when it came to the removal of loose particles after sandblasting. Therefore, we added the time required to remove loose particles by ultrasound to the time needed to get rid of adhesive remnants by sandblasting. Especially the time was significantly short in group 2 with a mean of 126.58 seconds when compared with group 3 with a mean of 922.63 seconds and group 4 with a mean of 1,031.42 seconds. As a consequence, it was found that the exclusive use of Er.Cr:YSGG laser only could shorten the treatment time the most. Therefore, we though that this method was clinically the most useful. Although recycling brackets may lead to cost-cutting [25], the problem is that Er.Cr:YSGG laser systems are still expensive.

In conclusion, our study demonstrated that Er,Cr:YSGG laser certainly could serve the purpose of promoting the use of recycled orthodontic brackets.

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Figure legends

Figure 1. Scanning electron microscope (SEM) photographs of bracket bases.

A, Untreated; B, Treated with Er,Cr:YSGG laser; C, Treated with sandblaster; D, Treated with Er,Cr:YSGG laser and sandblaster; E, Unused.

Table 1. Shear bond strengths for two debondings of four groups and statistical comparisons

		Shear bond strengths (MPa)						Comparison between debondings
		First debonding (DB1)			Second debonding (DB2)			
		Mean	SD	Range	Mean	SD	Range	Paired t-test / P value
Group 1	Control	10.97	2.26	7.74 - 15.18	3.91	1.33	2.08 - 6.24	<.001
Group 2	Er,Cr:YSGG	10.70	2.27	6.40 - 15.12	9.86	2.28	5.84 - 15.10	.425
Group 3	Sandblasting	10.70	2.16	6.67 - 14.58	9.05	2.31	5.28 - 13.28	.123
Group 4	Er,Cr:YSGG+ Sandblasting	10.93	2.36	6.90 - 14.25	9.39	2.44	5.34 - 13.91	.180

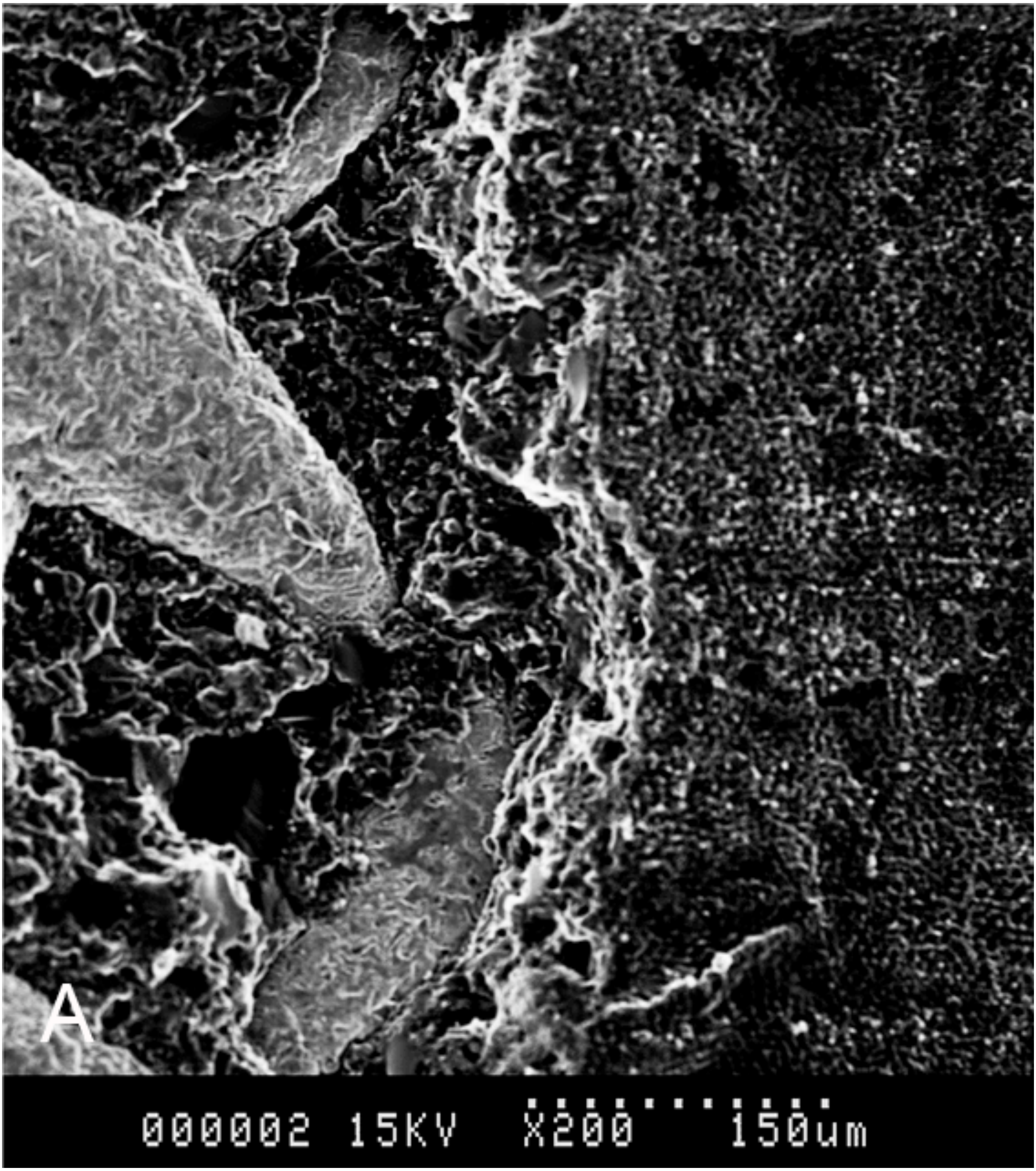
	Comparison between groups	
	First debonding (DB1)	Second debonding (DB2)
ANOVA / P value	.972	<.001
Scheffe test / significant comparison (P value)	–	Group 1 vs Group 2 (<.001) Group 1 vs Group 3 (<.001) Group 1 vs Group 4 (<.001)

SD indicates standard deviation.

Table 2. Distribution of ARI Scores and statistical comparisons

		ARI scores								Statistical comparison		
		First debonding (DB1)				Second debonding (DB2)				Kruskal-Wallis test	Steel-Dwass test	
		0	1	2	3	0	1	2	3	P value	Significant comparison	P value
Group 1	Control	6	9	4	0	1	1	8	9		Group 1 (DB2) vs Group 1 (DB1)	.001
											Group 1 (DB2) vs Group 2 (DB1)	.008
Group 2	Er,Cr:YSGG	6	6	6	1	7	7	4	1		Group 1 (DB2) vs Group 3 (DB1)	.007
										<.001	Group 1 (DB2) vs Group 4 (DB1)	.002
Group 3	Sandblasting	2	11	5	1	2	11	4	2		Group 1 (DB2) vs Group 2 (DB2)	.003
											Group 1 (DB2) vs Group 3 (DB2)	.018
Group 4	Er,Cr:YSGG+ Sandblasting	6	7	6	0	3	9	5	2		Group 1 (DB2) vs Group 4 (DB2)	.026

The ARI scores: 0, no adhesive remaining on the tooth surface;
1, less than half of the adhesive remaining on the tooth surface;
2, more than half of the adhesive remaining on the tooth surface;
3, all adhesive remaining on the tooth surface with a distinct impression of the bracket base.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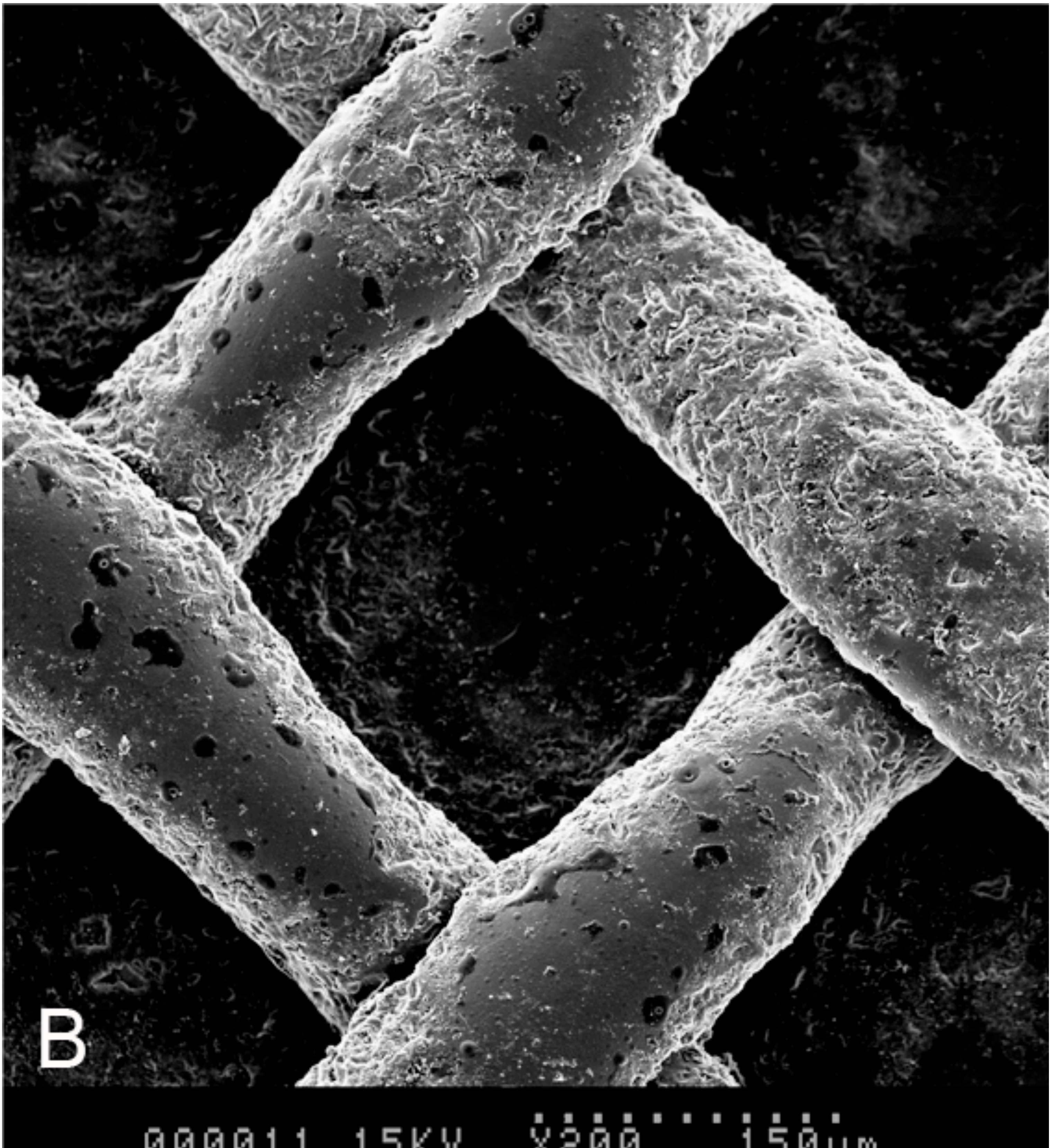
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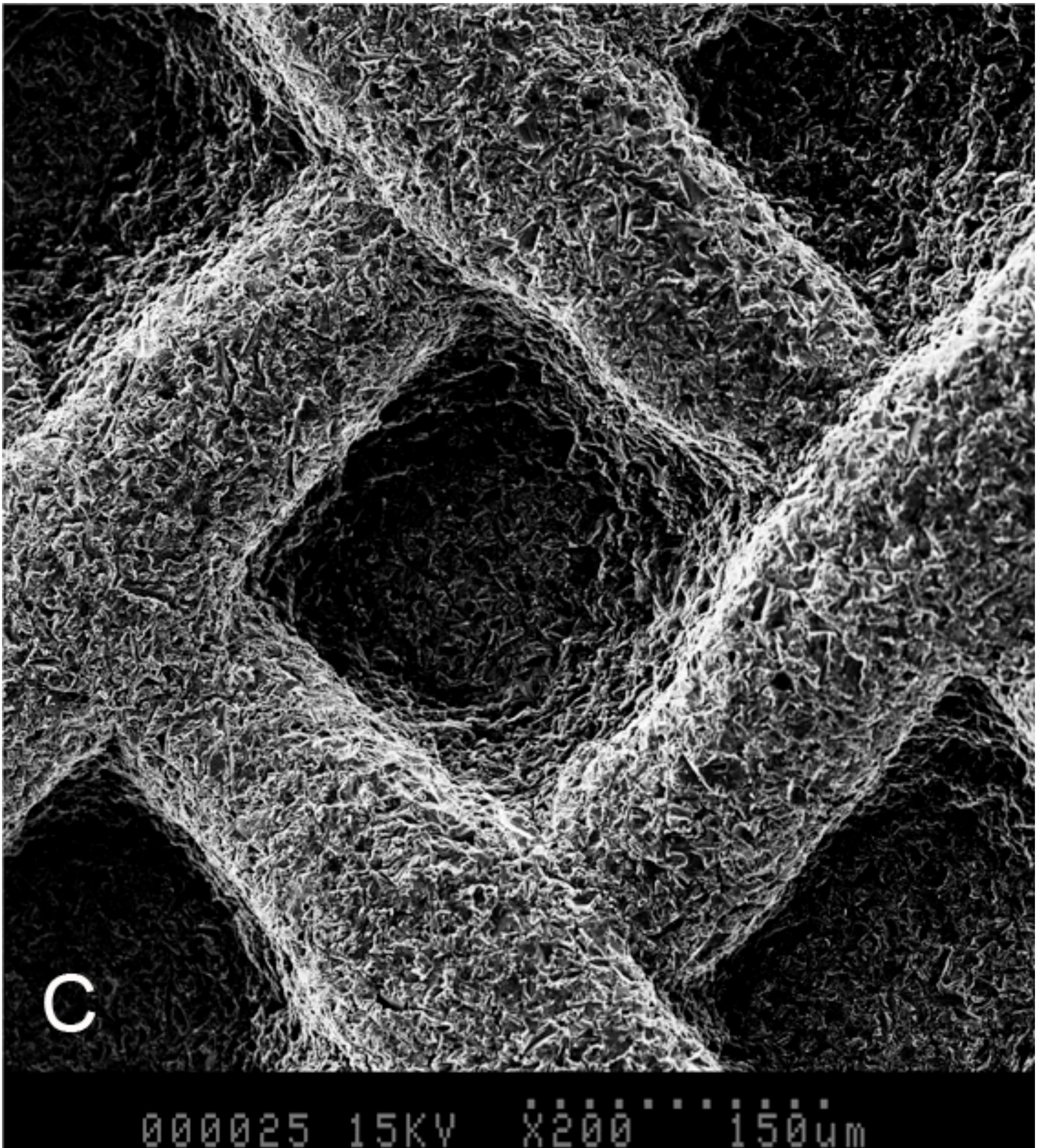
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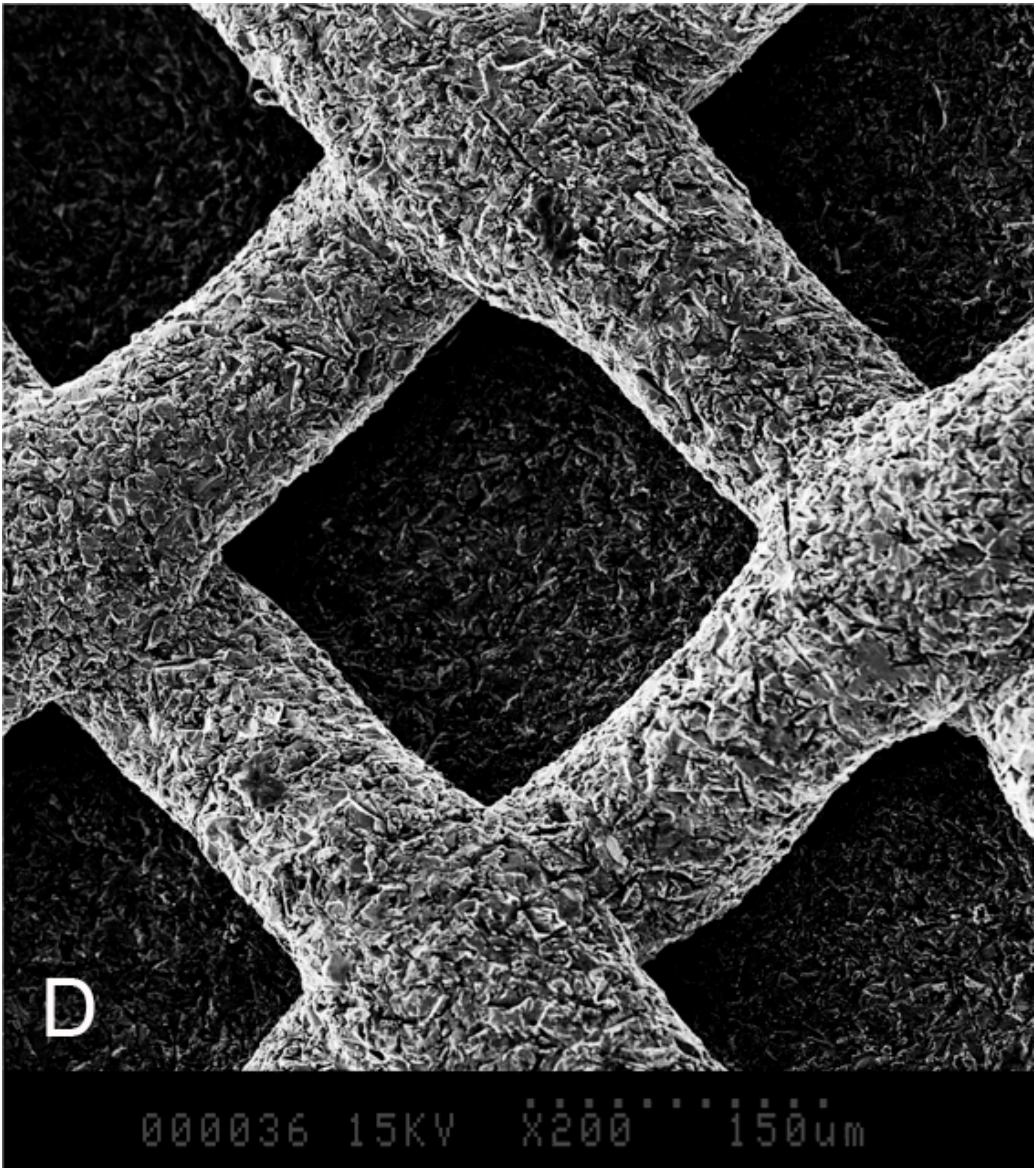

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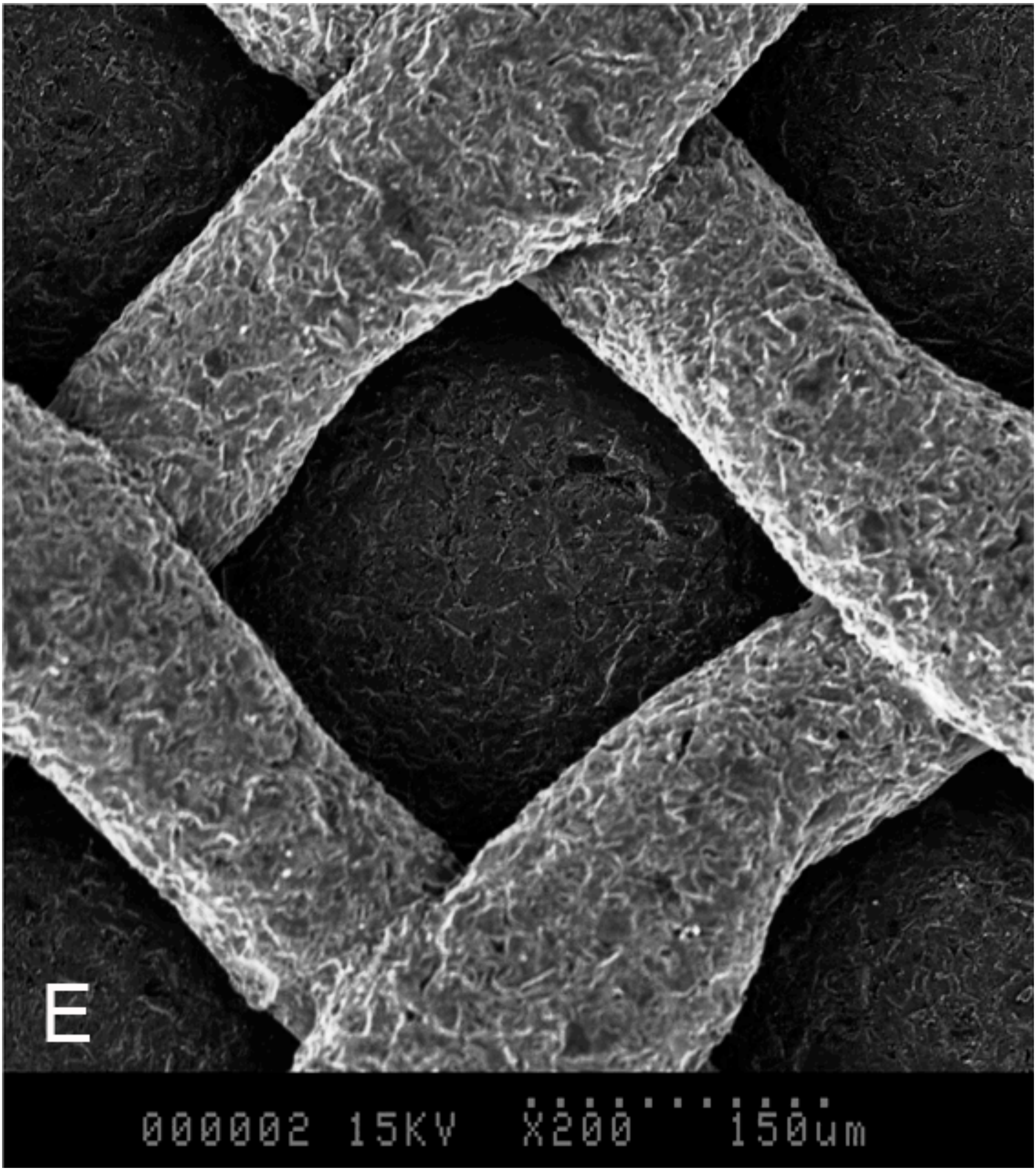
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