Original Article

pISSN, eISSN 0125-5614
M Dent J 2023; 43 (Suppl) : S11-S18

Evaluation of bond strength and failure mode of attachments in clear aligner orthodontic appliance using self-adhesive composite resin

Siriwan Thongkom[1], **Supassara Sirabanchongkran**[2]

[1] *Postgraduate in MSc.(Orthodontics), Department of Orthodontics and Pediatric Dentistry, Chiang Mai University, Chiang Mai, Thailand*

[2] *Department of Orthodontics and Pediatric Dentistry, Chiang Mai University, Chiang Mai, Thailand*

Objectives: The study was designed to 1) compare the shear bond strength (SBS) between self-adhesive composite resin and etch and rinse adhesive systems with a conventional flowable composite resin in fabricating the attachment of clear aligner on an enamel surface and 2) to evaluate the mode of failure.

Materials and Methods: The rectangular attachment size of 2.5x3x2 mm was fabricated on 48 upper first premolars. These premolars were randomly allocated into three groups based on the attachment bonding protocols: **Group 1** (etch and rinse + conventional flowable composite resin), **Group 2** (self-adhesive composite resin), and **Group 3** (etching + self-adhesive composite resin). The samples were subjected to thermocycling (1,000 cycles between 5°C and 55°C). The SBS was measured by a universal testing machine. The data were analyzed using one-way analysis of variance (ANOVA) with a significance level of $p<0.05$. All samples were examined under a stereomicroscope at 20x magnification to evaluate the Adhesive Remnant Index (ARI) scores. The scores were presented in percentages.

Results: 62.5% of the attachments in **Group 2** became dislodged after thermocycling. The mean SBS of **Group 1** (17.3±5.76 MPa) and **Group 3** (18.91 ± 9.94 MPa) were statistically significantly higher than that of **Group 2** (3.69 ± 1.30 MPa) ($p<0.05$). No statistically significant differences were observed between **Group 1** and **Group 3** ($p>0.05$). For ARI evaluation, the majority of samples in **Group 1** showed mixed failure, **Group 2 showed** Interfacial failure between composite resin and enamel and **Group 3** showed **cohesive failure in composite resin**.

Conclusion: The attachments that were fabricated with self-adhesive composite resin had the lowest SBS in this study. However, etching prior to using self-adhesive composite resin enhanced SBS comparable to etch and rinse + conventional flowable composite resin in fabricating the attachment.

Keyword: attachment of clear aligner, self-adhesive composite resin, shear bond strength

How to cite: Thongkom S, **Sirabanchongkran S**. Evaluation of bond strength and failure mode of attachments in clear aligner orthodontic appliance using self-adhesive composite resin. M Dent J 2023;43(Suppl):S11-S18.

Introduction

Clear aligner orthodontic appliances have gained popularity recently due to the increased focus on esthetics among orthodontic patients during their treatment [1]. Composite resin attachments, serving as auxiliary components of clear aligners, demonstrate the capability to enhance tooth movement, allowing for the correction of severe and complex malocclusion and improving retention of appliances [2, 3]. Nonetheless, loss of attachments remains a therapeutic challenge, impacting treatment outcomes negatively and prolonging the duration of the treatment [4]. According to Reynold's study, clinically accepted bond strengths range from 5.9 to 7.8 MPa, which allows them to withstand masticatory forces effectively [5]. The bond strength should be adequate to minimize bond failures during treatment but not excessively high to avoid any potential damage to the substrate surface during debonding [6].

Corresponding author: Supassara Sirabanchongkran
Department of Orthodontics and Pediatric Dentistry, Faculty of Dentistry, Chiang Mai University
239 Huay Kaew Rd., Muang District, Chiang Mai 50200, Thailand.
Tel.: +668 5866 9759, Fax: +66 5322 2844
E-mail: supassara.siraban@cmu.ac.th
Received: 15 August 2023 **Revised:** 17 September 2023 **Accepted:** 19 September 2023

The most dependable and efficient method to obtain effective bonding to the enamel surface is the etch and rinse system [7]. Nonetheless, it has been widely reported that etching with phosphoric acid produces a greater loss of enamel [8]. Moreover, these systems can be very time-consuming because of many bottles and application steps [9]. Presently, the innovations in dental adhesives are focused on simplification of the bonding procedures to eliminate technique sensitivity and time-consuming procedures, so self-adhesive composite resin that is non-rinseable was recently introduced [7,10]. Self-adhesive composite resin is indicated for the restoration of small Class I and V cavities, repairing porcelain, as a liner for large Class I and II restorations, or as a pit and fissure sealant, and is also used for orthodontic bracket bonding [10, 11]. Valizadeh *et al.* reported that Vertise® Flow™ Resin, which is a self-adhesive composite resin, can be used as an alternative to etching + Transbond XT™, which is conventional orthodontic adhesive, in bracket bonding on aged composite resin [11]. In addition, the mode of failure of Vertise® Flow™ Resin was mainly adhesive and mixed failure [11].

Considering the limited information on the bonding of self-adhesive composite resin as an attachment of clear aligner orthodontic appliance, the aim of this study was to compare the shear bond strength (SBS) between self-adhesive composite resin and etch and rinse adhesive systems with conventional flowable composite resin and to evaluate the mode of failure in the aspect of fabrication of the attachments of clear aligner orthodontic appliances.

Materials and Methods

This study was approved by the Faculty of Dentistry Human Experimentation Committee. The ethical approval number is 37/2022. The sample sizes were calculated from the pilot study using the n4Studies application for one-way analysis of variance. A total of 48 intact upper premolars were collected and stored in a 10% formalin solution. The inclusion criteria of tooth were recently extracted intact upper first premolar for orthodontic purposes with the absence of any large or buccal surface restoration, and without enamel abnormally. They were randomly divided into 3 groups. The teeth in each group were put into plaster of Paris blocks, four teeth per block, and then the models were scanned to develop the 3D model by an intraoral scanner (TRIOS®, 3SHAPE, Denmark) and the 3D model was exported as a STL file. The rectangular box size of 2.5x3x2 mm was designed by Blender 3.1 software and was attached to the 3D model (Figure 1a). The 3D models with rectangular attachments were printed as resin models by a 3D printer (Formlab Form 2 3D printer, Somerville, MA, USA). The resin models were used for the fabrication of individual templates.

The teeth were cleaned with pumice for 10 seconds using a rubber cup, then thoroughly washed with water and air-dried. The adhesive systems and composite resin were performed in each group (Figure 1b).

In **Group 1**: etch and rinse (Adper™ Scotchbond Multi-Purpose et, 3M ESPE, St. Paul, MN, USA) was tested. The teeth were etched with 37% phosphoric acid for 15 seconds, rinsed with water for 15 seconds, excess water was removed with an air syringe and the enamel surface was air-dried to gain a chalky white appearance. The primer was applied on the enamel surface and gently dried for 5 seconds, then the adhesive was applied and mild air-blown to be thin film, light cured with a high-power light-emitting diode curing unit (Mini LED™, Satelec® Acteon Group, Merignac, France) for 10 seconds. The composite resin attachment was fabricated by loading the template with conventional flowable composite resin (Filtek™

Z350Xt 3M ESPE, St. Paul, MN, USA). Then, the template was positioned on the tooth block and the composite was light cured for 20 seconds.

In **Group 2**: self-adhesive composite resin (Vertise® Flow™ Resin, Kerr, Orange, CA, USA) was applied in a thin layer of 0.5 mm to the bonding area, then the template was filled with Vertise® Flow™ Resin and positioned on the tooth block, light cured for 20 seconds.

In **Group 3**: the tooth was pre-etched with 37% phosphoric acid (Adper™ Scotchbond Multi-Purpose etchant, 3M ESPE, St. Paul, MN, USA) for 15 seconds, rinsed with water for 15 seconds, excess water was removed with an air syringe, and dried to gain a chalky white appearance. Then, self-adhesive composite resin (Vertise® Flow™ Resin, Kerr, Orange, CA, USA) was applied in a thin layer of 0.5 mm to the bonding area, the template was filled with Vertise® Flow™ Resin and positioned on the tooth block, light cured for 20 seconds.

All samples were aged by thermal cycling machine (model HWB332R CWB332R TC301, King Mongkut's Institute of Technology Ladkrabang, Thailand) for 1,000 cycles between 5°C and 55°C with dwell time of 20 seconds and transfer time of 10 seconds. After the aging process, the teeth were cut with the round end taper diamond bur to separate the crown and root, and the crowns were embedded in the PVC mold filled with Plaster of Paris. A gingivo-occlusal load, produced by a universal testing machine (Instron 5566, Instron Calibration Laboratory, Canton, MA, USA), was applied to test the SBS at a crosshead speed of 1 mm/min (Figure 1c). The shear bond strength was recorded in Newton (N) and was calculated using the following formula: SBS (MPa) = Force (N)/ A (mm^2). A (mm^2) is the enamel surface under the attachment base, which was computed by Materialise 3-Matic software (3-Matic Research 13.0 software, Materialize, Leuven, Belgium) (Figure 1d).

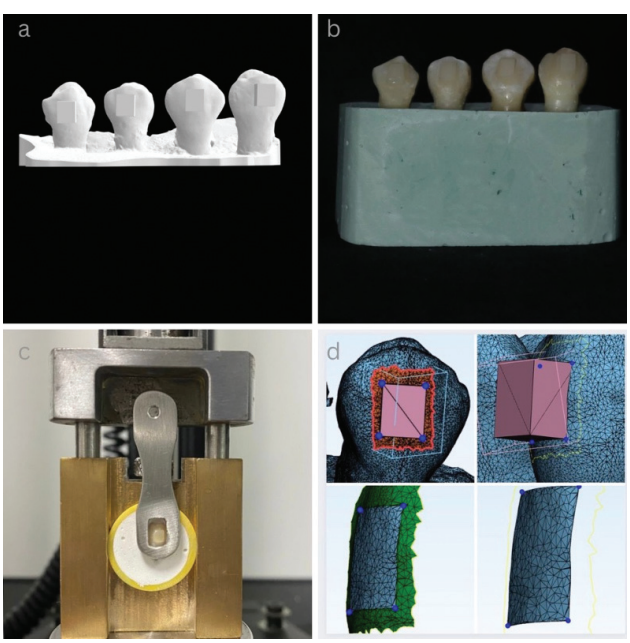

Figure 1 Show testing for shear bond strength (SBS): (a) Fabrication for the 3D model with rectangular attachments; (b) The rectangular attachment was fabricated on the teeth; (c) SBS testing was performed by pulled force; (d) Bonding area was simulated by Materialise 3-Matic software (3-Matic Research 13.0 software).

The ARI (Adhesive Remnant Index) was evaluated after testing the SBS. The bonding areas were inspected under a stereomicroscope (model CK 40 culture microscope and DP 12 digital camera, Olympus, Japan) at 20X magnification. The ARI evaluation criteria were adapted from Pipatphatsakorn *et al* in 2015 [12] and employ the following scale: 1, Cohesive failures in enamel; 2, Interfacial failure between composite resin and enamel; 3, Mixed failure with less than 50 percent of bonding areas covered by composite resin; 4, Mixed failure with more than 50 percent of bonding areas covered by composite resin; and 5, Cohesive failure in composite resin. The process of ARI evaluation was repeated after 4 weeks for intra-rater reliability testing.

The data were analyzed using SPSS 25.0 software (IBM® SPSS® Statistics, IBM, NY, USA) The normality distribution of the data was assessed using the Shapiro-Wilk test. One-way analysis of variance (ANOVA) was performed to assess the effect of different attachment bonding protocols on the SBS *and follo*wed by Dunnett's T3 which was used for pairwise comparison between group ($p<0.05$). Pretest failures were not included in the statistical analysis. The ARI was also described by percentages to describe the extent of composite resin remaining on each sample.

Result

The means of SBS of three groups are shown in Table 1 and Figure 2. Significantly different SBS were not found between **Group 1** and **Group 3** ($p>0.05$). The means SBS of **Group 1** and **Group 3** were significantly greater than that of **Group 2** ($p<0.05$). Some attachments (62.50%) in **Group 2** became dislodged after thermocycling.

Table 1 Mean and standard deviation of shear bond strength in the 3 groups.

Group	Mean SBS (MPa) ± SD	Group difference
1	17.31 ± 5.76	A
2	3.69 ± 1.30	B
3	18.91 ± 9.94	A

Group1: etch and rinse (Adper™ Scotchbond Multi-Purpose) + conventional flowable composite resin (Filtek™ Z350Xt), **Group 2**: self-adhesive composite resin (Vertise® Flow™ Resin), **Group 3**: etching (Adper™ Scotchbond Multi-Purpose etchant)+ self-adhesive composite resin (Vertise® Flow™ Resin)
Note: Groups with different letters are significantly different from each other.

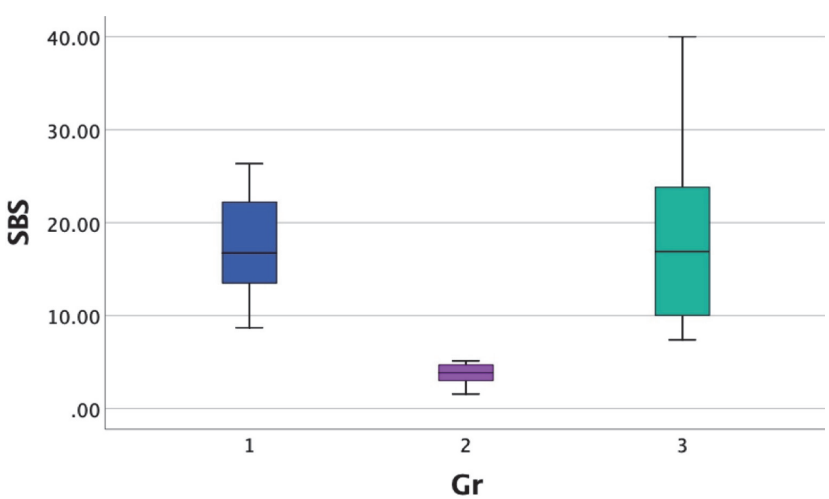

Figure 2 Box-plots the mean of shear bond strength (SBS)

Table 2 displays the ARI of composite resin that remains after bond failure, presented in both frequency and percentages. In **Group 1**, the majority of the samples exhibited less than 50 percent coverage of bonding areas by residual composite resin, and there was no residual composite resin observed on the bonding areas without enamel fractures. In **Group 2**, all samples had no residual composite resin on the bonding area without enamel fracture. In **Group 3**, almost all of the samples had residual composite resin on the total bonding area, and had more than half of the bonding areas covered by residual composite resin.

Discussion

There are several characteristics of the ideal attachment material for a clear aligner appliance, such as being tough to slip off, resistant, and simple to use [13]. Presently, innovations in dental materials are focused on simplification of bonding procedures [14]. To simplify the clinical procedure, a self-adhesive composite resin that is a self-etch approach is introduced and is claimed to be less technique-sensitive with reduced chairside time [15]. This study intended to evaluate SBS and the failure mode of self-adhesive composite resin in fabricating attachment. In the present study, the SBS of composite resin attachments were compared in different bonding protocol as follow: **Group 1**: etch and rinse + conventional composite resin, **Group 2** self-adhesive composite resin, and **Group 3** etching + self-adhesive composite resin. The ability to bond to the tooth structure of dental adhesive system depends on two main factors: (1) Demineralized surface, which partially removed the mineral components and increased tooth receptivity, and (2) subsequent infiltration of monomers into the demineralized zone [7]. Valizadeh *et al* [11] assessed the tooth surface by SEM. They found that the higher the SBS, the higher the surface roughness. This study found that the mean SBS in **Group 1** was higher than that of **Group 2** significantly. The explanation was that 37% phosphoric acid has more acidity (pH 0.1-0.4) than the acid in Vertise® Flow™ Resin (pH 1.9), so it produced more surface roughness and improved mechanical retention. However, etching with 37% phosphoric acid prior to the self-adhesive composite resin improved the SBS significantly. **Group 3** showed the highest mean on SBS in this study,

Table 2 Frequency and percentage of the Adhesive Remnant Index (ARI) scores in 3 groups

Group	Adhesive Remnant Index (ARI) scores				
	1	2	3	4	5
1	0 (0.00%)	6 (40.63%)	9 (53.12%)	1 (6.25%)	0 (0.00%)
2	0 (0.00%)	16 (100%)	0 (0.00%)	0 (0.00%)	0 (0.00%)
3	0 (0.00%)	0 (0.00%)	3 (18.75%)	5 (34.37)	8 (46.88%)

Group 1: etch and rinse (Adper™ Scotchbond Multi-Purpose) + conventional flowable composite resin (Filtek™ Z350Xt), **Group 2**: self-adhesive composite resin (Vertise® Flow™ Resin), **Group 3**: etching (Adper™ Scotchbond Multi-Purpose etchant)+ self-adhesive composite resin (Vertise® Flow™ Resin)

but it was not significantly different from **Group 1**. The explanation was that enamel pretreatment with 37% phosphoric acid increased microporosities to enchant resin-interlocking and micromechanical retention. In addition, Vertise® Flow™ Resin has chemical adhesion that occurs by the phosphate functional group of the glycero-phosphate dimethacrylate (GPDM) united with the calcium ions within the tooth structure [10]. This result was in accordance with several studies that confirmed the bond strength of self-adhesive composite resin increased with pretreatment of the surface with acid etching [16, 17]. Reynold suggested that the clinically accepted bond strength should be 5.9 to 7.8 MPa. So, this study found that the SBS of **Group 1** and **Group 3** were accepted for clinical use.

For the assessment of ARI score, all of **Group 2** showed failure at the interface between composite resin and tooth surface. The low acidic level of Vertise® Flow™ Resin might produce minimal surface roughness and further decreased mechanical retention. However, **Group 3** showed higher ARI score than **Group 2**. Almost all of **Group 3** had residual composite resin on the total bonding area and had more than half of the bonding areas covered by residual composite resin. Enamel pretreatment with 37% phosphoric acid increased microporosities and improved micromechanical retention of Vertise® Flow™ Resin to intact enamel surface. This finding agreed with Valizadeh S *et al* [11] that using 37% phosphoric etching prior to Vertise® Flow™ Resin increased ARI score. While Group 1 showed lower ARI score than Group 3. Almost all of **Group 1** had less than half of the bonding areas covered by residual composite resin and no residual composite resin on the bonding area without enamel fracture. In other words, **Group 3** showed higher percentages of remnants of composite resin on enamel surface than **Group 1**. The explanation is that Vertise® Flow™ Resin created chemical retention by GPDM, and mechanical retention was increased by pretreatment with 37% phosphoric acid. This result conformed to the SBS result. An ARI score of 3,4 or 5 indicates more remnant of adhesive material is still present on the bonding area, so removing the adhesive material can lead to surface roughness and the loss of the intact enamel surface [18, 19]. The lower the score or a score of 2 with decreased composite resin remnant may ease the tooth surface cleanup and time saving [19, 20]. The bond failure at enamel-adhesive interface can lead to enamel fracture [20]. This study did not find any cohesive failure in enamel.

However, this study had some limitations. The experiments in this study were carried out in vitro and might not exactly reflect clinical circumstances. The randomized controlled split-mouth clinical trial should be performed in further study.

Conclusion

1. The attachment fabricated with self-adhesive composite resin had the lowest SBS in this study. However, etching before self-adhesive composite resin enhanced the SBS comparable to etch and rinse + conventional flowable composite resin in fabricating the attachment.

2. Etching with 37% phosphoric acid was necessary in enhancing the bond strength to the level of clinical acceptable for fabricating the attachments with the self-adhesive composite resin in a clear aligner. However, more remnants of composite resin may be found. Thus, the loss of intact enamel surface from removing remnants of composite resin process should be aware.

Acknowledgement

The authors acknowledged the crucial contribution of Dr.Thanapat Sastraruji for the supervision of the statistical analysis for this research. Furthermore, the authors appreciated the support and resources provided by the Faculty of Dentistry, Chiang Mai University

Funding

The present study received funding and extensive support from the Faculty of Dentistry, Chiang Mai University

References

1. Tai S. Clear aligner technique. Hanover Park, IL: Quintessence Publishing; 2018.
2. Proffit WR, Fields HW, Larson B, Sarver DM. Contemporary orthodontics. 6th ed. Philadelphia, PA: Elsevier Health Sciences; 2019.
3. Al Noor HSS, Al-Joubori SK. Retention of different orthodontic aligners according to their thickness and the presence of attachments. *Int J Med Res Health Sci*. 2018 Jan;7(11):115-21.
4. Dasy H, Dasy A, Asatrian G, Rózsa N, Lee HF, Kwak JH. Effects of variable attachment shapes and aligner material on aligner retention. *Angle Orthod*. 2015 Nov;85(6):934-940. doi: 10.2319/091014-637.1.
5. Reynolds IR. A review of direct orthodontic bonding. *Br J Orthod*. 1975 Jul;2(3):171-178. doi: 10.1080/0301228X.1975.11743666.
6. Bayram M, Yesilyurt C, Kusgöz A, Ulker M, Nur M. Shear bond strength of orthodontic brackets to aged resin composite surfaces: effect of surface conditioning. *Eur J Orthod*. 2011 Apr;33(2):174-179. doi: 10.1093/ejo/cjq048.
7. Hilton TJ, Ferracane JL, Broome JC. Summitt's fundamentals of operative dentistry: A contemporary approach. 4th ed. Hanover Park, IL: Quintessence Publishing; 2013.
8. Vicente A, Bravo LA, Romero M. Influence of a nonrinse conditioner on the bond strength of brackets bonded with a resin adhesive system. *Angle Orthod*. 2005 May;75(3):400-405. doi: 10.1043/0003-3219(2005)75[400:IOANCO]2.0.CO;2.
9. Sofan E, Sofan A, Palaia G, Tenore G, Romeo U, Migliau G. Classification review of dental adhesive systems: from the IV generation to the universal type. *Ann Stomatol (Roma)*. 2017 Jul;8(1):1-17. doi: 10.11138/ads/2017.8.1.001.
10. kerrdental.com [Internet]. CA; 2016 [cited 2022 Apr 22]. Available from: https://www. kerrdental.com/kerr-restoratives/vertise-flow-self-adhering-flowable-composite.
11. Valizadeh S, Alimohammadi G, Nik TH, Etemadi A, Tanbakuchi B. Invitro evaluation of shear bond strength of orthodontic metal brackets to aged composite using a self- adhesive composite: Effect of surface conditioning and different bonding agents. *Int Orthod*. 2020 Sep;18(3):528-537. 10.1016/j. ortho. 2020.04.005.
12. Pipatphatsakorn M. Microtensile Bond strength of new self-adhesive flowable resin composite on different enamel substrates. *CU Dent J*. 2015;38: 83-96.
13. Chen W, Qian L, Qian Y, Zhang Z, Wen X. Comparative study of three composite materials in bonding attachments for clear aligners. *Orthod Craniofac Res*. 2021 Nov;24(4):520-527. doi: 10.1111/ocr.12465.
14. Van Meerbeek B, De Munck J, Yoshida Y, Inoue S, Vargas M, Vijay P, *et al*. Buonocore memorial lecture. Adhesion to enamel and dentin: current status and future challenges. *Oper Dent*. 2003 May-Jun;28(3): 215-235.
15. Vichi A, Margvelashvili M, Goracci C, Papacchini F, Ferrari M. Bonding and sealing ability of a new self-adhering flowable composite resin in class I restorations. *Clin Oral Investig*. 2013 Jul;17(6):1497-1506. doi: 10.1007/s00784-012-0846-6.
16. Chantchaimongkol S, Srisawasdi S. Microtensile bond strength of self-adhesive resin composite to dentin. *CU Dent J*. 2015;38:21-34.
17. Talan J, Gupta S, Nikhil V, Jaiswal S. Effect of mechanical alteration of enamel surface on shear bond strength of different bonding techniques. *J Conserv Dent*. 2020 Mar-Apr;23(2):141-144. doi: 10.4103/JCD. JCD_163_19.

18. Scougall Vilchis RJ, Yamamoto S, Kitai N, Yamamoto K. Shear bond strength of orthodontic brackets bonded with different self-etching adhesives. ***Am J Orthod Dentofacial Orthop***. 2009 Sep;136(3):425-30. doi: 10.1016/j.ajodo.2007.08.024.
19. Al Shamsi A, Cunningham JL, Lamey PJ, Lynch E. Shear bond strength and residual adhesive after orthodontic bracket debonding. ***Angle Orthod***. 2006 Jul;76(4):694-699. doi: 10.1043/0003-3219(2006)076 [0694:SBSARA]2.0.CO;2.
20. Bishara SE, Ostby AW, Laffoon JF, Warren J. Shear bond strength comparison of two adhesive systems following thermocycling. A new self-etch primer and a resin-modified glass ionomer. ***Angle Orthod***. 2007 Mar;77(2):337-341. doi: 10.2319/0003-3219(2007)077[0337:SBSCOT]2.0.CO;2.