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Risk factors for open gingival embrasures after clear aligners treatment: a retrospective study

Wenjie Cui[1], Yibai Liu[1], Yang Zhao[1], Lang Lei[2*] and Houxuan Li[3*]

Abstract

Background To explore the incidence and risk factors of open gingival embrasures (OGEs) in the front region of adult none-extraction cases with clear aligner treatment (CAT).

Methods This retrospective study included eighty-two adult patients with non-extraction and CAT treatment, all of which were provided by Invisalign. A total of 820 tooth sites were assessed for OGEs in intraoral photographs. These sites were categorized into nonoccurrence group and occurrence group. The parameters– including crown shape, root angulation (parallel root recorded as zero and divergent root as positive), distance between cementoenamel junction, and distance from interproximal contact point (ICP) to alveolar bone crest (ABC)– were compared between occurrence group and nonoccurrence group using independent t-test and were further analyzed based on the severity. Logistic regression analysis was used to determine the significant risk factors of OGEs.

Results The overall incidence of OGEs was 13.4% in the maxilla and 30.7% in the mandible. The highest incidence was found between the mandibular central incisors, reaching 39.02%. Age (Maxilla: OR = 1.119, 95%CI (1.048–1.195); Mandible: OR = 1.068, 95%CI (1.018–1.121), mandibular crowding (OR = 0.846, 95%CI (0.729–0.981), distance between adjacent maxillary teeth at the cementoenamel junction (Maxilla: OR = 2.400, 95%CI (1.146–5.027) and distance from ICP to ABC (Maxilla: OR = 8.046, 95%CI (4.016–16.122); Mandible: OR = 3.475, 95%CI (2.390–5.052) in the maxilla and mandible have significant correlation with the occurrence of OGEs ($P<0.05$).

Conclusions OGE is a common complication after CAT, adversely affecting the smiling aesthetics. Clinicians should be well aware of risk factors, such as age, degree of dental crowding, and the distance from the ICP to ABC.

Keywords Open gingival embrasures, Black triangles, Orthodontic treatment, Clear aligners

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Introduction

Open gingival embrasures (OGEs), also called black triangles, are gaps below proximal contacts and not filled with the papilla. A high incidence of OGEs was observed in adult orthodontic patients, ranging from 38% to 43.7% [1]. The presence of the OGEs greatly impairs smiling aesthetics, and it is the third most unpleasant aesthetic issue after dental caries and crown margins [2]. In addition, they may affect pronunciation, and bring periodontal problems, such as food retention and biofilm accumulation [1].

Multiple factors contribute to the occurrence of OGEs. Most notably, alveolar bone resorption and thin-scalloped periodontal biotype are major risk factors of OGEs [3–6]. OGE is one of the most complained issue in the adult orthodontics. Patient age, the degree of dentition crowding, the distance from the proximal contact point to the crest of the bone, tooth morphology, and the direction of gingival movement during orthodontic tooth movement with fixed appliances can also increase the likelihood of OGEs [1, 7, 8].

Despite its wide acceptance of clear aligner therapy(CAT) in adult patients due to its less interference on facial aesthetics, OGEs are commonly present after CAT. The incidence rate stands at 25.7% and 40.3% between the two central incisor of the maxilla and mandible, respectively [9]. Several modalities have been proposed to reduce the adverse effect of OGEs, such as adjustment of the tooth axial inclination, interproximal enamel reduction (IPR) to modify the crown shape, or restorative procedures using resin or veneers [10]. However, the potential risk factors for the occurrence of OGEs during CAT are less clear.

Currently, researches on OGEs in the context of CAT are very limited. One study examined the relationship between the number of attachments and IPR on the occurrence of OGEs between central incisors. The findings indicated that while IPR was not linked to the incidence of OGEs, it did play a role in reducing their severity. Additionally, a higher number of attachments increases the incidence of OGEs [9]. But the relationship between patient-related factors such as age, periodontal phenotype, tooth shape, and degree of dental crowding with OGEs remains unclear. Therefore, further research on the relationship between these factors and the occurrence of OGEs is essential.

Therefore, the purposes of this study were (1) to determine the presence of OGEs between anterior teeth in adult none-extraction cases with CAT, and (2) to explore the potential factors that affect the occurrence of the OGEs.

Methods

Subjects

This retrospective study was approved by the Ethical Committee of Nanjing Stomatological Hospital, Affiliated Hospital of Medical School, Institute of Stomatology, Nanjing University, Nanjing, China (NJSH-2023NL-036). All patients signed the informed consent.Research carried out on humans and/or human data must be in compliance with the Helsinki Declaration.

Eighty-two adult patients (13 males, 69 females; average age 25.82 ± 5.27 years old) were selected from the Department of Orthodontics at the Nanjing Stomatological Hospital between September 2017 and December 2021.

Patients were selected based on the following criteria: (1) Age ≥18 years old; (2) Patients underwent non-extraction clear aligners treatment; (3) Complete initial (T0) and final (T1) orthodontic records, including frontal intraoral photos, panoramic radiographs and study models; (4) Patients who do not have a long-term history of medication or have used medication that alters gingiva condition; (5) Patients without systemic diseases. The exclusion criteria were as follows: (1) Missing one or several anterior teeth; (2) History of periodontal disease; (3) Unclear or containing foreign objects such as saliva, food residue, etc. in the front photos; (4) Having a history of periodontal surgery in the upper and lower anterior teeth areas; (5) Women who are pregnant, breastfeeding, or planning to become pregnant during orthodontic treatment; (6) Smoking history. The average treatment time was 26.63 ± 6.70 months, and regular oral hygiene instruction was provided during the treatment period.

Classification of the OGEs incidence and severity

Based on frontal and lateral intraoral photos taken before and one week after orthodontic treatment, the incidence and severity of the OGEs in the upper and lower anterior teeth areas of patients were statistically analyzed. The incidence and severity were evaluated jointly by one orthodontist and two periodontists. Patients would only be included in the study if the evaluation results of at least two doctors were consistent. Based on the assessment results, the tooth sites were divided into occurrence and non-occurrence groups. Based on the Jemt index (Fig. 1), the occurrence group was categorized into three sub-groups: mild, moderate, and severe [8, 11]. The patient's intraoral photographs were taken by a dedicated photographer from our orthodontic department using the same model of equipment.

The IOTN scoring system and the classification of malocclusions

Based on the frontal and lateral photographs of the oral cavity taken before orthodontic treatment, the types of

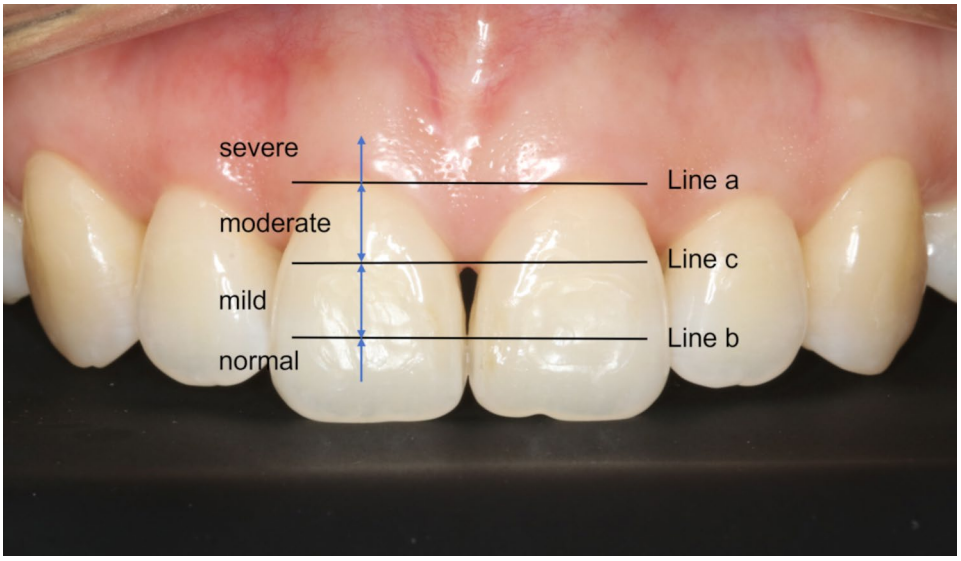

Fig. 1 Classification of the OGEs incidence and severity. Open gingival embrasures were classified according to severity. Line a, a tangent line to the highest gingival curvature of the crown. Line b, a line that passed through the most cervical contact point and was parallel to line (**a**) Line c, a line that bisected the distance between line a and line (**b**) The severity of the open gingival embrasures (normal, mild, moderate, severe) was determined according to the position of the tip of each gingival papilla in the anterior dental region

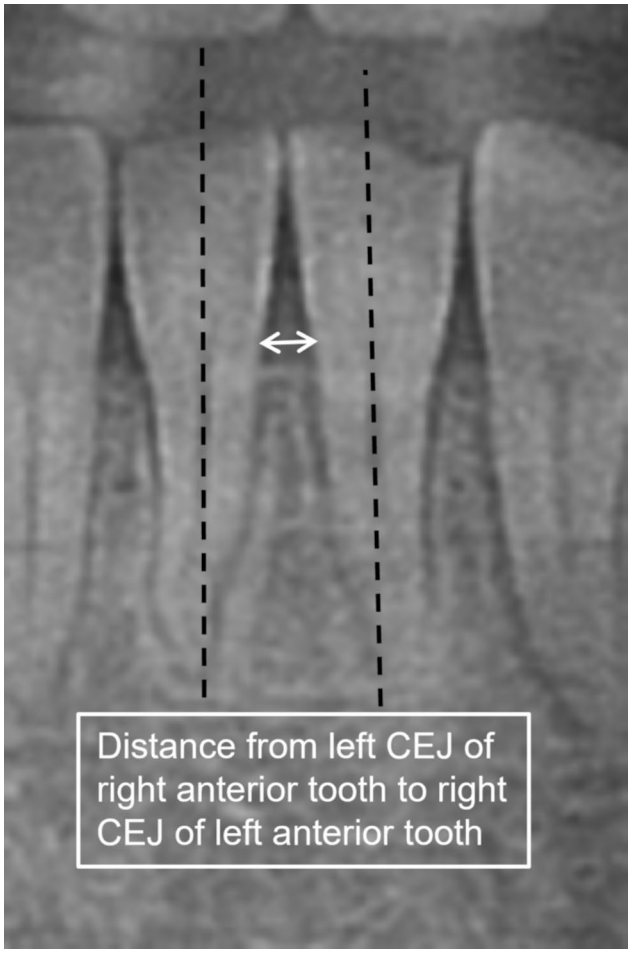

Fig. 2 Measurement of the distance between cementoenamel junction (CEJ)

malocclusion were recorded and the IOTN score was assessed [12, 13]. The IOTN scoring was evaluated by two doctors. Only patients with consistent assessment results were included in the study.

Measurement of root angle, distance between cementoenamel junctions (CEJs) and distance from proximal contact point (ICP) to alveolar bone crest (ABC) on panoramic radiographs

All variables from panoramic radiographs were measured by using ImageJ software (Version 1.54 g; National Institutes of Health, USA), including: (1) distance between the mesial cementoenamel junctions of the two adjacent teeth (Fig. 2); (2) distance between the interproximal contact point and alveolar bone crest before (T0), after (T1) and during treatment (Δ=T1-T0) (Fig. 3); (3) the angle between the long axes of adjacent anterior teeth at T1(Fig. 3). This angle was defined as root angulation, with parallel root recorded as zero and divergent root as positive [8, 14].

Measurements of crowding and crown morphology on digital models

Pre-treatment digital models provided by ClinCheck (Align Technology, California, USA) and Dolphin Imaging Software (Dolphin Imaging & Management Solutions, Chatsworth, USA) were captured according to tooth position and imported into ImageJ software (National Institute of Health, USA), respectively. The crown length (CL) and crown width (CW) of each front tooth were measured, and crown morphology was defined as CW/CL. The tooth crown was evenly divided

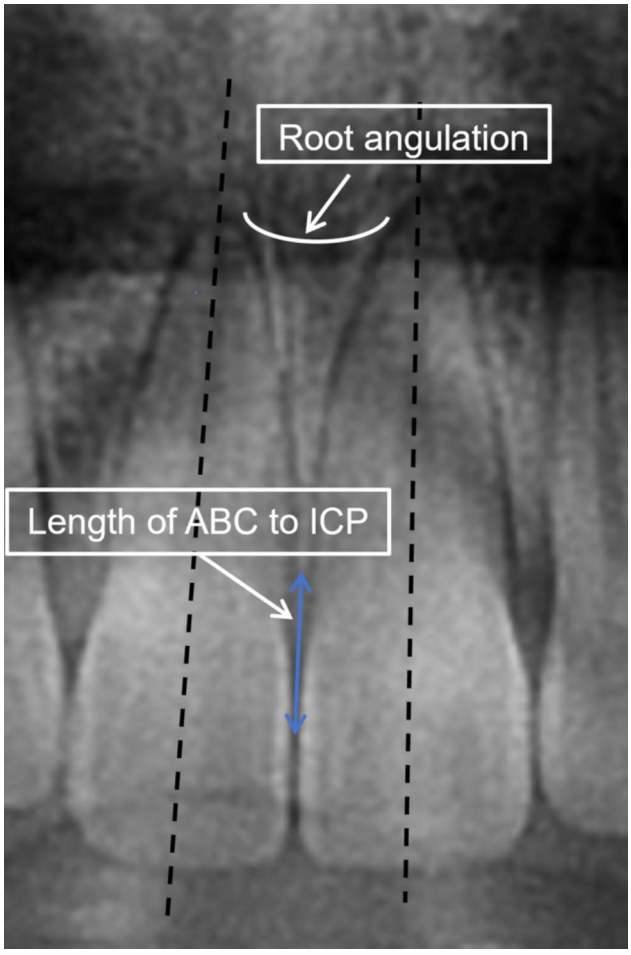

Fig. 3 Measurement of root angulation and distance from interproximal contact point to alveolar bone crest

into three parts, and CW was defined as the proximal and distal distance between middle 1/3 and cervical 1/3 junction; CL was defined as the distance from the apex of the gingival margin to the midpoint of the incisal margin or the cusp (Fig. 4). The crowding was measured by the difference between the total size of the crown of the front teeth and the existing arch length.

Statistical analysis

IBM SPSS Statistics 26 (International Business Machines Corp., Chicago, IL, USA) software was used for statistical analysis, and kappa value was used to determine the consistency and repeatability among raters, with a significance level set at $P<0.05$.

All data were measured three times and averaged by an inspector. Independent t-test was used to analyze the crowding degree and crown morphology, treatment time, age, root angle after treatment, distance between cementoenamel junction and distance from ICP to ABC in both groups. Logistic regression analysis was performed to assess the correlation between multiple variables.

Results

The overall kappa statistic of 0.917 reflected an almost complete level of agreement. ($P<0.001$). After orthodontic treatment, 64 out of 82 non-extraction patients had OGEs in their front teeth. Additionally, OGEs occurred in 73.17% of the observed dental sites. Among these sites, the incidence of mandibular central incisors was the highest, at 39.02%; this was followed by that between mandibular lateral incisors and central incisors (34.15% and 35.37% at sites 31–32 and 41–42, respectively) (Table 1). The incidence of maxillary central incisors was 25.61%. Moderate OGEs were mainly observed between the lower central incisors, with a incidence of 12.20%. No

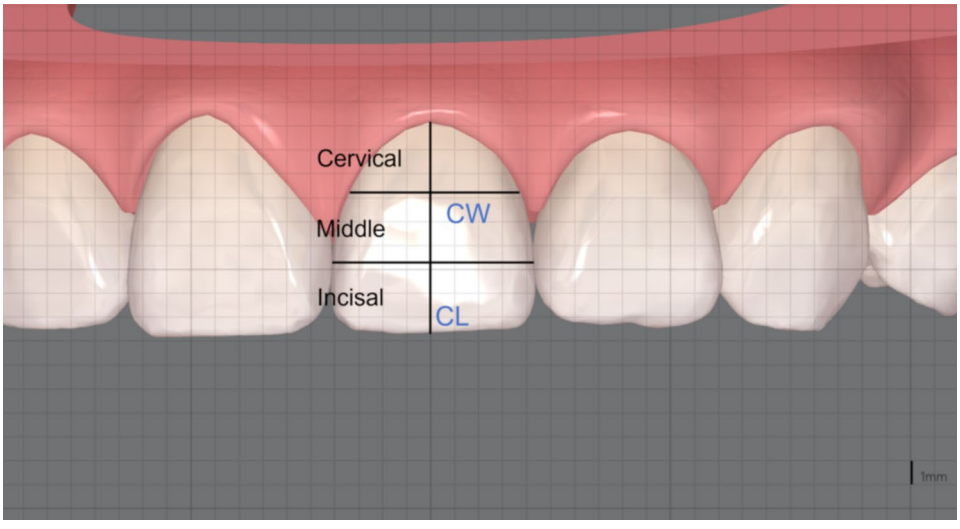

Fig. 4 Measurement of the crown ratio. CW crown width, CL crown length

Table 1 Incidence and severity of open gingival embrasures

Tooth site	Occurrence			
	Nonoccurrence	Mild	Moderate	Severe
Maxilla				
13 – 12	71 (86.6)	11 (13.4)	0	0
12 – 11	74 (90.2)	8 (9.8)	0	0
11–21	61 (76.3)	19 (23.2)	2 (2.4)	0
21–22	75 (91.5)	5 (6.1)	2 (2.4)	0
22–23	74 (90.2)	8 (9.8)	0	0
Total	355 (86.6)	51 (12.4)	4 (1.0)	0
Mandible				
33 – 32	65 (79.3)	15 (18.3)	2 (2.4)	0
32 – 31	54 (65.9)	24 (29.3)	4 (4.9)	0
31–41	50 (61.0)	22 (26.8)	10(12.2)	0
41–42	53 (64.6)	26 (31.7)	3 (3.7)	0
42–43	62 (75.6)	20 (24.4)	0	0
Total	284 (69.3)	107 (26.1)	19 (4.6)	0

Data were presented as *n* (%)

Nonoccurrence: the gingival papilla completely fills the interdental space

Mild: the reduction of papilla height is less than half the distance between the interproximal contact point and gingival margin

Moderate: the reduction of papilla height exceeds half the distance between the interproximal contact point and gingival margin but does not extend beyond the gingival margin

Severe: the reduction of papilla height extends beyond the gingival margin

severe OGEs were found at 820 sites in the anterior maxilla and mandible.

Among the 82 patients included in the study, the orthodontist's evaluation indicated that 47 patients scored ≤ 4 on the aesthetic component, while 72 patients (87.8%) were classified at level 1 or 2 for the dental health component. The distribution of different types of malocclusion was relatively balanced (Table 2).

In the maxilla, the age, distance between enamel cementum after treatment, distance from ICP to ABC before and after treatment, and their differences in the non-occurrence group were all smaller than those in the occurrence group ($P < 0.05$, Table 3). While in the mandible, the non-occurrence group had significantly smaller age, crowding, distance from ICP to ABC before and after treatment and its difference, and significantly larger mesial crown morphology and root angulation after treatment ($P < 0.05$). The OGEs were evaluated according to the severity between the incisors in the mandible. The crown morphology of left mandibular central incisors in the mild group was larger than that in the moderate group. The distance from ICP to ABC after treatment and the difference during treatment were smaller than those of the moderate group ($P < 0.05$, Table 4).

In order to explore the relationship between the incidence of OGEs and each measurement index, Logistic regression analysis was carried out separately for the upper and lower jaw. In the maxilla, age, the distance between enamel cementum, and the distance from ICP to ABC after treatment were significant influencing factors. The age, crowding degree, and distance from ICP to ABC after treatment in the mandible were significantly correlated with the formation of the OGEs ($P < 0.05$, Table 5).

Discussion

Negative emotions are often associated with CAT, primarily due to factors such as pain, aesthetic attachments, and sleep disturbances [15]. Among these, OGEs are regarded as one of the most significant contributors to post-treatment appearance. Consequently, evaluating the risk factors for OGEs and exploring potential

Table 2 The distribution of OGEs across different IOTN classifications and various types of malocclusions

Variables	Male (*n*)	Female (*n*)	OGEs			
			Nonoccurrence (*n*)	Mild (*n*)	Moderate (*n*)	Severe (*n*)
IOTN Dental Health Component						
Level 1	2	20	187	30	3	0
Level 2	6	44	380	107	13	0
Level 3	3	5	59	16	5	0
Level 4	1	0	4	4	2	0
Level 5	1	0	9	1	0	0
Total	13	69	639	158	23	0
Aesthetic Component (AC) of IOTN						
1–4 No need	6	41	389	76	5	0
5–7 Moderate need	7	26	250	82	18	0
8–10 Definite need	0	0	0	0	0	0
Total	13	69	639	158	23	0
Malocclusion						
Class I	1	27	237	39	4	0
Class II	8	22	226	65	9	0
Class III	4	20	176	54	10	0
Total	13	69	639	158	23	0

Table 3 Comparison of OGEs between the nonoccurrence and occurrence groups in the maxilla and mandible

Measurements	Maxilla			Mandible		
	Nonoccurrence (*n* = 355)	Occurrence (*n* = 55)	*P* value	Nonoccurrence (*n* = 284)	Occurrence (*n* = 126)	*P* value
Age, y	25.44 ± 4.872	28.24 ± 6.760	**0.004***	25.21 ± 4.665	27.18 ± 6.160	**0.002***
Treatment duration, month	26.713 ± 6.832	26.082 ± 5.534	0.449	26.357 ± 7.088	27.238 ± 5.595	0.178
Crowding, mm	2.129 ± 1.498	2.369 ± 1.411	0.266	2.182 ± 1.651	2.811 ± 1.642	**0.000***
Mesial crown ratio	0.785 ± 0.133	0.763 ± 0.141	0.259	0.606 ± 0.124	0.573 ± 0.076	**0.006***
Distal crown ratio	0.759 ± 0.139	0.760 ± 0.150	0.987	0.631 ± 0.090	0.617 ± 0.162	0.365
Root angulation at T1, °	0.072 ± 4.645	1.293 ± 4.046	0.066	3.040 ± 5.672	1.744 ± 5.954	**0.036***
Right CEJ-left CEJ distance at T1, mm	1.676 ± 0.446	1.970 ± 0.608	**0.001***	1.492 ± 0.793	1.616 ± 0.435	0.101
Distance from ICP to ABC at T0, mm	3.713 ± 0.663	4.063 ± 0.874	**0.006***	3.735 ± 0.833	4.000 ± 0.832	**0.003***
Distance from ICP to ABC at T1, mm	4.552 ± 0.613	5.349 ± 0.662	**0.000***	4.248 ± 0.789	5.031 ± 0.827	**0.000***
ΔDistance from ICP to ABC, mm	0.839 ± 0.662	1.286 ± 1.065	**0.004***	0.513 ± 0.779	1.030 ± 0.961	**0.000***

The independent t-test was used to compare the occurrence and non-occurrence groups

The negative value of root angulation indicated convergent roots

SD, standard deviation

P value < 0.05 was considered significant (*)

Table 4 Comparison of OGEs between the mild and moderate groups in the mandible

Measurement	Mild (*n* = 22)	Moderate (*n* = 10)	*P* value
Age, y	27.050 ± 6.528	29.400 ± 6.346	0.348
Treatment duration, month	26.091 ± 5.453	29.800 ± 4.809	0.075
Crowding, mm	2.712 ± 1.575	3.162 ± 1.549	0.457
Mesial crown ratio	0.563 ± 0.065	0.540 ± 0.061	0.339
Distal crown ratio	0.563 ± 0.067	0.510 ± 0.068	**0.044***
Root angulation at T1, °	-0.951 ± 3.636	0.590 ± 3.104	0.255
Right CEJ-left CEJ distance at T1, mm	1.336 ± 0.383	1.485 ± 0.248	0.199
Distance from ICP to ABC at T0, mm	4.340 ± 0.805	3.986 ± 1.060	0.305
Distance from ICP to ABC at T1, mm	5.027 ± 0.811	5.780 ± 0.820	**0.022***
ΔDistance from ICP to ABC, mm	0.687 ± 1.048	1.795 ± 1.194	**0.013***

The independent t-test was used to compare the mild and moderate groups in the mandible

The negative value of root angulation indicated convergent roots

SD, standard deviation

P value < 0.05 was considered significant (*)

Table 5 The relationship between risk factors and OGE by multilevel logistic regression analysis

Measurements	Maxilla			Mandible		
	OR	95% CI	*P* value	OR	95% CI	*P* value
Age, y	1.119	1.048–1.195	**0.001***	1.068	1.018–1.121	**0.007***
Sex	1.180	0.480–2.899	0.719	1.093	0.577–2.070	0.786
Treatment duration, mon	0.968	0.913–1.026	0.276	0.993	0.956–1.031	0.700
Crowding, mm	0.961	0.745–1.241	0.763	1.182	1.020–1.371	**0.027***
Mesial crown ratio	0.275	0.010–7.240	0.439	0.343	0.018–6.467	0.475
Distal crown ratio	1.820	0.152–21.787	0.636	3.619	0.272–48.166	0.330
Root angulation at T1, °	1.064	0.970–1.166	0.188	1.010	0.961–1.062	0.688
Right CEJ-left CEJ distance at T1, mm	2.400	1.146–5.027	**0.020***	1.171	0.860–1.594	0.316
Distance from ICP to ABC at T0, mm	0.825	0.488–1.396	0.474	0.853	0.614–1.185	0.342
Distance from ICP to ABC at T1, mm	8.046	4.016–16.122	**0.000***	3.475	2.390–5.052	**0.000***
3 – 2 vs. 1–1	0.358	0.143–0.896	**0.028***	0.512	0.242–1.084	0.080
2 – 1 vs. 1–1	0.321	0.122–0.842	**0.021***	0.845	0.437–1.631	0.615

In multilevel logistic regression analysis, 11 and 41 were defined as mesial

The negative value of root angulation indicated convergent roots

SD, standard deviation

P value < 0.05 was considered significant (*)

interventions to mitigate this risk is of critical importance. Rather than assessing the incidence of OGEs between central incisors [9, 14], we evaluated the overall OGEs incidence at 10 sites in the front region. We observed that the incidence of OGEs in the anterior region of non-extraction patients with CAT stands as high as 73.17%, implicating the importance of notifying patients the risk of OGEs during CAT. In addition, we identified several patient-derived risk factors, such as patient's age, severity of crowding, and the distance between ICP to ABC.

Incidence of OGEs in CAT is higher than that of fixed appliances treatment, which may be partly due to the higher stress of clear aligners, adversely affecting periodontal tissues [16, 17]. On the other hand, clear aligners cover all crown surface to improve retention, resulting in insufficient gingiva filling space [18, 19]. Additionally, clear aligners may have slight cytotoxic effects on gingival fibroblasts and could also affect the expression of proteins related to inflammatory responses in oral epithelial cells, potentially affecting cell proliferation and OGEs incidence [20, 21].

Currently, whether age is a risk factor for the development of OGEs are inconsistent [22–24]. In this study, age was identified as one of the influencing factors for OGEs. Ko-Kimura et al. [3] found that the probability of OGEs in patients over 20 years old was greater than that in young patients under 20. On the one hand, aging may contribute to thinning of the oral epithelium and widening of the interdental spaces, leading to a decrease in the gingiva thickness and a reduction in the papilla height [25, 26]. The thickness of the gingiva and the thickness of the alveolar bone mutually influence each other [27]. Compared with the thick gingival type, the "scalloped-thin" gingiva has thinner alveolar bone beneath the gingiva, experiences more bone loss, and has insufficient defense against external stimuli, often leading to gingival recession due to mechanical or biological irritation [5, 28, 29]. Additionally, during the process of aligning teeth, the direction of tooth movement also influences the height of the gingival papillae. When teeth move buccally, the height and thickness of the gingiva are reduced, which might increase the incidence of OGEs [4, 19, 30]. On the other hand, aging is accompanied by long-term plaque accumulation and occlusal trauma, exacerbating periodontal status [23]. Simultaneously, the capacity for tissue healing diminishes with aging, compromising the intactness of periodontal structures [3, 31].

In the present study, the distance from ICP to ABC after treatment has a significant impact on the occurrence of OGEs. When the distance between ICP and ABC was less than 5 mm, the possibility of OGEs was relatively low. The result supported findings of Tarnow et al. [32], who reported that the incidence of OGEs was only 2% when the distance between ICP and ABC was 5 mm, but significantly increased to 44% when the distance reached 6 mm. In addition, Kurth & Kokich [1]and Chang [33] also reported an increase in the incidence of OGEs with the greater distance between the ICP and ABC. Orthodontic treatment can lead to an average absorption of approximately 0.29 mm of alveolar bone [34]. In addition, Artun et al. found that the support of alveolar bone in the anterior dental area decreased by about 2.24% in adults after orthodontic treatment [35]. Out of the 820 sites examined in this study, only a few sites exhibited increased alveolar bone level.

Therefore, several interventions, including appropriate interproximal enamel reduction and proper axial movement of the teeth, should be taken into consideration in the treatment design to decrease the risks of OGEs [36, 37].

The occurrence of OGEs was also influenced by the shape of teeth, particularly the morphology of the cervical one-third of the tooth. The probability of OGEs was higher when the crown shape was divergent or triangular. This was consistent with previous ideas proposed by Chow YC and Jacklyn R [1, 38]. This phenomenon was attributed to the greater amount of dental tissue and longer proximal contact distances in square teeth compared to triangular ones. The increased distance between adjacent contact points in triangular teeth and the osseous crest led to a higher incidence of OGEs. Additionally, triangular crowns may also be associated with "scalloped-thin" gingiva. In contrast to thick periodontal biotypes, "scalloped-thin" gingiva has poorer vascularity and reduced biological capacity when exposed to external stimuli, making it more susceptible to gingival recession and attachment loss [39]. Although no significant statistical differences were observed in the regression analysis, this may be due to several factors. Gingival status and tooth attrition may affect measurement of crown length, while the shape of the adjacent area and the width of the contact area may impact measurement of crown width.

Initial crowding was also identified as a risk factor for OGEs. Regression analysis revealed that the degree of crowding only had a significant impact on the mandible ($P<0.05$). The odds ratio was 1.182, indicating thatfor each one-unit increase in mandibular crowding, the odds of developing OGEs increased by 1.182 times. Aligning crowded teeth may result in the root separation, stretching the interdental papilla and reducing gingival thickness, all of which increase the risk of the OGEs [19, 40]. The reason for no statistical significance in the maxillary region may be that the patients included in this study were all non-extraction cases, and the crowding in the anterior tooth area was minimal, which weakened the influence of crowding on the OGEs. Moreover, the mandibular arch was narrower than the maxilla, particularly

in the anterior region, resulting in reduced space available for alignment. Additionally, the higher bone density of the mandible necessitates greater forces for tooth movement, leading to increased resistance and a slower rate of movement [41]. At the same time, reduced vascular supply in the mandible compromises the tissue's repair capacity [42]. The gingiva, especially around the mandibular incisors, was thinner and more susceptible to a reduction in the height of the gingival papillae [36].

In addition, the occurrence of OGEs was also affected by the morphology of the embrasure. In the present study, the distance between adjacent enamel cementum after treatment had a significant effect on maxillary ($P<0.05$). This effect could be attributed to the greater bone loss in the long-wide and short-wide group compared to the long-narrow and short-narrow group at the same crest bone absorption height [24]. Moreover, greater root angulation was observed in the occurrence group in mandible ($P<0.05$), indicating that excessive root angulation may contribute to an increased incidence of OGEs. Traditional attachments design and appropriate overcorrection should be taken into consideration in the potential OGE sites to reduce root divergence. However, root angulation did not have a significant effect on the development of OGEs. This may be due to the fact that after the end of orthodontics, most of the roots were parallel, thus diminishing the impact of root angles [14].

However, there are some limitations to this study. Due to the inherent limitations of retrospective study, the periodontal status of the patients, such as periodontal phenotype and probing depth, could not be completely recorded. Despite this, we had made efforts to minimize the influence of periodontal status on the statistical analysis of OGEs incidence, we excluded patients who used medications affecting gingival conditions, had a history of periodontitis, or underwent periodontal surgery in the anterior region. Additionally, although OGEs are recognized as the third most undesirable aesthetic concern by patients, this study did not assess their acceptance and perceptions of the presence of OGEs following treatment.

At present, there are limited articles about the occurrence of OGEs after clear aligner treatment, and most of them concentrate on the upper and lower central incisors. However, with the increasing popularity of clear aligners, further research with larger sample sizes and investigations are needed to explore the potential influencing factors, so as to prevent or reduce the occurrence of OGEs and provide a theoretical basis for the prediction of OGEs.

Conclusions

1. In non-extraction cases treated with Invisalign, the incidence of OGEs in the anterior region of the upper and lower jaw was 73.17%, with the highest incidence rate being the mandibular central incisor at 39.02%, followed by the site between mandibular central incisors and lateral incisors, with an incidence rate of 34.15% -35.37%.
2. Age, mandibular crowding, the distance between maxillary enamel cementum and the distance between ICP and ABC increased the risk of the development of OGEs. Through comprehensive consideration of these factors, it is crucial to implement targeted interventions—including IPR, attachment design, and controlled tooth movement—to significantly mitigate the incidence of OGEs.

Abbreviations

OGEs	Open gingival embrasures
CAT	Clear aligner treatment
ICP	Interproximal contact point
ABC	Alveolar bone crest
IPR	Interproximal enamel reduction
CEJ	Cementoenamel junction
CL	Crown length
CW	Crown width

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Author contributions
WJ.C: Conceptualization; Data curation; Formal analysis; Investigation; Methodology; Project administration; Software; Supervision; Visualization; Roles/Writing - original draft; and Writing - review & editing. YB.L: Project administration; Software; SupervisioBBMMCCBBn; and Visualization. Y.Z: Data curation; Formal analysis; Investigation; and Software. L.L: Conceptualization; Funding acquisition; Investigation; Methodology; Resources; Supervision; Validation; and Writing - review & editing. HX.L: Conceptualization; project administration; resources; supervision; critical revision of the manuscript.

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Data availability
The datasets used and/or analyzed during the study are available from the corresponding author upon reasonable request.

Declarations

Ethics approval and consent to participate
All experiments in this study were conducted in accordance with the Helsinki Declaration. This retrospective study was approved by the Ethical Committee of Nanjing Stomatological Hospital, Affiliated Hospital of Medical School, Institute of Stomatology, Nanjing University, Nanjing, China (NJSH-2023NL-036). Informed consent for the anonymous use of patient data was obtained from all individual participants included in the study.

Consent for publication
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Competing interests
The authors declare no competing interests.

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The authors report there are no competing interests to declare.

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