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Shear Bond Strength of Ceramic Brackets to Ceramic Surfaces Using No-primer Adhesive

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Abstract:

Objective(s): To simplify the bonding steps of orthodontic brackets, GC Ortho Connect adhesive with a primer solution in its composition has been presented. As a result, the primer application phase after etching has been eliminated. This study examined the shear bond strength (SBS) and adhesive remnant index (ARI) of ceramic brackets to the ceramic surfaces using two bonding systems, GC Ortho Connect and Brace Paste American Composite, in the presence or absence of silane. **Methods:** In this laboratory study, 40 IPS e.max ceramic blocks were assigned to four groups, and Protect ceramic brackets were bonded to them using GC Ortho Connect or Brace Paste American Composite adhesive in the presence or absence of silane (Primer Ceramic X Rely). Under a stereo microscope, the ARI was ascertained, and a universal testing machine assessed the SBS amounts. One-way ANOVA, Post hoc Tukey tests, and chi-squared test were used for statistical analysis, at a significance level of 0.05. **Results:** The SBS of ceramic brackets to porcelain using GC Ortho Connect without silane and Brace Paste American Composite with silane differed significantly (p=0.008), although other pair comparisons did not show significant differences. There was no discernible difference between the groups in terms of type of failure (p=0.84). **Conclusion:** It is acceptable to use Brace Paste American Composite adhesive with or without silane, or GC Ortho Connect adhesive with silane, to achieve the bond of ceramic brackets to porcelain surfaces. However, the bond strength between ceramic brackets and porcelain surfaces was inadequate when using GC Ortho Connect without silane.

Keywords: Ceramic Brackets; Shear Bond Strength; Silane

Introduction

Nowadays, composite resins are being routinely used in clinical settings for adherence of orthodontic attachments (like brackets and tubes) to the tooth surface. In orthodontic treatments, the bonding agent should have enough strength to hold the brackets during treatment, but it should not be so high as to damage the tooth enamel when the bracket is removed and its remnants are cleaned. Adequate bond strength in orthodontic treatments has been reported to be in the 6–10 MPa range.[1] It is also recommended that the ideal bond strength in orthodontic treatments should be lower than the force necessary to break the tooth enamel, which is approximately 14 MPa.[2]
Advances in cosmetic dentistry and the expansion of orthodontic treatments have led to an increase in the number of adult patients seeking these treatments. Most adult patients have already received various cosmetic treatments, including porcelain veneers, composite restorations, and amalgam restorations; therefore, orthodontic attachments should be bonded to these restored surfaces.[3, 4] Ceramics, such as porcelain materials, have many applications as restorative and aesthetic materials in veneers and fixed partial dentures, and many adult patients who are candidates for orthodontic treatments often have these restorations in their oral cavities. Although obtaining a good bond to the tooth's non-enamel surfaces can be problematic, the orthodontist must be able to correctly bond to enamel and a variety of restorative materials, such as composite resin, amalgam, and porcelain. Since the likelihood of orthodontic bracket bonding failure on porcelain surfaces is higher than on tooth enamel, researchers are concerned about bonding issues with porcelain surfaces.[5] At the same time, choosing the proper bonding system and polishing the porcelain surface are among the main factors affecting the bond strength.[6]
When bonding orthodontic brackets to porcelain, there are two significant challenges: achieving the optimal bond strength of 6–10 MPa, which is necessary to reduce the risk of bond failure during the treatment period, and the necessity of maintaining the beauty and function of the ceramic restoration after deboning.[7]
In order to modify the porcelain or the cement on it, the ceramic surface must be prepared, which has its own problems because the porcelain color might change, it might fracture due to future preparation, or plaque accumulation might be facilitated due to the lack of polishing and glazing on the porcelain surface. Consequently, it is crucial to pretreat porcelain surfaces in

order to attain adequate bonding strength values between orthodontic brackets and ceramic restorations.[6]

One of the recent advances in orthodontic bonding systems is the use of GC Ortho Connect (GC Orthodontics, Breckerfeld, Germany) bondless composite resins. Previous studies on this bonding agent have reported the bond strength to the enamel to be 6.57 MPa, but there is no information about its bond strength to porcelain.[8]

An acceptable bracket bonding system must resist both the destructive forces from the orthodontic wires and the forces from the oral environment. Bond strength is the force applied to a unit of surface to cause bond failure so that this failure occurs at the bonding interface or near to it. Most of the research comparing bracket-to-tooth bond strength among different bonding systems has focused on measuring tensile, compressive, or shear strength. Furthermore, due to the presence of functional forces in the oral environment, the bonding of brackets may undergo negative effects, leading to treatment failure. Shear bond strength is the main factor for evaluating the adhesion of materials, and the bond strength of orthodontic brackets should be at a level that can withstand the forces applied during treatment.[9]

The present study aimed to compare the shear bond strength and residual adhesive index of ceramic brackets on the ceramic surface using two different bonding methods in orthodontics (GC Ortho Connect and Brace Paste American Composite) with or without silane.

Methods

Sample size

In this in-vitro study, 40 ceramic brackets were bonded to ceramic blocks using four different bonding methods according to the presence or absence of silane and the type of bonding agent. The minimum required sample size was found to be 10 samples per group using Minitab software's multiple means comparison tool, taking into account the average standard deviation of 2 MPa, $\alpha = 0.05$, and $\beta = 0.2$. Both the sample selection and grouping of samples were randomized using a systematic random sampling method.[10]

Procedural steps

To prepare porcelain samples, 40 ceramic blocks measuring 0.6×1.5×0.2 cm were sintered and glazed from IPS emax ceramics (IPS e.max Ceram, Ivoclar Vivadent, Liechtenstein; components: SiO_2, Al_2O_3, Na_2O, K_2O) (Figure 1), and randomly allocated into four groups (N=10 each).

Figure 1: The porcelain samples.

Orthodontic bonding

Ceramic brackets (Protect ceramic bracket) of maxillary central incisors were used for the research. The study groups were prepared as follows:

Group A: bonding ceramic brackets on the ceramic surface by GC Ortho Connect (GC Corporation, Japan) in the absence of silane.

Group B: bonding of ceramic brackets on the ceramic surface by GC Ortho Connect in the presence of silane.

Group C: bonding of ceramic brackets on the ceramic surface by Brace Paste American composite (American Orthodontics, USA) in the absence of silane.

Group D: bonding of ceramic brackets on the ceramic surface by Brace Paste American composite in the presence of silane.

Two bonding systems, GC Ortho Connect (light-cured orthodontics adhesive) and Brace Paste American, were used for bonding brackets. In each experimental group, bracket bonding was performed according to the instructions of the bonding agent's manufacturer; 9.6% hydrofluoric acid etchant was placed on the porcelain for 40 seconds, washed for 60 seconds, and the sample was air-dried for 60 seconds.[11]

In groups B and D, two layers of silane (RelyX Ceramic Primer, 3M, ESPE, St. Paul) were placed on porcelain surfaces after etching, and the surfaces were dried for 60 seconds. Then, ceramic brackets were bonded on porcelain samples by GC Ortho Connect in group B and Brace Paste American Composite in group D, in compliance with the manufacturer's guidelines.

In groups A and C, following the etchant, ceramic brackets were bonded to the ceramic blocks by GC Ortho Connect and Brace Paste American Composite, respectively, following the manufacturer's guidelines. In all samples, excess adhesive material was removed with a scaler, and using an LED light-curing device (UltraLume 5, Ultradent, South Jordan, UT, USA), the samples were irradiated from four sides, 10 seconds from each side, for a total of 40 seconds[12]. The samples were kept in distilled water at 37ºC for 24 hours and alternately thermocycled at 55ºC/5ºC. In each cycle, the samples were placed at 5°C for 30 seconds and at 55°C for 30 seconds. For each sample, a total of 2000 cycles were repeated. An orthodontist performed all the steps of bracket bonding.

Evaluation of shear bond strength

Each group's shear bond strength was assessed using the universal testing machine (UTM; SANTAM STM 20 machine) with a needlehead diameter of 4.3 mm and a crosshead speed of 1 mm/min. A flat-ended steel rod was attached to the testing apparatus for this purpose, and a shearing force was then delivered in the direction of the porcelain blocks' longitudinal axis. Lastly, the highest power needed to debond the brackets was noted. For this purpose, bond strength values were computed in Newtons and then converted to MPa by dividing them by the brackets' cross-sectional area.

Adhesive remnant index (ARI) evaluation

A digital camera was used to determine the remaining adhesive index of the debonded matrix surface and the bracket surface. ARI scores were determined using a stereo microscope with 10x magnification (Figure 2) and graded as follows:

Grade 0: the porcelain surface had no remaining adhesive substance (Figure 2).

Grade 1: the porcelain surface had less than half of the adhesive substance left on it.

Grade 2: about 50% of the adhesive substance was still present on the porcelain surface.

Grade 3: Nearly all of the adhesive was still present on the porcelain surface (Figure 3).

The images were randomly selected to minimize the bias in this field, and two calibrated researchers were selected to check the ARI index. If the grades determined by the two researchers were different, the higher grade was selected as the final one. To reduce bias, the researchers were blinded to the experimental conditions of each sample during data collection and analysis.

Data analysis

SPSS 25 was used to analyze the data. GC Ortho Connect and Brace Paste American agents were used in groups to calculate and report the central dispersion indices (mean, standard deviation, standard error, upper and lower bounds, 95 confidence interval, and minimum and maximum values) of the shear bond strength of ceramic brackets to porcelain surfaces with and without silane. Two-by-two comparisons using post hoc Tukey tests were conducted after the bond strength data in the four study groups were analyzed using a one-way ANOVA. Additionally, the failure modes in the study groups were examined using the chi-squared test. This study's type 1 error was established at 0.05 (α=0.05).

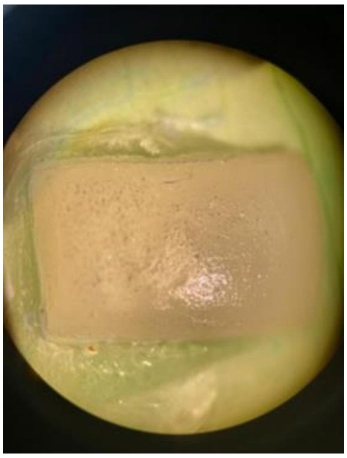

Figure 2: Complete debonding of the adhesive

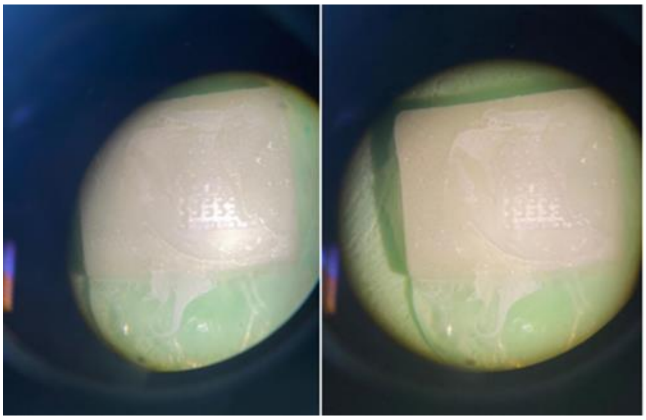

Figure 3: The remaining adhesive.

Results

According to Table 1, the results of the Shapiro-Wilk test showed that the p-value in all groups was greater than 0.05, indicating the normal distribution of data. The results of the Levene's test also showed that the p-value was 0.165 and the data was homogeneous; therefore, the ANOVA test could be performed for this study.

The shear band strength values of brackets in each group is presented in Table 2 and Graph 1. According to the results of one-way ANOVA, The shear bond strength values of ceramic brackets to porcelain varied significantly among the study groups (P=0.02).

Table 1 - Shapiro-Wilk test and Levene's test results		
	Shapiro-Wilk test	Levene's test
Group A: GC Ortho Connect without silane	0.075	0.165
Group B: GC Ortho Connect with silane	0.403	
Group C: Brace Paste American composite without silane	0.158	
Group D: Brace Paste American composite with silane	0.189	

Table 2 - Mean ± SD of shear bond strength (MPa) in different study groups						
group		Mean ± SD	%95 Confidence interval		Minimum	Maximum
			Upper bound	Lower bound		
A: GC Ortho Connect	-	1.23±1.36	0.26	2.2	0	4.49
B: GC Ortho Connect	silane	4.68±3.31	2.31	7.04	0.07	9.28
C: Brace Paste American	-	4.66±4.59	1.38	7.95	0.1	14.2
D: Brace Paste American	silane	7.01±4.74	3.61	10.4	1.87	17.62

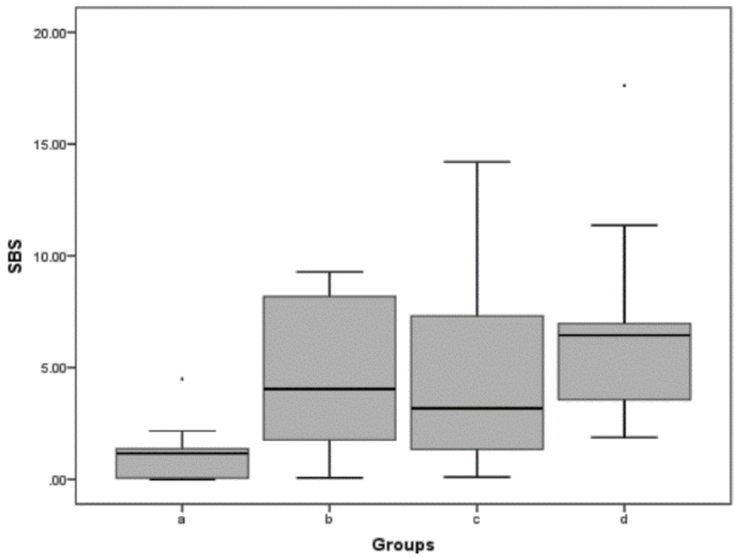

Diagram 1: Distribution of shear bond strength values of ceramic brackets in different groups.

Two-by-two comparisons using post hoc Tukey test revealed that the shear bond strength values of ceramic brackets to porcelain in groups A (GC Ortho Connect without silane) and D (Brace Paste American Composite with silane) differed significantly (p=0.008), although other pair comparisons did not show statistically significant differences (Table 3).

Table 3 - Two-by-two comparison of shear bond strength between different groups			
		Mean differences	P-value
GC Ortho Connect without silane	GC Ortho Connect with silane	3.44	0.19
	Brace Paste American composite with out silane	3.43	0.19
	Brace Paste American composite with silane	5.78	0.008
GC Ortho Connect with silane	Brace Paste American composite without silane	0.01	1
	Brace Paste American composite with silane	2.33	0.51
Brace Paste American composite without silane	Brace Paste American composite with silane	2.34	0.51

The result of the Cohens Kappa test was 0.83, indicating very high agreement between the raters. Table 4 presents the type of debonding (failures) frequencies in different groups. The chi-squared test showed no significant difference in the type of failure between different groups (P=0.84).

Table 4 - Frequencies of failure modes in different groups						
		Adhesive remnant index (ARI)				total
		0	1	2	3	
GC Ortho Connect	-	2	2	2	4	10
	silane	3	2	3	2	10
Brace Paste American composite	-	4	3	1	2	10
	silane	4	1	2	3	10

Discussion

Clinicians and researchers have always considered achieving a proper bond between porcelain surfaces and orthodontic brackets due to the importance of applying orthodontic forces without breaking the bond during treatment. These surfaces are not appropriate for resin penetration because of the physical characteristics of glazed porcelain surfaces and the chemical characteristics of bonding resins.[13]

In the present study, the results indicated that the Brace Paste American Composite adhesive with or without silane, or GC Ortho Connect adhesive with silane, were acceptable in achieving the bond of ceramic brackets to porcelain surfaces. However, the bond strength between ceramic brackets and porcelain surfaces was inadequate when using GC Ortho Connect without silane.

In the study by Shapinko et al.[8], which was conducted on bovine teeth using the conventional Transbond XT system and a new system (Connect Ortho GC containing the combination of primer in the adhesive), the mean shear bond strength for the two groups was 7.25 and 6.57 MPa, respectively, with no significant difference between the two groups. The researchers in the aforementioned study came to the conclusion that orthodontic bonding can be accomplished successfully with the GC Ortho Connect bonding. In the Bahrami et al. study, in contrast to the current research, the GC Ortho Connect group's bond strength (15.5 Mpa) was greater than that of the control group (Transbond XT) with (12.66 Mpa) or without primer (11.18 Mpa) This difference may be attributed to the fact that, unlike the present study, human premolar teeth were used in that investigation, and the control group employed Transbond XT adhesive.[14] Shalini et al.'s study compared Transbond XT light cure adhesive and Transbond Plus self-etching primer with brace paste adhesive. The shear bond strengths of 16.6, 18.05, and 16.2 were their respective values. All groups had adequate bond strength. Unlike the present study, that study used premolar teeth and metal brackets.[15] In the study by Pellitteri et al., the debonding rate of metal brackets bonded with two adhesives, GC ortho connect and ortho solo, was clinically compared. Both adhesives were acceptable and there was no statistically significant differences. This is in contrast to the present study. However, that study was conducted clinically and the present study was experimental.[16] The bond strength values obtained in the present study were somewhat lower than the results of the previous study. This difference could be attributed to the difference in substrate (porcelain substrate in this study versus bovine tooth enamel in the previous study). Different laboratory circumstances and research techniques may be the cause of the varying shear bond strength values of brackets reported in other studies using light-cured adhesives.[17, 18]

Conversely, case studies have compared the bond strength values of orthodontic brackets using self-adhesive and self-etch systems with those of conventional systems.[19] In addition, it has been claimed that orthodontic bonding can be accomplished with one-step and two-step self-etch/adhesive systems. The shear bond strength of ceramic brackets to porcelain substrate employing adhesive systems including primer has not been reported in any studies previously, to the best of the researchers' knowledge, so it is impossible to compare the findings of these investigations.[20, 21]

Previous studies have found varying values for the bonding strength of orthodontic brackets. Lower bond strengths were deemed unsuitable by Maijer and Smith, who thought that 8 MPa was adequate for brackets.[22]

In the current study, the blade tip's crosshead speed during the shear test was 1 mm/min. For the shear band strength test, the majority of investigations on the topic have employed a blade tip speed range of 1.0–10 mm/min. Notably, the chewing speed is between 81 and 100 mm/second or 4860 and 6000 mm/minute, and its frequency has been reported to be between 1.03 and 1.2 Hz, which means that these values are inconsistent with the clinical conditions in the oral cavity.[23]

The average bond strength stresses in bond strength test investigations are calculated by dividing the debonding force by the bracket base's surface area. This approach removes the significant regional component of the "bracket base surface," which has little bearing on the results. Additionally, the dimensions taken in the bracket base are not the same as the surface areas that come into contact with the adhesive. This restricts how broadly the findings may be applied to clinical settings. Additionally, the presence of slots and grooves enhances the mechanical retention produced by the adhesive layer in addition to increasing the effective surface area in contact with the bonding agent. The final morphology and interfacial properties of the adhesive–bracket set have resulted in different outcomes, and the adhesive layer thickness is obviously influenced by the bracket base design; flat bracket bases produce thinner adhesive film layers and more uniform forces than rough bracket bases. The size of the pores and grooves created in the bracket base, as well as the adhesive's rheological characteristics, determine this variable.[24]

With these explanations, perhaps using the average values of the shear band strength in evaluating the stress distribution is not very logical; furthermore, they are not identical to the forces leading to clinical failures. However, there seems to be no choice other than the present research methods due to the lack of alternative research strategies.[24]

The aim of bonding in orthodontic treatments is not to create a long-lasting attachment with the highest bond strength values, in contrast to the restorative procedures. Bonding in orthodontic treatments should be semi-permanent and to the extent that it resists the possible debonding of the appliances. It should also be low enough that additional forces would not be required for debonding. The minimum bond strength values for the brackets are in the range of 6–8 MPa.[25] In other words, different materials and techniques used in the bonding of brackets to dental surfaces should be able to create this level of bond strength. Otherwise, it would fail. Additionally, the maximum bond strength is 14 MPa, which should be lower than the enamel's breaking point.[26] All groups in our study, except for Group A, fell within this range. Studies conducted on porcelain surfaces using silane have concluded that the bond strength of brackets to porcelain surfaces increases using silane.[12] These observations were also seen in the present research. Silane is used to boost the shear bond strength of brackets because it forms chemical connections with both organic and inorganic surfaces, strengthening the final bond.[12] Eslamian et al. [27] stated that if the goal of clinical practice is not to achieve high values of shear band strength, there is no need to use silane agents when bonding orthodontic brackets to filled composite resins. The low shear bond strength values of orthodontic brackets to porcelain are mostly due to the fact that acid is not used to treat the porcelain surfaces before the brackets are bonded to it. Etching is the major procedure under these circumstances, even if the use of silane is the key factor limiting the successful bonding of porcelains. Simultaneously, silane forms a weak chemical connection between composite resin and porcelain.[10]

Nowadays, the irreversible hydrolytic bond theory is more acceptable concerning the mechanism of silane's effects on bond strength values. According to this theory, the bond between the silane and the mineral component is broken in the presence of water and re-established, which releases the stress but does not decrease adhesion. In other words, silane only participates as an intermediary in the bond.[28] In addition, the application of silane is a technique-sensitive method, and several factors can affect its outcomes, including the pH of the solvent and its composition, the size of its molecules or the evaporation of the solvent, indicating that insufficient evaporation of the solvent can lead to decreased bonding.[29] In the present research, 60% of the failures were adhesive, and 40% were mixed when GC Ortho Connect was used without silane. When GC Ortho Connect was used with silane, 50% of the fractures were adhesive, and 50% were mixed. When bonding to the enamel substrate, the liquid form of the new GC Ortho Connect bonding system can lead to the perforation of the material in the etched enamel surfaces, while these conditions will be different in the case of bonding to the porcelain substrate. The current results can only be generalized to the field of ceramic brackets, the adhesives used, and the specific research protocol. In the study by Shapinko et al. on bovine teeth usiing the Transbond XT and the new GC Ortho Connect systems, debonding failures often occurred in the adhesive interface area in the GC group, with no significant difference in adhesive residues between the three groups.[8] It appears that the results might change if different orthodontic appliances and other adhesives are used. Therefore, it is necessary to design further research under clinical conditions to compare the results of using GC Ortho Connect adhesive with conventional adhesives.

In this research, the amount of residual adhesive was evaluated based on a 4-scale system, and the type of debonding was divided into two groups: adhesive and mixed. Several studies have assessed the amount of leftover adhesive using the ARI index.[30] This index facilitates the evaluation of failed surfaces, and with its application, several different indices can be estimated based on the amount of adhesive remaining on the surface. Although it is not easy to compare the results of different studies in this field because most of them have changed the ARI index and reported different results. Also, this index is very subjective, and it is not easy to distinguish between teeth and resin in debonded areas and under the conditions of its use.[31] In addition, this index has been reported to be different at ×20 and ×10 magnifications.[32] In the study by shalini et al, the ARI was assessed using SEM.. The enamel surface in group Transbond Plus with Transbond XT was smooth after debonding because it was self-etched. Similar to our study, there was no difference between the brace paste and Transbond XT groups.[15]

To prevent breakage or cracking of the enamel surface or restorations on the enamel surface, it is better to leave the resin residue on the dental surfaces after debonding the brackets. Removal of adhesives from dental surfaces after debonding can be difficult and time-consuming and can damage the enamel or restoration surfaces. The adhesive must have sufficient bond strength and resist orthodontic and masticatory forces. At the same time, its removal should be easy enough and prevent damage to the enamel or existing restorations on the teeth. According to the results of the present research, there were no significant differences between the study groups in the type of fractures. It appears that the role of other factors, such as the mechanism of bracket retention, is also significant in the ARI index values.[33]

The role of saliva, oral habits, and other factors make it impossible to replicate the multifactorial environment of the oral cavity using existing research and laboratory techniques. This is a fundamental limitation of laboratory research, including the current research. As a result, evaluating the effectiveness of orthodontic appliances and materials in orthodontic treatments may only involve a preliminary use of laboratory techniques. OK et al. examined both the in vitro and clinical shear bond strength and failure rate of GC ortho connect, Transbond XT, and Biofix; nevertheless, they found similar results in clinical settings and no statistically significant differences with the laboratory settings.[34]

Conclusion

When using Brace Paste American Composite with and without silane or Ortho Connect GC with silane, the shear bond strength of ceramic brackets to porous surfaces was acceptable. However, the bond strength between ceramic brackets and porcelain surfaces was insufficient when Connect GC Ortho was applied without silane.

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P.T: Investigation, Data Curation
Z.S.: Review & Editing, Visualization
N.T.: Conceptualization, Methodology, Software, Validation, Original Draft, Writing – Review & Editing, Visualization, Supervision, Project Administration.

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