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Multifactorial analysis of factors influencing premolar mobility in stage III/IV grade C periodontitis patients ≤ 35 years of age: a cross-sectional study

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Abstract

Background Previous studies have suggested a potential link between the crown-to-root ratio (CRR) and root morphology in patients with mild chronic periodontitis, which may be associated with tooth mobility. However, these findings have not been thoroughly investigated. Our previous study found that 76% of patients with aggressive periodontitis, particularly those with premolar involvement, exhibited abnormal root morphology, severe alveolar bone loss, and increased tooth mobility, leading to poor clinical outcomes. This study aims to investigate the specific correlations among alveolar bone resorption, root morphology, CRR, and periodontal clinical indicators with premolar mobility in stage III/IV grade C periodontitis patients aged ≤ 35 years.

Materials and methods A total of 1,064 premolars from 151 stage III/IV grade C periodontitis patients aged ≤ 35 years were included in the study. Clinical periodontal parameters and radiographic measurements were recorded. Logistic regression analysis was used to explore the relationships between these indicators and tooth mobility.

Results Significant variations in premolar root lengths were observed, ranging from 6.80 mm to 20.96 mm. Teeth with shorter roots (mean length: 10.22 mm) exhibited grade I mobility with only 28% alveolar bone resorption, whereas those with medium-length (mean length: 12.67 mm) and longer roots (mean length: 14.91 mm) exhibited mobility at 34% and 37% bone resorption, respectively. Regression models incorporating the bone-level CRR, average probing depth, and root length demonstrated strong predictive accuracy for tooth mobility ($P < 0.001$, AIC = 1700.574).

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Conclusion Premolar mobility is influenced by variations in root length, alveolar bone resorption, and probing depth. The bone-level CRR is an effective predictor for assessing tooth mobility, especially when there are differences in root length and alveolar bone resorption.

Keywords Tooth mobility, Stage III/IV grade C periodontitis, Alveolar bone resorption, Tooth root morphology, Multifactorial analysis

Background

Tooth mobility measures the movement of a tooth in response to external forces, and is a critical clinical indicator for assessing the severity of periodontal disease, predicting tooth prognosis, and guiding treatment strategies. Previous studies have identified correlations between tooth mobility and various systemic and local factors, including periodontitis, trauma, occlusal trauma, periapical inflammation, and systemic hormone administration [1, 2]. The main cause of increased tooth mobility in periodontal disease is the loss of periodontal support, due to junctional epithelium migration and alveolar bone resorption [3, 4]. However, precise data on the direct relationship between the extent of alveolar bone resorption and tooth mobility are still limited. Additionally, imbalances in the crown-to-root ratio (CRR) and variations in root morphology can also influence tooth mobility. W. Schulte et al. identified a potential link between CRR and root morphology in patients with mild chronic periodontitis, suggesting a connection to tooth mobility, but no further comprehensive investigations were conducted [5].

Aggressive periodontitis (AgP) is a fast-progressing form of periodontal disease, characterized by severe alveolar bone resorption and tooth mobility. It usually affects patients younger than 35 years who are diagnosed with stage III/IV grade C periodontitis according to the 2018 classification [6]. Our previous research, based on periapical radiographs, revealed that 76% of AgP patients exhibited abnormal root morphology, with a higher prevalence in premolars [7]. AgP patients often present with disproportionate CRR, characterized by short, tapered roots that reduce the root surface area. These clinical features, coupled with severe alveolar bone resorption and abnormal tooth mobility, contribute to a poor prognosis and can lead to premature tooth loss, significantly affecting patients' quality of life [8–10]. Therefore, a comprehensive analysis of the factors influencing premolar mobility in AgP patients is crucial.

This study aims to investigate the specific correlations among alveolar bone resorption, root morphology, CRR, and periodontal clinical indicators, and their impact on premolar mobility in stage III/IV grade C periodontitis patients aged ≤ 35 years.

Materials and methods

Patient Population

A total of 151 patients diagnosed with aggressive periodontitis (AgP) were enrolled in the Periodontal Department of Peking University School and Hospital of Stomatology between 2001 and 2015. The diagnosis of AgP was made based on clinical and radiographic criteria proposed by the 1999 International World Workshop for a Classification of Periodontal Diseases and Conditions [11].

Inclusion criteria:

1. Age ≤ 35 years.
2. At least 20 remaining teeth in the mouth.
3. At least 6 teeth with a probing depth (PD) of ≥ 5 mm and attachment loss of ≥ 3 mm on adjacent surfaces.
4. Non-smokers.

All patients were diagnosed with stage III/IV grade C periodontitis according to the 2018 classification. Xian-e Wang carried out all diagnostic translations.

Exclusion criteria:

1. Participants with fewer than 20 teeth (excluding third molars).
2. Pregnant or lactating females.
3. Participants with a history of orthodontic treatment or trauma.

Before diagnosis and treatment, full-mouth periapical radiographs were taken for all subjects by radiology technicians. The study was approved by the Ethics Committee of PKUSS (approval number: PKUSSIIT02305).

Clinical examinations

All clinical data, including the following indicators, were obtained through repeated measurements by two experienced clinical physicians (Li Xu and Li Zhang): probing depth (PD), bleeding index (BI), and tooth mobility (TM). The intraclass correlation coefficient (ICC) for PD measurements was 0.84, and for TM measurements, it was 0.90. The average PD (APD) was calculated as the mean value of six measurement points for each tooth. Similarly, the average BI (ABI) was obtained by averaging the measurements taken on both the buccal and lingual sides.

Tooth mobility was assessed using handheld dental examination forceps and classified based on the direction and extent of movement [12]:

- Degree 1: Movement in the buccolingual direction only.
- Degree 2: Movement in both buccolingual and mesiodistal directions.
- Degree 3: Presence of vertical mobility.

Additionally, the degree of tooth mobility was adjusted according to the amplitude of tooth movement: displacement of less than 1 mm corresponds to degree 1; displacement between 1 and 2 mm corresponds to degree 2; and displacement exceeding 2 mm corresponds to degree 3 [13].

Radiographic analyses

Full-mouth periapical radiographs were taken for all subjects by radiology technicians using the paralleling technique to ensure standardization. All radiographs were reviewed by experienced radiological technologists and clinical doctors to ensure appropriate exposure time and suitable projection angles. Inclusion criteria for the radiographs were as follows:

- Accurate capture, with teeth positioned at the center of the image and complete visibility of the entire tooth structure.
- Clear images with good contrast.
- Proper projection angle, with accurate vertical alignment and teeth length approximating actual measurements.
- Well-defined interproximal structures, correct horizontal angles, no apparent overlap with adjacent structures, and absence of caries, fillings, restorations, or rotations.
- No abnormalities in the periodontal ligament space (e.g., widening or disappearance), periodontal-pulp complex lesions, or residual roots.

All radiographic images were scanned for digital documentation (UMAX Powerlook1000 manual control, 600 dpi) and analyzed using GeoGebra software (Classic 5.0.735.0-d, International GeoGebra Institute, Linz, Austria) by one researcher (Jia-Ming Li). Measurements were taken twice with an interval of over 3 months, with an ICC of 0.99, indicating extremely high reproducibility.

Measurement of Periapical Radiographs.

1. Confirm points: Set points on the mesial and distal marginal ridges of the crown (A, B), mesial and distal enamel-dentin junctions (C, D), root apex (G), and mesial and distal alveolar crest points (E, F). Alveolar ridge point confirmation was based on the method by Schulte et al. [5].
2. Confirm the tooth axis: The tooth axis was determined by considering the crown area below the mesiodistal marginal ridge and the coronal two-thirds of the root area, ensuring that the axis evenly divides the tooth into mesial and distal halves. Variations in the curvature of the apical third were disregarded.
3. Measure crown-to-root Ratio (CRR): The mesial and distal central CEJs (C, D) were connected, and parallel lines passing through the mesial and distal marginal ridge points (A, B) were drawn, intersecting the long axis of the tooth at two points (H, I). The midpoint between these points (J) was selected as the crown point. A line parallel to the CEJ passing through the root apex point (G) intersected the long axis of the tooth at a hypothetical root apex point (K). The crown length (JL) and root length (KL) were measured, and the ratio of crown length to root length was defined as JL/KL.
4. The parameter of root width (PRW): PRW was measured according to the methodology proposed by Xu Li et al. [7]. According to Liu et al. [14]root width was classified into two types—normal and cone-shaped—based on a threshold value of 0.37.
5. Measure the alveolar bone loss Ratio (ABLR): Parallel lines to the CEJ passing through points E and F at varying distances from the alveolar crest were constructed. These lines intersected the long axis of the tooth at two distinct points (R and Q). The midpoint (S) of R and Q represents the average mesial and distal alveolar crest. The linear distance between these points (RK) and the hypothetical root apex (QK) was measured. The average bone loss ratio (ABLR) was calculated as 1-$(\frac{QK+RK}{2\mathrm{LK}}) \times 100\%$or 1-$\frac{SK}{\mathrm{LK}}$.
6. Bone level crown-to-root Ratio (B-CRR): B-CRR was calculated as B-CRR=(CRR + ABLR)/(1 – ABLR). This indicator estimates the remaining volume of periodontal ligament tissue and the lever arm magnitude during tooth loading, thereby partially reflecting the resistance torque generated by teeth when subjected to external forces.

The measurement methods used are depicted in Fig. 1.

Statistical methods

Statistical analyses in this study were conducted using two-tailed tests, with a significance level set at $P<0.05$. The choice of statistical methods depended on the type of data (categorical or continuous). Analyses were performed using R software version 4.2.3 [GUI 1.79 (8198 High Sierra build), S. Urbanek & H.-J. Bibiko, © R

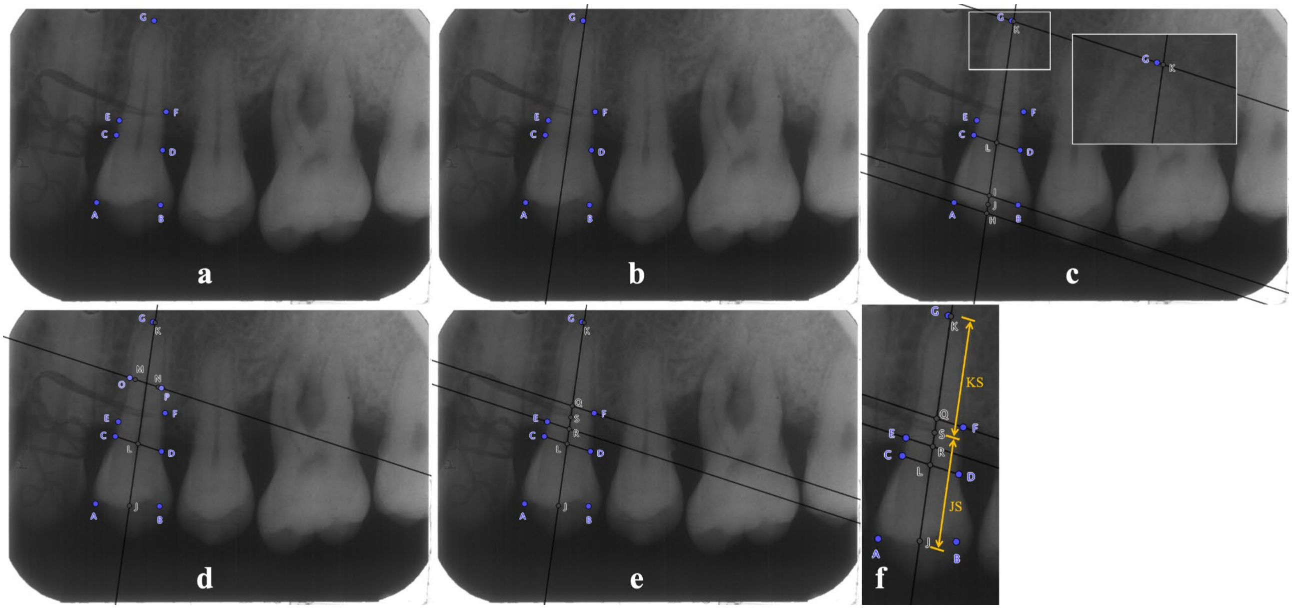

Fig. 1 (**a**) Set points; (**b**) Determine the long axis of the tooth; (**c**) Measure crown-root ratio (CRR); (**d**) Measure parameter of root width (PDW); (**e**) Measure the mesial and distal bone loss ratio; (**f**) Bone level crown-root ratio (B-CRR = JS / KS).Points A and B represent the mesial and distal points of the marginal ridge of the crown, respectively; Points C and D denote the mesial and distal points of the central cemento-enamel junction (CEJ); Point G is the root apex; and Points E and F are the mesial and distal alveolar crests, respectively. The tooth axis was determined by considering the crown area below the mesio-distal marginal ridge and the coronal two-thirds of the root area, ensuring that the axis evenly divides the tooth into mesial and distal halves. The mesial and distal central CEJ points (C and D) are connected, and parallel lines passing through the mesial and distal marginal ridge points (A and B) are drawn, intersecting the long axis of the tooth at two points (H and I). Point J, the midpoint of H and I, is identified, with line segment JL representing the crown length. A line parallel to the CEJ is drawn through the root apex point (G), intersecting the long axis of the tooth at a point designated as the hypothetical root apex (K). The line segment KL represents the root length. M and N are the midpoints of points CK and DK, respectively. A line passing through M and N intersects the root outline at points O and P. Parallel lines are constructed through points E and F, respectively, representing varying distances from the alveolar crest and intersecting the long axis of the tooth at points R and Q. Point S, the midpoint of R and Q, represents the average position of the mesial and distal alveolar crests. The line segment JS represents bone level crown length and KS represents bone level root length

Foundation for Statistical Computing, 2021]. The methods used included t-tests, chi-square tests, nonparametric tests, and logistic regression analysis.

Normality tests were conducted to assess the distribution of continuous data. Normally distributed continuous data are presented as mean ± standard deviation ($\bar{x} \pm s$), while non-normally distributed continuous data are presented as median and interquartile range [M(P_25 ~ P_75)]. Categorical data are expressed as rates or proportions.

For normally distributed continuous data, paired t-tests or analysis of variance (ANOVA) methods were used. For non-normally distributed variables, such as the crown–root ratio and reference values for root width, either transformation techniques to achieve normality or nonparametric tests were employed. Categorical data were analyzed using chi-square tests or similar approaches.

To identify factors influencing tooth mobility, a multifactor analysis was conducted. Tooth mobility served as the dependent variable (with control = I). Since it had more than two levels and passed the parallelism test ($P < 0.05$), an unordered multinomial logistic regression analysis was applied. A backward selection method was used to select variables and establish the optimal model, which provided odds ratios (ORs) and 95% confidence intervals for relevant variables.

Results

A total of 1,064 premolars from 151 patients with stage III/IV grade C periodontitis, all aged ≤ 35 years, were included in the study. The cohort consisted of 72 males and 79 females, with a mean age of 29.32 ± 3.06 years. Among the premolars, there were 286 maxillary first premolars (26.88%), 286 maxillary second premolars (26.88%), 236 mandibular first premolars (22.18%), and 256 mandibular second premolars (24.06%). The numbers of premolars with mobility degrees 0, I, II, and III were 213, 458, 300, and 93, respectively.

The average root length of the 1,064 premolars was 12.60 ± 2.13 mm, ranging from 6.80 to 20.96 mm. Root lengths were treated as a continuous variable and were categorized into three groups: short, medium, and long roots. The mean root lengths for these groups were 10.22 ± 1.12 mm, 12.67 ± 0.54 mm, and 14.91 ± 2.13 mm, respectively, with an approximate 2 mm difference between each group's mean values. The average

Table 1 Analysis of premolar root morphology and alveolar bone resorption

	Variable	Total ($n=1064$)	Short ($n=353$)	Medium ($n=356$)	Long ($n=355$)	Statistic	P
Mobility = 0	Average BLR, Mean ± SD	0.18 ± 0.10	0.15 ± 0.11	0.18 ± 0.10	0.20 ± 0.09	F = 4.708	0.010 *
	Max BLR Mean ± SD	0.22 ± 0.11	0.19 ± 0.13	0.21 ± 0.10	0.24 ± 0.11	F = 2.828	0.061
	B-CRR, Mean ± SD	0.74 ± 0.21	0.78 ± 0.23	0.74 ± 0.21	0.71 ± 0.21	F = 1.832	0.163
Mobility = 1	Average BLR, Mean ± SD	0.33 ± 0.14	0.28 ± 0.15	0.34 ± 0.14	0.37 ± 0.13	F = 13.839	0.000 *
	Max BLR, Mean ± SD	0.39 ± 0.16	0.36 ± 0.19	0.40 ± 0.15	0.42 ± 0.14	F = 4.314	0.014 *
	B-CRR, Mean ± SD	1.22 ± 0.60	1.23 ± 0.59	1.23 ± 0.68	1.20 ± 0.50	F = 0.020	0.998
Mobility = 2	Average BLR, Mean ± SD	0.42 ± 0.16	0.39 ± 0.18	0.45 ± 0.15	0.44 ± 0.13	F = 4.999	0.007 *
	Max BLR, Mean ± SD	0.48 ± 0.16	0.46 ± 0.19	0.50 ± 0.15	0.49 ± 0.14	F = 1.493	0.226
	B-CRR, Mean ± SD	1.72 ± 1.18	1.80 ± 1.36	1.83 ± 1.33	1.52 ± 0.67	F = 1.648	0.194
Mobility = 3	Average BLR, Mean ± SD	0.56 ± 0.19	0.55 ± 0.21	0.59 ± 0.19	0.56 ± 0.17	F = 0.316	0.730
	Max BLR, Mean ± SD	0.63 ± 0.20	0.62 ± 0.21	0.64 ± 0.21	0.64 ± 0.19	F = 0.116	0.891
	B-CRR, Mean ± SD	3.46 ± 4.12	3.06 ± 1.97	4.41 ± 6.54	3.02 ± 2.91	F = 0.346	0.709

BLR: bone loss ratio; B-CRR: bone level crown-root ratio; *: $P<0.05$

Table 2 Univariate Analysis of Premolar Mobility with Periodontal Clinical Indices, alveolar bone resorption, and Crown Root morphology

Variable	Total ($n=1064$)	Non ($n=213$)	I ($n=458$)	II ($n=300$)	III ($n=93$)	Statistic	P
Tooth position, n (%)						15.69	0.074
1 (14 & 24)	286 (26.9)	45 (21.2)	124 (27.1)	89 (29.7)	28 (30.1)		
2 (15 & 25)	286 (26.9)	51 (23.9)	116 (25.3)	93 (31.0)	26 (28.0)		
3 (34 & 44)	236 (22.2)	60 (28.2)	107 (23.4)	51 (17.0)	18 (19.4)		
4 (44 & 45)	256 (24.1)	57 (26.8)	111 (24.2)	67 (22.3)	21 (22.6)		
Average PD, M (Q1, Q3)	5.17 (4.17, 6.17)	4.21 (3.33, 5.00)	5.01 (4.17, 5.83)	5.70 (4.83, 6.50)	6.62 (5.50, 7.50)	K = 233.151	0.000 *
Average BI, M (Q1, Q3)	4.00 (3.50, 4.00)	3.54 (3.00, 4.00)	3.69 (3.50, 4.00)	3.74 (3.50, 4.00)	3.80 (4.00, 4.00)	K = 16.433	0.001 *
Root length(mm), Mean ± SD	12.61 ± 2.13	13.12 ± 1.88	12.58 ± 2.18	12.35 ± 2.17	12.42 ± 2.16	F = 5.968	0.001 *
Crown length(mm), Mean ± SD	5.09 ± 0.74	5.19 ± 0.64	5.03 ± 0.71	5.13 ± 0.81	5.01 ± 0.81	F = 3.003	0.030 *
CRR, Mean ± SD	0.42 ± 0.10	0.40 ± 0.08	0.41 ± 0.10	0.43 ± 0.11	0.42 ± 0.10	F = 3.130	0.025 *
Average BLR, Mean ± SD	0.35 ± 0.18	0.18 ± 0.10	0.33 ± 0.14	0.42 ± 0.16	0.56 ± 0.19	F = 173.061	0.000 *
Max BLR, Mean ± SD	0.41 ± 0.20	0.22 ± 0.11	0.40 ± 0.16	0.48 ± 0.16	0.63 ± 0.20	F = 175.348	0.000 *
PRW (mm), Mean ± SD	5.69 ± 5.49	6.38 ± 1 1.32	5.45 ± 2.33	5.51 ± 2.23	5.84 ± 2.86	F = 0.528	0.663
Root width type, n (%)						2.317	0.509
0	848 (79.7)	167 (78.4)	360 (78.6)	242 (80.7)	79 (84.9)		
1 (tapered root)	216 (20.3)	46 (21.6)	98 (21.4)	58 (19.3)	14 (15.1)		
B-CRR, Mean ± SD	1.46 ± 1.59	0.74 ± 0.21	1.22 ± 0.60	1.72 ± 1.18	3.46 ± 4.12	F = 151.812	0.000 *

CRR: crown-root ratio; BLR: bone loss ratio; PRW: parameter of root width; B-CRR: bone level crown-root ratio; *: $P<0.05$

crown lengths were similar among the three groups (5.12±0.67 mm, 5.07±0.78 mm, and 5.07±0.77 mm, P=0.515). However, statistically significant differences in crown–root ratios (CRRs) were observed among the three groups: 0.51±0.09 for the short root group, 0.40±0.07 for the medium root group, and 0.34±0.05 for the long root group (P=0.000).

The mean values of the parameter for root width (PRW) in the three groups were 0.56±0.23 mm, 0.57±0.63 mm, and 0.58±0.55 mm, respectively, with no statistically significant differences (P=0.830).

Significant variations in alveolar bone resorption were observed among the three groups (short, medium, and long roots) when the degree of tooth mobility was the same. For instance, the average alveolar bone resorption for grade I mobility was 0.28±0.15 for the short root group, 0.34±0.14 for the medium root group, and 0.37±0.13 for the long root group (P=0.000).

No statistically significant differences in the bone level crown–root ratio (B-CRR) were observed among the short-, medium-, and long-root groups when the degree of tooth mobility was the same. The 95% confidence intervals for the B-CRRs of premolars with mobility grades of 0, I, II, and III were (0.68, 0.74), (1.07, 1.16), (1.43, 1.59), and (2.13, 2.89), respectively (Table 1).

The average probing depth (APD), average bleeding index (ABI), root length, crown length, CRR, average bone loss ratio (ABLR), maximum bone loss ratio (BLR), and B-CRR showed significant differences among different degrees of tooth mobility (Table 2).

Based on the results of univariate analysis, a multilevel logistic regression model was developed to classify tooth mobility into four categories (0, I, II, III), incorporating key indicators such as ABLR, maximum BLR, and B-CRR. Due to their lower retention rate in clinical practice (often leading to extraction), teeth with grade III mobility were underrepresented; therefore, the model combined teeth with grades II and III for analysis. The regression results are presented in Table 3.

All three multilevel logistic regression models showed significant differences ($P<0.001$). Model 3 had the lowest Akaike information criterion (AIC) of 1700.574 and residual of 1676.574, indicating the best performance. At a significance level of $\alpha=0.05$, compared to teeth with mobility degree I as a reference, teeth with no mobility (degree 0) showed significant differences in APD ($P<0.001$, OR=0.681), root length ($P<0.05$, OR=1.142), and B-CRR ($P<0.001$, OR=0.017). Significant differences were also found in the APD ($P<0.001$, OR=1.581) and B-CRR ($P<0.05$, OR=0.824) between teeth with mobility degrees II and III.

Discussion

Investigating the etiological factors of tooth mobility is important for predicting tooth prognosis. In a comprehensive study on periodontitis patients, Chun-Teh Lee et al. used machine learning to identify predictive factors for tooth loss, with tooth mobility being a key predictor (mobility degree 1, OR=1.831, $P=0.001$; mobility degree 2/3, OR=1.210, $P<0.001$) [15]. Similarly, a retrospective study on aggressive periodontitis demonstrated that teeth with mobility degree 1 had a 4.71-fold increased risk of tooth loss compared to non-mobile teeth, while teeth with mobility degrees 2 and 3 had 6.12-fold and 16.7-fold increased risks, respectively [16].

In our study, we investigated factors influencing premolar mobility in stage III/IV grade C periodontitis patients aged ≤ 35 years. We found significant variations in premolar root lengths (ranging from 6.80 mm to 20.96 mm) but no differences in crown lengths. This suggests that the crown-to-root ratio (CRR) is primarily determined by root length, consistent with our previous findings [7]. Additionally, premolars with medium and long roots exhibited more alveolar bone resorption compared to those with shorter roots, indicating that teeth with shorter roots are more susceptible to increased mobility when the percentage of alveolar bone loss relative to root length is similar. Under conditions of uncontrolled periodontal inflammation (PD: 4–6 mm, BI: 3–4), teeth with shorter roots (average length 10.22 mm) exhibited grade I mobility at an ABLR) of 28%. In contrast, medium-rooted teeth (average length 12.67 mm) required an ABLR of 34%, while long-rooted teeth (average length 14.91 mm) required an ABLR of 37%. These findings underscore

Table 3 Multilevel logistic regression model for factors influencing premolar mobility

No. of Model	Mobility	Variable	Beta.	Std. Errors	*P*	OR (95%CI)	Accuracy	AIC	Residual Deviance
1	Non/I	APD	0.426	0.104	0.000 *	0.653 (0.533, 0.801)	59.77	1702.317	1678.317
		ABI	0.018	0.182	0.920	1.018 (0.713, 1.454)			
		Root length	0.300	0.070	0.000 *	1.350 (1.224, 1.489)			
		ABLR	9.618	0.934	0.000 *	<0.001			
	I/II&III	APD	0.447	0.075	0.000 *	1.563 (1.357, 1.800)			
		ABI	0.193	0.171	0.246	0.824 (0.595, 1.142)			
		Root length	0.131	0.061	0.000 *	0.878 (0.816, 0.943)			
		ABLR	4.197	0.581	0.000 *	66.469 (22.62, 195.32)			
2	Non/I	APD	0.404	0.105	0.000 *	0.668 (0.544, 0.821)	59.87	1713.149	1689.149
		ABI	0.036	0.184	0.844	0.965 (0.673, 1.383)			
		Root length	0.269	0.049	0.000 *	1.309 (1.188, 1.442)			
		Max BLR	8.770	0.823	0.000 *	<0.001			
	I/II&III	APD	0.484	0.071	0.000 *	1.622 (1.411, 1.864)			
		ABI	0.219	0.163	0.180	0.804 (0.584, 1.106)			
		Root length	0.103	0.036	0.005 *	0.902 (0.84, 0.969)			
		Max BLR	3.229	0.481	0.000 *	25.260 (9.847, 64.801)			
3	Non/I	APD	0.384	0.104	0.000 *	0.681 (0.555, 0.835)	60.24	1700.574	1676.574
		ABI	0.004	0.181	0.981	0.996 (0.698, 1.420)			
		Root length	0.133	0.048	0.005 *	1.142 (1.040, 1.254)			
		B-CRR	4.056	0.395	0.000 *	0.017 (0.008, 0.038)			
	I/II&III	APD	0.458	0.072	0.000 *	1.581 (1.371, 1.821)			
		ABI	0.202	0.166	0.222	0.817 (0.590, 1.130)			
		Root length	0.057	0.036	0.110	0.944 (0.880, 1.013)			
		B-CRR	0.816	0.124	0.000 *	2.261 (1.772, 2.885)			

APD: average probing depth; ABI: average bleeding index; RW Type: root width type; ABLR: average bone loss; Max BLR: the maximum bone loss ratio in mesial or distal aspect; B-CRR: bone level crown-root ratio; *: $P<0.05$

why teeth with shorter roots are more prone to mobility, emphasizing the need to consider root length in prognostic assessments rather than relying solely on bone loss percentage by age.

Our findings suggest that when estimating tooth mobility based primarily on alveolar bone loss ratio (ABLR), adjustments must be made to account for root length. Interestingly, we found no significant differences in the B-CRR) among groups with short, medium, and long roots at equivalent mobility degrees. This indicates that B-CRR is independent of absolute root length and is a more reliable indicator of tooth mobility. In our univariate analysis, the B-CRR thresholds for mobility grades I, II, and III were 1, 1.3, and 1.9, respectively. Under conditions of uncontrolled inflammation, teeth are prone to grade I mobility when the B-CRR reaches or exceeds 1, grade II mobility when it reaches or exceeds 1.3, and grade III mobility when it reaches or exceeds 1.9. This study is the first to provide empirical data supporting the clinical observation that teeth can become mobile when the B-CRR approaches 1.

In clinical practice, dentists or big data algorithms could preliminarily estimate tooth mobility based on the B-CRR during initial assessments. However, if a significant discrepancy exists between observed mobility and the B-CRR, occlusal factors or non-periodontitis-related alveolar bone loss should be considered. Additionally, caution is advised when planning treatments such as crown lengthening or orthodontic movement for premolars with a B-CRR approaches 1, as the risk of tooth mobility increases if periodontal inflammation occurs.

Tooth mobility under external forces is primarily caused by rotational movements resulting from mechanical forces applied to the teeth. The factors influencing tooth mobility can be categorized into three aspects: external force (dynamic force), resistance, and the interaction between dynamic and resistance arms. During functional activities such as chewing, occlusal forces constitute the primary external forces experienced by teeth. In this study, external force was defined as a stable and appropriately measured force applied by researchers during clinical examinations. Resistance is primarily determined by the deformation of nonrigid periodontal tissues, which is closely related to the volume (surface area and width), composition, and structure of the periodontal ligament [17].

Teeth with short, tapered, or single roots have reduced periodontal ligament surface areas, making them more susceptible to mobility under similar levels of alveolar bone loss. The width of the periodontal ligament space is also correlated with changes in tissue structure and occlusal forces [18–20]. To minimize the impact of abnormal periodontal ligament width on tooth mobility, this study excluded teeth with widened or narrowed ligament spaces, as observed on periapical radiographs. Additionally, periodontal inflammation increases tooth mobility by reducing collagen fibers, increasing blood vessels, causing pathological changes in fibroblasts, and disrupting the alignment of the principal fibers in the periodontal ligament [21–23]. This study further confirmed the association between periodontal inflammation (PD, BI, etc.) and tooth mobility.

The center of resistance represents the point at which the forces acting on a tooth achieve equilibrium, influenced by factors such as root morphology and the extent of alveolar bone resorption. In this study, we used the B-CRR to estimate resistance and determine the center of resistance, providing a comprehensive assessment of factors influencing tooth mobility. Our findings indicate that B-CRR is an optimal variable for evaluating tooth mobility.

This study has several limitations. First, due to the relatively low incidence of aggressive periodontitis, we used data from patients collected between 2001 and 2015, all selected from the aggressive periodontitis sample bank established by our research group. These patients underwent detailed clinical examinations and full-mouth periapical radiographs, both of which remained consistent throughout the study period. In this study, the diagnosis of 1999 classification was translated into the diagnosis of 2018 classification by Xian-e Wang, using patient age, bone resorption percentage, CAL, and tooth loss as criteria. All patients were diagnosed with stage III/IV grade C periodontitis according to the 2018 classification. While the regression model demonstrated a significant association between root length and tooth mobility, it did not show a significant relationship between root width and tooth mobility. Additionally, the model did not account for buccolingual factors that cannot be captured on periapical radiographs, highlighting some limitations in evaluation [14]. Other limitations include the small sample size of grade III mobile teeth, the use of two-dimensional periapical radiographs to evaluate root and alveolar bone conditions, and the focus on premolars. Although three-dimensional CBCT provides more detailed observations of root and alveolar bone conditions, periapical radiographs remain the most commonly used imaging modality in clinical practice.

The findings of this study offer valuable clinical insights, such as the need for caution when considering treatment plans like crown lengthening or orthodontic movement for premolars with a B-CRR of 1. The study has significant clinical value and warrants further research, including expanding the study to incisors and molars, establishing large databases for model development, and utilizing artificial intelligence to enhance predictive models for clinical applications, ultimately improving patient outcomes.

Conclusion

This study provides preliminary evidence that tooth mobility in patients with AgP is associated with the crown-to-root ratio, alveolar bone resorption, and probing depth of premolars. The bone-level crown-to-root ratio is an effective predictor of tooth mobility across varying root lengths and degrees of alveolar bone resorption, offering clinicians valuable insights for assessing the factors contributing to tooth mobility and making prognostic judgments for teeth with different root lengths. Additionally, this study establishes a foundation for future applications of big data and artificial intelligence in rapidly estimating tooth mobility from periapical radiographs.

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Author contributions
J.L., X.W., L.X. and H.M. conceived and presented this study.J.L. and X.W. wrote the main manuscript text and prepared figures and tables.X.X. and J.L. offered help with imaging measurements.L.Z., X.F. and R.L. were responsible for collecting clinical data. All authors reviewed the manuscript.

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Data availability
The datasets used and/or analysed during the current study are available from the corresponding author on reasonable request. The datasets generated and/or analysed during the current study are not publicly available because patient imaging data is a matter of personal privacy.

Declarations

Ethics approval and consent to participate
This study was approved by the Peking University Ethics Committee and Competent Authority (No. PKUSSIRB-202495004). Consent was obtained from all participants in this study. All patients in our hospital will sign informed consent before receiving oral treatment, which includes that the patient's medical records can be used for teaching and research. This study was performed in accordance with the 1964 Declaration of Helsinki and its later amendments or comparable ethical standards.

Consent for publication
Not applicable.

Competing interests
The authors declare no competing interests.

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References

1. Muhlemann HR. Pathological tooth mobility. Annu Meet Am Inst Oral Biol 1969:99–101.
2. Giargia M, Lindhe J. Tooth mobility and periodontal disease. J Clin Periodontol. 1997;24(11):785–95.
3. Persson R, Svensson A. Assessment of tooth mobility using small loads. I. Technical devices and calculations of tooth mobility in periodontal health and disease. J Clin Periodontol. 1980;7(4):259–75.
4. Ericsson I, Lindhe J. Lack of significance of increased tooth mobility in experimental periodontitis. J Periodontol. 1984;55(8):447–52.
5. Schulte W, d'Hoedt B, Lukas D, Maunz M, Steppeler M. Periotest for measuring periodontal characteristics–correlation with periodontal bone loss. J Periodontal Res. 1992;27(3):184–90.
6. Tonetti MS, Greenwell H, Kornman KS. Staging and grading of periodontitis: Framework and proposal of a new classification and case definition. J Clin Periodontol. 2018;45(Suppl 20):S149–61.
7. Xu L, Meng HX, Tian Y, Zhang L, Feng XH, Zhang G. [Evaluation of root abnormity in patients with aggressive periodontitis]. Zhonghua Kou Qiang Yi Xue Za Zhi. 2009;44(5):266–9.
8. Xu L, Meng HX, Zhang L, Feng XH, Shi D, Tian Y. [Analysis of alveolar bone loss and related factors in patients with aggressive periodontitis]. Zhonghua Kou Qiang Yi Xue Za Zhi. 2010;45(12):745–8.
9. Qiao M, Xu L, Meng HX, Tian Y, Zhang L, Feng XH. [Alveolar bone loss in nuclear families of aggressive periodontitis and the heredity of root shape]. Zhonghua Kou Qiang Yi Xue Za Zhi. 2013;48(10):577–80.
10. Lu D, Meng HX, Xu L, Wang XE, Zhang L, Tian Y. Root abnormalities and nonsurgical management of generalized aggressive periodontitis. J Oral Sci. 2017;59(1):103–10.
11. Lang Nea. Consensus Report: aggressive periodontitis. Ann Peri Odontol. 1999;4(1):53–53.
12. Newman MG, Takei HH, Klokkevold PR, Carranza FA. Carranza's clinical periodontology, twelfth edition. edn. St. Louis, Missouri: Elsevier Saunders; 2015.
13. Lindhe J, Lang NP, Berglundh T, Giannobile WV, Sanz M, Ebook Central Academic C. Clinical periodontology and implant dentistry, Sixth edition. West Sussex ; Ames, Iowa: Wiley Blackwell;: edn. Chichester; 2015.
14. Liu J, Xu X, Wang XE, Jia PC, Pan MQ, Xu L. A novel three-dimensional quantitative assessment method for abnormal root morphology of the maxillary premolars in vivo on cone-beam computed tomography. BMC Oral Health. 2022;22(1):229.
15. Lee CT, Zhang K, Li W, Tang K, Ling Y, Walji MF, Jiang X. Identifying predictors of tooth loss using a rule-based machine learning approach: a retrospective study at university-setting clinics. J Periodontol. 2023;94(10):1231–42.
16. Shi S, Meng Y, Li W, Jiao J, Meng H, Feng X. A nomogram prediction for mandibular molar survival in Chinese patients with periodontitis: a 10-year retrospective cohort study. J Clin Periodontol. 2020;47(9):1121–31.
17. Storey E. The nature of tooth movement. Am J Orthod. 1973;63(3):292–314.
18. Niver EL, Leong N, Greene J, Curtis D, Ryder MI, Ho SP. Reduced functional loads alter the physical characteristics of the bone-periodontal ligament-cementum complex. J Periodontal Res. 2011;46(6):730–41.
19. Nanci A, Bosshardt DD. Structure of periodontal tissues in health and disease. Periodontol 2000. 2006;40:11–28.
20. Denes BJ, Mavropoulos A, Bresin A, Kiliaridis S. Influence of masticatory hypofunction on the alveolar bone and the molar periodontal ligament space in the rat maxilla. Eur J Oral Sci. 2013;121(6):532–7.
21. Zoellner H, Hunter N. The vascular-response in Chronic Periodontitis. Aust Dent J. 1994;39(2):93–7.
22. Attstrom R. Presence of leukocytes in crevices of healthy and chronically inflamed gingivae. J Periodontal Res. 1970;5(1):42–7.
23. Goellner M, Berthold C, Holst S, Petschelt A, Wichmann M, Schmitt J. Influence of attachment and bone loss on the mobility of incisors and canine teeth. Acta Odontol Scand. 2013;71(3–4):656–63.

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