This is "Advance Publication Article". Received Date: 27 November 2020 Accepted Date: 24 May 2021
J-STAGE Advance published Date: 25 September 2021 Journal of Prosthodontic Research

journal of prosthodontic research 65 (2021) ●–●

Journal of Prosthodontic Research

Official Journal of the Japan Prosthodontic Society

Original article

Four-year clinical evaluation of CAD/CAM indirect resin composite premolar crowns using 3D digital data: Discovering the causes of debonding

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Abstract

Purpose: To analyze the causes of debonding of computer-aided design/computer-aided manufacturing (CAD/CAM) indirect resin composite premolar crowns with a focus on the morphological factors of the crown and abutment teeth.
Methods: The clinical courses of 109 CAD/CAM indirect resin composite crowns were observed, and the patients' background characteristics, crown locations, luting methods, types of abutments, distal-most/non-distal-most molars, and types of resin blocks were confirmed. To investigate the influence of the morphology of the crown and abutment teeth, the 1) vertical dimension of the abutment teeth, 2) taper, and 3) thickness of the crown occlusal surface during events were measured from the three-dimensional digital data. The Kaplan–Meier method and multivariable Cox proportional hazard model were used for the statistical analyses. The nonlinearity of the effect of each comparison factor was included in the model.
Results: Complications included 21 debonding cases, two crown fractures, five root fractures, and two core debondings. The cumulative no-debonding and no-crown-fracture rate over 1423 days (3 years and 11 months) was 77.4%. The multivariable Cox regression analysis revealed that the abutment teeth type of tooth (first or second premolar) ($P = 0.02$) and luting materials ($P < 0.01$) significantly influenced the debonding frequency. All morphological factors (1–3) significantly influenced the debonding. The hazard ratios and nonlinear graph indicated that the crown thickness was less effective than the vertical dimension and taper.
Conclusions: The combination analysis of clinical outcomes and 3D digital data revealed that preparation of the abutment is important for avoiding crown debonding.

Keywords: *Adhesive dentistry, Clinical study, Dental bonding, Follow-Up Studies, Survival analysis*

Received 27 November 2020, Accepted 24 May 2021, Available online 25 September 2021

1. Introduction

Advances in computer-aided design/computer-aided manufacturing (CAD/CAM) technology have enabled the manufacturing of crowns in a shorter period of time and at a lower cost compared to the previous lost-wax casting method [1]. Several material classes have been used for indirect restoration fabrication with a CAD/CAM system [2]. Ceramics are mostly used for CAD/CAM crowns, but are more brittle and susceptible to fracture than resin-based compound materials in the case of an inappropriate load or overload [3]. Compared with ceramics, composite resins show fewer material fractures and a higher margin stability after milling [3]. In 2014, resin composite crowns for premolars produced using CAD/CAM technology received approval from the Japanese social insurance system [4]. Suese [5] first reported the clinical results for up to 120 days; 9% of the approved crowns were debonded, and 2% were fractured after just a few days. Yamase et al. [6] conducted a clinical follow-up of resin composite crowns for 2 years, and reported that 4.2% of the observed issues involved debonding/fracture. Miura et al. [7] reported the longest period of clinical data for such crowns, covering 3 years of follow-up (mean follow-up: 1.3 ± 0.9 years); they evaluated 547 crowns, 87 (15.9%) of which had at least one complication, with loss of crown retention being the most common (12.8%).

Another merit of CAD/CAM technology is that the digital data used to manufacture crowns remains as a record in the CAD software program [8]. The management of digital data is easier, and enables the semi-permanent storage of information on abutment teeth and crowns. Three-dimensional (3D) digital data enables a representation and analysis of the morphology of the abutment teeth and crowns, even in retrospective clinical studies. It is not feasible to store the plaster casts of the crowns used in conventional manufacturing methods (typically the lost-wax casting method) for a long period of time. Regarding the morphology of the abutment (i.e., the clearance and taper of the abutment teeth), several indications have been noted for the preparation for CAD/CAM indirect crowns [9]. For example, 1.5–2.0 mm of clearance is recommended (this is sometimes explained as "more than 2.0 mm") to avoid crown fracture. To our knowledge, no studies have specifically investigated how the morphological factors of

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https://doi.org/10.2186/jpr.JPR_D_20_00287
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crowns and abutment teeth affect the clinical results.

Therefore, in this study, we retrospectively investigated the clinical courses of all CAD/CAM indirect composite resin crowns, and analyzed the results with reference to recorded 3D digital data. We then statistically analyzed the causes of failure of CAD/CAM indirect resin composite crowns, with a focus on how the morphological factors of the crowns and abutment teeth affect the clinical results. The null hypothesis to be evaluated was that the morphology of the crown and abutment teeth did not influence the clinical outcomes of CAD/CAM indirect resin composite premolar crowns.

2. Materials and methods

2.1. Patients and treatments

In total, 123 cases of CAD/CAM indirect resin composite crowns manufactured from April 2014 to November 2015 at the Division of Prosthodontics, Osaka University Dental Hospital, were obtained from the ledger of the dental technician, and their clinical courses were reviewed based on the medical records (Ethics Review Board at Osaka University Approval No.: H27–E11). The crown preparation was performed with a deep chamfer and standardized as much as possible in accordance with the reduction guidelines [9]. The resin composite block used for manufacturing the crown exhibits better physical properties than conventional composite resin, and has received approval from the Japanese social insurance system [4]. Crowns involving the following were excluded: 1) the data between the dental technician ledger and medical record were inconsistent; 2) the fabricated CAD/CAM crown was not inserted; and 3) the clinical course after crown cementation was not recorded (i.e., cementation of the crown was the last day in the medical record). After excluding 14 crowns meeting the above exclusion criteria, 109 crowns were included in the analysis.

2.2. Retrospective cohort study

The patients' background characteristics (age, sex), anatomic crown location (maxillary/mandible, first premolar/second premolar), luting method (presence or absence of alumina-blasting, presence or absence of silane treatment, type of cement), type of abutment (vital/resin core/cast metal core), and whether the tooth was a distal-most molar were investigated by referencing the medical records. The types of resin blocks were confirmed from the dental technician ledger. The investigation duration was from the date of cementation to July 31, 2018. We treated any problems (e.g., crown debonding, crown fracture, tooth root fracture) occurring during the investigation period as events. If no events were observed by the last hospital visit, the observation was considered as complete within the investigation period.

The Kaplan–Meier method and multivariable Cox proportional hazard model were used for the statistical analyses. The Cox proportional hazard model was used to assess the associations between five items (location, type of resin block, type of abutment, luting material, and whether it was a distal-most molar) and the period until any problem occurred. Each model included one item, and was adjusted for age and sex as covariates. All analyses were carried out using methods accounting for data clustering, because the data encompassed repeated observations for a single patient. A two-sided P value of ≤ 0.05 was considered as statistically significant. All statistical analyses were performed using R software (version 3.3.2; http://cran.rstudio.com/).

2.3. Analyses of 3D digital data

The 3D digital data (STL file) were obtained retrospectively using a CAD software program (Shofu S-WAVE Scanner D850; Shofu, Kyoto, Japan). To investigate the influence of the morphology of the crowns and abutment teeth, the following factors were measured (Fig. 1): 1) the vertical dimension of the abutment teeth (functional cusp side, non-functional cusp side, higher side, lower side, lingual side, buccal side), 2) taper, and 3) thickness of the crown occlusal surface during events. In the primary report (mean observation time: 18.7 ± 10.1 months; range: 6–988 days)

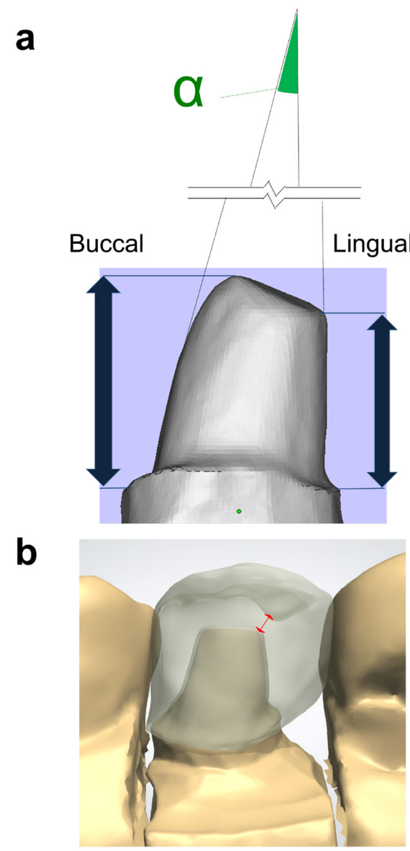


Fig. 1. Analyses of three-dimensional (3D) digital data. (a) Measurement site of the vertical dimension of the abutment teeth. Using the occlusal plane recorded as 3D digital data as a reference, the vertical distance between the lowest part of the finish lines to the highest part of the abutment teeth was measured. Taper measurement: Lines tangent to the axial surface on the widest contour of the buccal side and the lingual side of abutment teeth were drawn, and the taper was calculated as the sum of the angles (α) between the tangents and the tooth axis [24]. For cases with two-surface preparation, a line was drawn tangent to the surface close to the finish line. (b) The thickness of the crown: The thinnest part of the designed crown occlusal surface was measured.

[10], complications were seen in 22 cases, including 19 cases of debonding (17.5%), one crown fracture (0.9%), and two root fractures (1.8%). As debonding was the most common complication, the clinical outcome used for the digital data analysis was debonded or non-debonded (i.e., success).

A Cox proportional hazard model was used for the statistical analyses. To avoid overfitting, the model was limited to one item and two covariates (age and sex, because these two factors may bias the results in terms of how the morphology of the crowns and abutment teeth affect the events). The factors for comparison were the vertical dimension of the abutment teeth, taper, and thickness of the crown occlusal surface. The nonlinearity of the effect of each factor was included in the model. Additionally, bootstrap validation was used to assess the robustness of the model for predicting future data.

3. Results

3.1. Retrospective cohort study

A total of 109 crowns were placed in 93 patients (median age: 62 years; quartile range: 54–70 years; Table 1). Specifically, 43 and 66 crowns were fitted on the first and second premolars, respectively, with nearly the same number of crowns placed on the maxillary and mandibular molars (Table 1 and Appendix Table 1). In addition, there were seven vital and 102 non-vital teeth. Regarding the abutment construction, a resin core was used in 94 crowns, and a cast-metal core

Table 1. Characteristics of participants, abutment teeth, and CAD/CAM indirect resin crowns at baseline.

		All data (n=109)	3D data (n=75)
Age (y) (mean, 95%CI)		62.0 (54.0–70.0)	64.0 (56.0–71.0)
Sex	Male	27 (25%)	20 (27%)
	Female	82 (75%)	55 (73%)
Location of abutment teeth	Maxillary	54 (50%)	41 (55%)
	Mandible	55 (50%)	34 (45%)
	First premolar	43 (39%)	32 (43%)
	Second premolar	66 (61%)	43 (57%)
	Distal-most molar	13 (12%)	10 (13%)
	Non-distal-most molar	96 (88%)	65 (87%)
Condition of root canal	Vital	7 (6%)	4 (5%)
	Resin core	94 (86%)	64 (85%)
	Cast metal core	8 (7%)	7 (9%)
Type of resin blocks	Shofu HC	67 (61%)	51 (68%)
	GC Cerasmart	40 (37%)	24 (32%)
	Lava Ultimate	2 (2%)	0 (0%)
Luting Cement	ResiCem	49 (45%)	34 (45%)
	Panavia F2.0	38 (35%)	29 (39%)
	Clearfil SA luting	13 (12%)	8 (11%)
	Panavia V5	6 (6%)	1 (1%)
	G-CEM	2 (2%)	2 (3%)
	Super Bond C & B	1 (1%)	1 (1%)

All data means the final clinical data set; 3D data means extracted data after excluding cases without 3D digital data or with unusable 3D digital data. Data are expressed as numbers (value, %) except "age".

was used in eight crowns. The following types of resin blocks were used: Shofu Block HC (Shofu) for 67 crowns, GC Cerasmart (GC, Tokyo, Japan) for 40 crowns, and Lava Ultimate (3M ESPE, St. Paul, MN, USA) for two crowns. The following luting materials were used: ResiCem (Shofu) for 46 crowns, Panavia F2.0 (Kuraray Noritake Dental, Tokyo, Japan) for 38 crowns, Clearfil SA luting (Kuraray Noritake Dental) for 13 crowns, Panavia V5 (Kuraray Noritake Dental) for six crowns, G-CEM (GC) for two crowns, and Super Bond C & B (Sun Medical, Shiga, Japan) for one crown. Alumina-blasting (Miniblaster; Morita, Osaka, Japan) and silane treatments (CLEARFIL CERAMIC PRIMER PLUS, Kuraray Noritake Dental) were conducted in all cases.

Complications were observed in 30 cases, including 21 cases of debonding (19.3%), two crown fractures (1.8%), five root fractures (4.6%), and two core debondings (1.8%; i.e., debonding was not found between the core and crown). The cumulative no-debonding and no-crown-fracture rate over 1423 days (3 years and 11 months) was 77.4% (Fig. 2). The mean observation time was 27.3 ± 10.1 months (range: 6–1423 days). The multivariable Cox regression analysis revealed that the factors of the type of abutment teeth (first or second premolar) ($P = 0.02$) and luting materials ($P<0.01$) significantly influenced the frequency of events (Table 2). In contrast, the maxillary/mandible location ($P = 0.19$), four sites (maxillary or mandible, left or right; $P = 0.25$), distal-most/non-distal-most ($P = 0.12$), type of resin block ($P = 0.48$), and type of abutment ($P = 0.23$) had no significant influence on the frequency of events.

3.2. Analyses of 3D digital data

After excluding cases without 3D digital data or with unusable 3D digital data, the data for 75 crowns were extracted (debonding group: 18/21 crowns; no events group: 57/88 crowns) (Table 1). A Cox regression analysis revealed that the vertical dimension of the

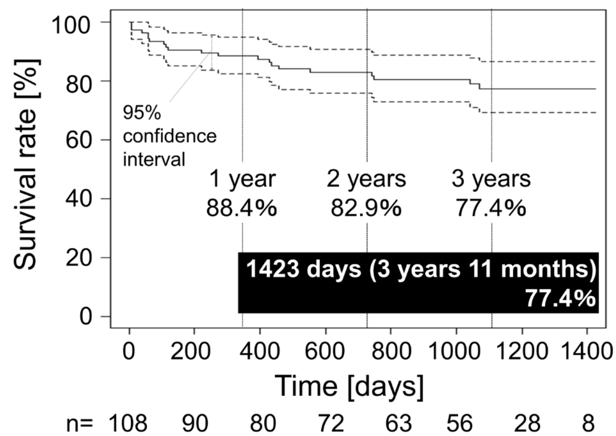


Fig. 2. Kaplan–Meier survival curve. The cumulative no debonding and no crown fracture rate.

Table 2. Bivariate analysis for factors related to any problems of the crown.

Factor*		Hazard ratio	Lower 95%CI	Upper 95%CI	P value**
Location of abutment teeth	Maxillary (n=54): mandible (n=55)	0.56	0.23	1.34	0.19
	First premolar (n=43): second premolar (n=76)	0.24	0.07	0.81	**0.02**
	Left maxillary (n=25): right maxillary (n=29)	3.89	0.73	20.81	0.25
	Right mandible (n=29): right maxillary (n=29)	5.28	1.04	26.85	
	Distal-most molar (n=13): Non-distal-most molar (n=96)	2.56	0.78	8.44	0.12
Condition of root canal	Vital teeth (n=7): resin core (n=94)	1.02	0.12	8.94	0.23
	Cast metal core (n=8): resin core (n=94)	2.76	0.86	8.81	
Type of resin blocks	GC Ceramart (n=40): Shofu HC (n=67)	0.68	0.26	1.75	0.48
Luting material	Panavia F2.0 (n=38): ResiCem (n=49)	0.92	0.32	2.7	**<0.01**
	Clearfil SA luting (n=13): ResiCem (n=49)	1.86	0.46	7.6	

A multivariable Cox proportional hazards model was used for the statistical analyses. *: "A: B" shows the effect of A with reference to B. **: Results of global tests for each item. CI: confidence interval

abutment teeth ($P = 0.011$ for the functional cusp side, $P < 0.001$ for the non-functional cusp side), taper ($P < 0.001$), and thickness ($P = 0.005$) significantly influenced the debonding (Table 3).

In addition, a nonlinear graph of the effects showed that the vertical dimension of the functional and non-functional cusps was associated with the risk of an event (Fig. 3a, b). The risk of an event increased for heights in the vertical dimension below 5 mm and 4.8 mm for the functional and non-functional cusps, respectively. Regarding the taper and thickness, the risk of an event increased for over 22 degrees and under 1.2 mm for the taper of the abutment and crown thickness, respectively (Fig. 3c, d). In addition, the vertical dimensions of the maxilla and mandibular data were classified as "buccal or lingual" and "lower or higher," respectively, and then a nonlinear graph of the effects was made (Appendix Fig. 1). The risk of an event was decreased by over 5.3, 4.2, 4.2, and 5.3 mm for the buccal, lingual, lower, and higher vertical dimensions, respectively.

Table 3. Multivariate analysis for morphological factors affecting debonding using 3D digital data.

Factor	Hazard ratio	Lower 95%CI	Upper 95%CI	P value
Vertical dimension of the functional cusp side	0.21	0.07	0.62	**0.011**
Vertical dimension of the non-functional cusp side	0.29	0.12	0.66	**<0.001**
Taper	4.3	1.88	9.87	**<0.001**
Crown thickness	0.47	0.24	0.91	**0.005**
(supplemental data)				
Vertical dimension of the higher side	0.3	0.1	0.85	**<0.001**
Vertical dimension of the lower side	0.25	0.1	0.59	**<0.001**
Vertical dimension of the lingual side	0.25	0.11	0.6	**0.003**
Vertical dimension of the buccal side	0.25	0.08	0.79	**<0.001**

All multivariable Cox regression models included one factor and two covariates (age and sex). CI: confidence interval

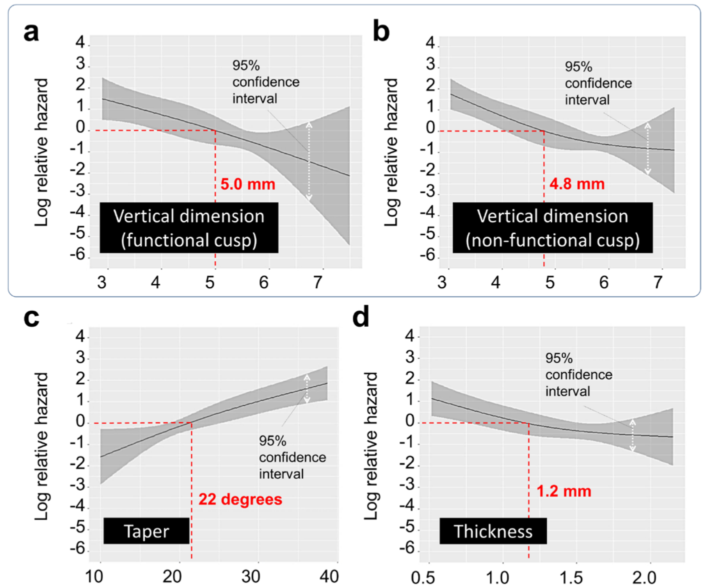


Fig. 3. Relationships between the morphological factors and the risk of a debonding event. (a) Vertical dimension of the functional cusp side of the abutment teeth and logarithm hazard ratio, (b) vertical dimension of the non-functional cusp side of the abutment teeth and logarithm hazard ratio, (c) taper and logarithm hazard ratio, and (d) thickness and logarithm hazard ratio.

4. Discussion

In this study, the cumulative survival rate of CAD/CAM indirect resin composite crowns after 3 years and 11 months was 77.4% (Fig. 2). The survival rates for 1, 2, and 3 years were 88.4%, 82.9%, and 77.4%, respectively; these results showed a similar tendency to those reported in other clinical studies [5–7]. Also similar to those other studies, the main complication was debonding (21/30 cases [70%]); in the present study, 50% of all debondings occurred within the first 4 months. These results suggest that debonding occurs intensively after cementation of CAD/CAM indirect resin composite crowns. In clinical practice, alumina-blasting followed by silane treatment of the internal surfaces of the crowns is recommended to enhance durable bonding [11–14]. In this study, through a review of medical records and interviews with the doctors in charge, we found that alumina-blasting and silane treatments were conducted in all crown debonding cases, suggesting that the treatment for bonding surfaces currently recommended in clinical practice cannot prevent crown debonding. In addition, only two crowns were fractured. An occurrence of a crown fracture during an occlusal adjustment procedure has been reported [5]; however, no such cases were observed in the present study. Surprisingly, apart from crown complications, root fractures were found in five cases (252, 550, 904, 959, and 1056 days after cementation). The annual rates of fracture for resin core build-ups and cast metal cores have been reported as 0.09% and 0.20%, respectively [15]; however, the annual rate of root fracture calculated in this study was 1.28%. Root fractures were observed in four resin cores and one cast-metal core. As the distribution was the same across all data, the material (i.e., cast-metal or resin core) was not considered as the reason for the frequent outbreaks. In the five root fracture cases, no indications, such as "a crack was observed on the root dentin," were seen in the medical records. Therefore, further research is needed to clarify the unknown factors and help avoid catastrophic clinical outcomes.

The multivariable Cox regression analysis revealed that the abutment teeth being a particular type of tooth (first or second premolar) was a significant factor ($P = 0.02$). In contrast, the maxillary/mandible location ($P = 0.19$), four sites (maxillary or mandible, left or right; $P = 0.25$), and distal-most/non-distal-most ($P = 0.12$) had no significant influence. In the primary report of the present study, the abutment teeth being a distal-most molar significantly influenced the frequency of events ($P = 0.03$), and being a first or second premolar had a significant influence on events ($P = 0.06$) [10]; both of these findings are inconsistent with the final result. The centrifugal rotation stress on a crown tends to increase with increasing occlusal force on the distal-most molar in cases with no centrifugal adjacent teeth. In the study set-up (same as the primary report), 13 crowns were placed on the distal-most molars (one on the first premolar and 12 on the second). Further studies with a larger number of crowns are therefore necessary to clarify the risk of events associated with being a first or second premolar, considering the relevance of being a distal-most molar. Moreover, removable partial denture (RPD) abutments are considered as a risk factor for crown debonding [9]. Miura et al. [7] reported that the risk of complications was significantly higher for RPD than for non-RPD abutment teeth. In the present study, only five crowns were RPD retention crowns. In addition to the cases with an event, this low number of cases was the reason for conducting the survey.

The luting material significantly influenced the frequency of events ($P < 0.01$, Table 2). In contrast, the types of resin blocks ($P = 0.48$) and abutments ($P = 0.23$) had no significant influence. Basically, the difference in materials is not a significant factor in terms of clinical outcomes, even if the material is shown to be completely different in an in vitro study [16]. Regarding the luting materials, the differences between "glass ionomer," "resin-modified glass ionomer (RMGI)," and "resin" have been reported [7], with the results indicating that RMGI achieved the best clinical performance. In the present study, only resin cement was used, and a large influence was observed between self-adhesive cement (Clearfil SA luting) and conventional resin cement with primer (ResiCem). Another clinical study on CAD/CAM resin composite molar crowns also found that some primers and/or bonding agents should be involved in the bonding procedure [17]. To clarify further the details regarding the differences in luting material, a statistical analysis involving a larger number of patients and a smaller dispersion of samples is needed. Just as the factor of an RPD abutment was excluded in the present study, statistical analyses in relation to a comparison of Panavia V5 (n = 6), G-CEM (n = 2), and Super Bond C & B (n = 1) were avoided in the multivariable Cox regression analysis. Moreover, in terms of the type of resin block, no significant differences were observed ($P = 0.48$), in part because the selection preference for the type of resin block was similar in all cases, as this study was conducted at a single facility. To overcome this limitation, multicenter and/or prospective studies are needed to reduce the missing values of the main factors. In addition, no significant differences resulting from the type of abutment were observed ($P = 0.23$). This was considered to be owing in part to the proportion of resin abutment being large in most cases, whereas the information on cast metal abutments and vital teeth was limited (94 resin cores, eight cast metal cores, seven vital teeth).

As we extracted 3D digital data from the CAD software program based on the information in the clinical investigation, we could obtain data for not only abutment teeth and crowns with events, but also for those with no events, thereby enabling a more detailed analysis. To our knowledge, this is the first study to investigate the relationship between CAD digital data and the clinical courses of patients with crowns. Regarding the three items measured in this study, neither the vertical dimension of the abutment teeth nor the taper changed after the data collection (i.e., from chairside in the clinic); however, the thickness of the crown occlusal surface might have decreased because of occlusal adjustment. Therefore, using the CAD software program, we measured the thinnest part existing in the pit and fissure part of the crown occlusal surface (i.e., no contact points). In the primary report of the present study, only the vertical abutment dimension of the "non-functional cusp side" significantly influenced the frequency of events [10]. This result suggests that, for inhibiting events, maintaining the vertical dimension of the non-functional cusp side of the abutment teeth is more important than maintaining that of the functional cusp side, the taper of abutment teeth, or the thickness of the crown occlusal surface, and has a tremendous influence on clinical practice [10]. In 1988, Zuckerman et al. [18] reported that the lack of a region that resists the overturning of a crown, which is located at the apex of the abutment teeth on the non-functional cusp side and known as "resistive area," increases the risk of crown debonding. The suggested reason for this is that if stress is added to the functional cusp, additional stress is concentrated on the axial surface of the non-functional cusp on the opposite side. The previous opinions regarding the causes of crown debonding were all derived from basic research. The clinical and digital findings in this study support those from the previous basic research, and highlight the clinical significance of the vertical dimension of the non-functional cusp side of the abutment teeth.

The present study, which reports longer and clearer clinical outcomes (i.e., debonding only), revealed that all three factors (vertical dimension, taper, and thickness) significantly influenced debonding (Table 3). The reasons for using only the debonding outcomes are as follows: 1) most of the complications involved debonding, 2) the debonding and crown fracture factors were completely different, and 3) the root fracture and core build-up debondings were not caused by any measured factor. The null hypothesis, i.e., that the morphology of the crown and abutment teeth did not influence the clinical outcome of the CAD/CAM indirect resin composite premolar crown, was rejected. According to the hazard ratios (Table 3) and nonlinear graphs (Fig. 3), the crown thickness was less effective than the vertical dimension and taper. Because the influence of the vertical dimension was more significant than that of the crown thickness of the occlusal surfaces, implementing excessive clearance for the preparation of the abutment teeth is not recommended in clinical practice. The results of this retrospective clinical study suggest that the proportion of fractures for CAD/CAM indirect resin composite crowns is much smaller than that of crown debonding; therefore, the most important point to consider when preparing abutment teeth to prevent crown fracture is not to implement excessive clearance. In addition, the vertical dimension of the abutment was grouped as a buccal/lingual side (Appendix Fig. 1c, d) and lower/higher side (Appendix Fig. 1e, f). These different groups did not reveal any new findings. From this result, it is speculated that only the bonding area plays a role in avoiding debonding, because a higher vertical dimension will provide a larger bonding area. As mentioned above, Miura et al. previously presented the following two theories to avoid crown debonding: "the thickness of the crown is less important" [19] and "the mount of the bonding area is important" [20].

In this study, we demonstrated synergistic effects by combining the factors of the vertical dimension of the abutment teeth, taper, and thickness of the crown occlusal surface. The results obtained using digital data may have important clinical implications. Whereas each of the investigation items in this study (i.e., the vertical dimension of the abutment teeth, taper of the abutment teeth, and thickness of the crown occlusal surface) were simplified as a single value for the analysis, it is also theoretically possible to use data considering the minimum and maximum values and dispersion (heterogeneity using 3D data) at a more advanced level. A recent study reported that artificial intelligence technology, that is, deep learning using a convolutional neural network method, demonstrated considerably good performance in terms of predicting the debonding probability of a CAD/CAM indirect resin composite premolar crown with 3D stereolithography models of a die scanned from patients [21]. In this study, we were unable to determine the occlusal force or occlusal contact conditions during the lateral movement of the patients. In the near future, we believe that the functional storage of digital jaw movement data [22] and occlusal force data [23] will enable the analysis of complicated factors on a large scale in clinical practice.

We have learned that clinical outcomes and digital information are always far from perfect, and are often generalized. First, the patients in the present study were relatively older than the normal population of Japan. This was owing to the continuous sample of the university hospital. Also, there was a deflection in sex of the population, as 75% of the patients in the present study were women; that discrepancy in population is a limitation of the study. Second, the details were not uniform and clear, as this was a retrospective clinical study. Even the 3D data of an abutment show its shapes; however, the amount of remaining dentin (i.e., existence of ferrule) was not certain. Further, the clinical selection criteria for the CAD/CAM indirect resin composite crowns were not defined before the treatment, and there was also a small amount of censored data. These factors should be considered in a future prospective study.

5. Conclusions

1) From the clinical courses of 109 CAD/CAM indirect resin composite premolar crowns, 21 cases of debonding, two crown fractures, five root fractures, and two core debondings were observed. The type of tooth (first or second premolar) and luting materials significantly influenced the frequency of events.
2) The cumulative no-debonding and no-crown-fracture rate over 1423 days (3 years and 11 months) was 77.4%.
3) From the clinical outcomes and 3D digital data of 75 crowns and abutment teeth, it was revealed that the vertical dimension and taper of the abutment teeth and thickness of the crown occlusion surface significantly influenced the debonding.

Acknowledgements

This work was supported by JSPS KAKENHI Grant No. JP17H04389. We would like to thank Forte Science Communications, Inc., for their English language editing services.

Part of this report was presented at the 127th Annual Meeting of the Japan Prosthodontic Society (2018, Okayama, Japan).

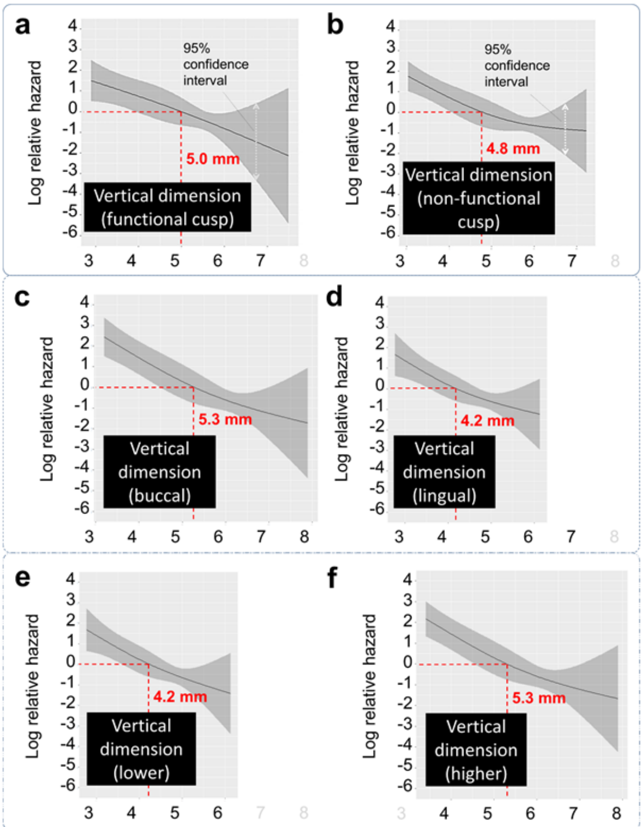
Conflicts of interest

None.

Appendix Table 1. Anatomic crown locations and number of CAD/CAM indirect resin crowns.

	Right second premolar	Right first premolar	Left first premolar	Left second premolar	Total
Maxillary	12, 10	17, 13	9, 7	16, 11	54, 41
Mandible	21, 12	8, 8	9, 4	17, 10	55, 34
Total	33, 22	25, 21	18, 11	43, 21	109, 75

The number of crowns (= abutment teeth) according to location are presented as (all data, 3D data). All data means the final clinical data set, 109 in total; 3D data means extracted data after excluding cases without 3D digital data or with unusable 3D digital data, 75 in total.



Appendix Fig. 1. Vertical dimension side of the abutment teeth and logarithm hazard ratio. (a): the functional cusp side (same as Fig. 3a), (b): the non-functional cusp side, (same as Fig. 3b) (c): the buccal side, (d): the lingual side, (e): the lower side, and (f): the higher side.

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