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ORIGINAL ARTICLE

Natural progression of periodontal diseases in Chinese villagers based on the 2018 classification

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Abstract

Background: Based on the 2018 classification, we aimed to determine the prevalence, distribution, and progression of periodontitis in the rural Chinese population without access to dental care.

Methods: In all, 404 subjects (28.7 ± 8.9 years, M:F = 182:222) were randomly enrolled in 1992 and re-called in 1996. With the new classification, the prevalence and distribution of stage, grade, and extent were characterized. Stage progression was compared with the progression of clinical attachment loss (CAL) and radiographic bone loss (RBL).

Results: At baseline, 94.1% villagers suffered from periodontitis, of whom 53.7% were in Stage III/IV. The prevalence of Stage III/IV increased from 18.2% in the age group of 15 to 24 years to 60.9% in 25 to 34-year-old group and 88.7% in the 35 to 44-year-old group. Significantly more Stage III/IV, generalized, and Grade C periodontitis were found in male villagers than female villagers. In 1996, the prevalence rate of periodontitis increased to 98.5%, with 80.0% in Stage III/IV. Further, 84.2% villagers presented with Grade C periodontitis based on longitudinal ΔCAL. The rate of progression (≥1 site with ΔCAL ≥3 mm) was 63.7%. Stage progression correlated significantly with CAL and RBL progression in Stage I/II, but this association was not found in Stage III/IV. Among subjects with disease progression in Stage III/IV, 90.4% shifted from localized to generalized cases. Furthermore, ceiling effects were observed in Stage III/IV.

Conclusions: In villagers without access to dental care, 94.1% suffered from periodontitis, with more than half having Stage III/IV disease based on the 2018 classification. The majority cases presented with rapid periodontal progression. Although stage progression correlated significantly with CAL and RBL progression in Stage I/II, ceiling effects existed in Stage III/IV.

KEYWORDS
extent, grade, natural progression, new classification, periodontal disease, stage

1 | INTRODUCTION

Periodontitis is a worldwide public health concern, and a high prevalence has been reported in many countries. However, the prevalence rates varied notably among populations between 19.59% and 83.5% (Brazil,[1–3] China,[4–7] Germany,[8–10] India,[11] Northern Italy,[12] Portugal,[13,14] Sweden,[15,16] and the United States[17,18]). Epidemiological surveys in untreated subjects are limited. The first report about periodontitis in the well-known series of Sri Lankan male tea laborers was published in 1978.[19] In this population, it was found that 11% periodontal sites were categorized as no disease (gingival index ≤1; no attachment loss [AL], or no pathological pocket); 59% as moderate periodontitis (pathological pocket depth, PD ≤5 mm); and 16% as advanced periodontitis (PD ≥6 mm).[20] Subsequently, another study of the natural history of periodontal diseases was conducted in Indonesia in 1998, wherein moderate periodontitis (maximum AL, 3 to 4 mm) was seen in 26% of the Indonesian untreated tea workers; advanced periodontitis (max. AL ≥5 mm) in 8%; and no or minor periodontitis (max. AL 0 to 2 mm) in 66%.[21] van der Velden et al. reported that 40% of the same Indonesian population had severe periodontitis (alveolar bone loss ≥50% at ≥2 teeth) in 2015.[22] As for some countries with well-developed public health care systems, the prevalence of severe periodontitis in populations varied from 7.8% to 48.0%.[8,15,18]

Overall, these epidemiological surveys reported that periodontal diseases were high in different populations, especially in untreated ones. However, the prevalence and disease progression of each population were significantly inconsistent among studies. One major reason was that parameters and associated thresholds for examination and diagnosis were highly different. Besides, methods used for disease analysis were also varied, for example, at the patient level, tooth level, or site level. In the past, no uniform case definition and classification criteria have been applied. In this way, the vastly divergent criteria and different thresholds for defining various types or classes of periodontitis have greatly hindered the direct comparisons among studies, which substantially affects the inference of reliable and valuable conclusions.

To overcome the issue of inconsistent classification, some classification standards for periodontal diseases have been proposed. In 2005, the 5th European workshop in periodontology based on clinical attachment loss (CAL) proposed criteria for "two-level periodontitis case definition."[23] The Centers for Disease Control (CDC) and the American Academy of Periodontology (AAP) proposed a "three-level definition."[24,25] On the basis of tooth level, Morelli et al. proposed and validated the Periodontal Profile and Tooth Profile Classes (PPC/TPC).[26,27] The initial purpose of the two-level definition was for risk factor analysis. The CDC-AAP definition was recommended for "chronic periodontitis" surveillance in population-based epidemiological studies.[28] As for the PPC/TPC, it was considered a tool to predict the risk of disease progression and tooth loss. Although the classification criteria became more specific, there was still no distinct definition of how to distinguish between periodontitis cases and periodontally healthy individuals.

In 2018, the AAP and the European Federation of Periodontology (EFP) proposed a new classification of periodontal and peri-implant diseases and conditions.[29,30] With an explicit case definition and sub-classifying standards for periodontitis, the renewed system is not merely instructive for daily clinical practice,[31–38] rather also suggested for epidemiological surveys.

To our knowledge, no research has been conducted yet on using the new classification in epidemiological studies. What are the prevalence and distribution characteristics of the population under the new classification? What are the characteristics of disease progression based on the new classification? Does it hint at any inherent problems when describing the distribution and progression of diseases? To answer these questions, it is necessary to use the new classification in epidemiological research. Therefore, we used the new 2018 classification to re-analyze the epidemiological data acquired from a study conducted from 1992 to 1996. The three aims of our study are as follows: (1) To determine the prevalence and distribution characteristics of periodontal diseases in a population without access to dental health care, under the new classification criteria; (2) To reveal the natural progression of periodontal diseases via the new classification framework; and (3) To apply the new classification system in epidemiological surveys and discuss its practical details.

2 | METHODS

2.1 | Participants

In 1992, a prospective study of the natural progression of periodontal diseases was carried out in a small village of Chengde, 300 kilometers north of Beijing, China.[39,40] Villagers were virtually without any access to dental health care, and less than half possessed a toothbrush. At baseline, 486 dentate subjects were enrolled from 2124 inhabitants by means of a stratified random sampling method, which consisted of three age-based strata—the 15 to 24-, 25 to 34-, and 35 to 44-year-old groups. Among them, 413 subjects were re-examined in 1996.[41] Of the 413 subjects, nine were excluded because of their obscure radiographs. Eventually, 404 subjects were selected for this study.

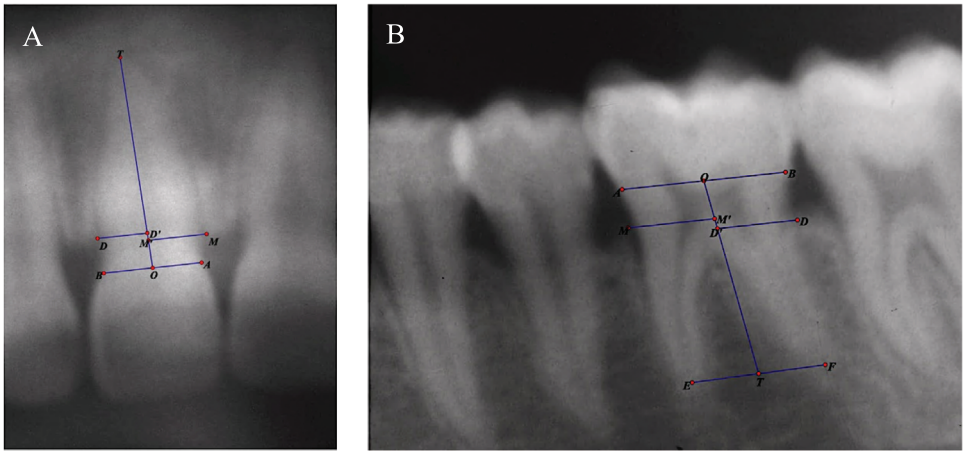

FIGURE 1 Measurement on anterior (**A**) and posterior (**B**) teeth on panoramic radiographs. The midpoint of the cemento-enamel junction (CEJ) line was considered as point O, and the apex of the root was marked as point T. OT represented the root length (RL). The lowest point of mesial (distal) alveolar bone was marked as point M (D). Being projected to the RL which was parallel to the CEJ line, point M (D) was then transferred to and intersected at the RL as point M' (D'). M'T (D'T) represented the mesial (distal) alveolar bone height (ABH)

All participants provided informed consent for the data analysis. This study was approved by the ethics board of Peking University School and Hospital of Stomatology (PKUSSIRB-201631120) and was conducted in accordance with the Helsinki Declaration of 1975, as revised in 2013.

2.2 | Clinical examinations

The original half-mouth clinical examinations were random, that is, either the maxillary right and mandibular left quadrants or the maxillary left and mandibular right quadrants. Probing pocket depths (PD) and clinical attachment loss (CAL) were examined using the National Institute of Dental Research (NIDR) periodontal probe at six sites per tooth (mesio-buccal, buccal, disto-buccal, mesio-lingual, lingual, and disto-lingual). Four examiners conducted the clinical examination. The examiner who conducted the baseline examination for an individual also conducted the re-examination for the same individual in 1996. Calibration based on 10 subjects was performed before the study started and in each examination year. Inter- and intra-examiner agreement was tested. The concordance ratio for PD and CAL were both over 0.9.[41]

2.3 | Radiographic assessment

Participants underwent a panoramic radiograph examination in 1992 and 1996 under the same radiographic conditions by using the same machine. The films were then scanned to a computer to conduct the subsequent digital radiographic assessment. Panoramic radiographs were analyzed with Geometer's Sketchpad 5.06 (the Key Curriculum Press, Inc.). Root length (RL), mesial and distal alveolar bone height (ABH), and the number of lost teeth were retrieved. The method used for radiographic measurement is presented in Figure 1.

All existing permanent teeth excluding third molars were assessed and measured. For unmeasurable teeth such as residual root, teeth with restoration, dental defect with cemento-enamel junction (CEJ) involved, and deciduous teeth, the measurement did not proceed but was recorded separately. Considering that the distance from the normal alveolar bone height to CEJ in radiographs was 0.62 to 1.67 mm (mean, 1.15 ± 0.32 mm),[42] we calculated the radiographic bone loss (RBL) as follows: $RBL\% = \frac{(RL-1.15)-ABH}{RL-1.15}$.

The radiographic measurement was done by one reviewer, who was well trained and calibrated prior to commencing the measurement. Twenty panoramic radiographs of 10 subjects in both 1992 and 1996 were randomly selected for reliability testing. The intra-class correlation coefficient (ICC) was used to compare the reliability. It showed that the ICC value of root length was 0.996 (95%CI: 0.994 to 0.997, $P < 0.001$), whereas that of the mesial and distal alveolar bone height were both 0.988 (95%CI: 0.981 to 0.992, $P < 0.001$).

2.4 | Diagnosis and sub-classification

After collecting clinical and radiographic data, the new classification system was used to diagnose and sub-classify the subjects.[43,44] CAL was the key appraisal parameter

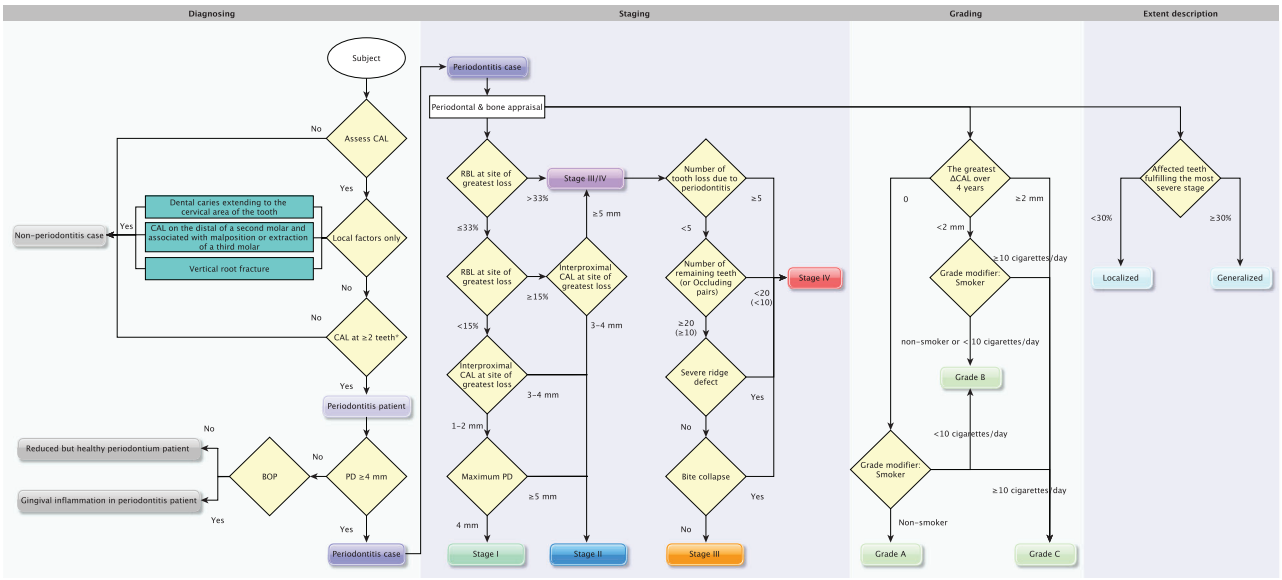

FIGURE 2 Flowchart for diagnosis and sub-classification for periodontitis. Clinical attachment loss (CAL) was the primary determinant to define a periodontitis case. When a subject was diagnosed with periodontitis, staging, grading, and extent were further described. *Interdental CAL was detected at ≥2 non-adjacent teeth, or buccal/lingual CAL ≥3 mm with pocketing >3 mm was detectable at ≥2 teeth; BOP, bleeding on probing; PD, probing pocket depth; RBL, radiographic bone loss; ΔCAL, the longitudinal change of CAL. **Figure can be enlarged in online version of the article**

for defining periodontitis. Once the participant was diagnosed, further description of case severity (stage), rate of progression (grade), and extent was provided. The procedure for diagnosis and sub-classification is illustrated in detail in Figure 2.

For staging, the RBL at the greatest loss site was the primary determinant. To discriminate between Stages III and IV, stage-shifting complexity factors were considered, which were the number of tooth loss because of periodontitis, the number of remaining teeth (occluding pairs), severe ridge defects, and bite collapse. Tooth loss because of periodontitis was defined as the baseline RBL reaching or exceeding half of the root length. Severe ridge defect was defined as alveolar bone resorption that reached or exceeded the apex. Bite collapse was defined as the adjacent teeth drifting or migrating to the missing tooth site, resulting in a significant lack of space for rehabilitation. On the other hand, overeruption of an opposing tooth may also be seen, leading to the loss of occlusal vertical dimension. Overall, one of the most differentiating factors between Stages III and IV was whether the patient required complex rehabilitation owing to multiple teeth loss and the sequelae of teeth loss.[44] When there were doubts regarding the diagnosis of Stage III or IV, we discussed with four periodontal specialists to make the final judgment.

Extent was an additional description of the number and distribution of the sites affected. The percentage of affected teeth fulfilling the most severe stage was the evaluation parameter. Thirty percent of affected teeth was still the threshold used to distinguish between localized and generalized cases.

Grading was based on direct evidence, which was the greatest change of CAL (ΔCAL) at one site over 4 years. Smoking was an additional grading modifier. Besides, we further increased the threshold of ΔCAL from 2 mm to 3 mm and 4 mm to explore the impact of different thresholds on disease sub-classification.

2.5 | Data management and statistical analysis

Participants were categorized into age groups of 15 to 24, 25 to 34, or 35 to 44 years based on their age in 1992. The subsequent 4-year prospective analysis in 1996 was also based on the 1992 age groups. For disease progression analysis, nine levels of periodontitis (stage progress) were adopted, from mild to severe which were: non-periodontitis (NP), localized Stage I (I-loc), generalized Stage I (I-gen), localized Stage II (II-loc), generalized Stage II (II-gen), localized Stage III (III-loc), generalized Stage III (III-gen), localized Stage IV (IV-loc), and generalized Stage IV periodontitis (IV-gen). If a subject progressed from one level to a higher level, such as from I-loc to I-gen, it was referred to as one-level progression. Three-level progression indicated that the subject had progressed to three higher levels, such as from I-loc to II-gen.

TABLE 1 Profile of the study population at baseline in 1992

	Age group (y)			
	15 to 24	**25 to 34**	**35 to 44**	**Total**
Subjects, *n* (%)	148 (36.6)	133 (32.9)	123 (30.4)	404 (100)
Mean age, years ± SD	18.8 ± 3.3	29.8 ± 2.9	39.3 ± 3.0	28.7 ± 8.9
Male, *n* (%)	55 (13.6)	67 (16.6)	60 (14.9)	182 (45.0)
Female, *n* (%)	93 (23.0)	66 (16.3)	63 (15.6)	222 (55.0)
Mean teeth per subject[a], *n* ± SD	27.4 ± 1.9	27.3 ± 1.7	26.1 ± 2.8	27.0 ± 2.1
Unmeasurable teeth (deciduous teeth, residual root, teeth with restoration, and dental defect with CEJ involved), *n* (%)	75 (32.5)	43 (18.6)	113 (48.9)	231 (100)
Measurable sites, *n* (%)	8098 (37.2)	7250 (33.3)	6415 (29.5)	21,763 (100)
Unmeasurable sites, *n* (%)	170 (34.3)	90 (18.2)	235 (47.5)	495 (100)
Non-smokers, *n* (%)	121 (44.3)	84 (30.8)	68 (24.9)	273 (100)
Smokers: <10 cigarettes/d, *n* (%)	10 (29.4)	12 (35.3)	12 (35.3)	34 (100)
Smokers: ≥10 cigarettes/d, *n* (%)	17 (17.5)	37 (38.1)	43 (44.3)	97 (100)
Mean untreated caries, *n* ± SD	0.18 ± 0.59	0.32 ± 0.79	0.58 ± 0.98	0.35 ± 0.81

[a]Third molars, deciduous teeth, residual root, teeth with restoration, and dental defect with cemento-enamel junction (CEJ) involved were excluded.

Data management and analysis were performed using SPSS 26.0 (IBM, Armonk, NY, USA). The prevalence and distribution of periodontitis among age groups and sex were analyzed via the chi-square test. Correlations among the variables (stages, grades, extent, age, and sex) were assessed by calculating the Pearson or Kendall's Tau-B correlation coefficient as appropriate. Correlations between stage progress and the progression of CAL and RBL were analyzed using Kendall's Tau-B correlation coefficient. The difference in the incidence of tooth loss because of periodontitis between subjects with stage progression and those without during the 4 years was evaluated by chi-square test.

3 | RESULTS

3.1 | Population profile at baseline

The profile of the study population at baseline is presented in Table 1. Of the 404 dentate subjects, 222 (55.0%) were female and 182 (45.0%) were male, with a mean age of 28.7 ± 8.9 (range: 15 to 44) years. There were no significant differences in sex distribution among age groups ($P > 0.05$).

3.2 | The prevalence and distribution characteristics at baseline

According to the new classification, 380 of 404 (94.1%) subjects were diagnosed with periodontitis (Figure 3A). Only 24 of 404 (5.9%) subjects were NP, aged between 15 and 24 years. Among the subjects with periodontitis, 3.7% were in Stage IV, 50.0% in Stage III, 35.9% in Stage II, and 4.5% in Stage I. Localized cases were more prevalent in both Stages II and III than the generalized form.

Comparison of the three age groups showed that the stage distribution was significantly different (Figure 3B to D). With aging, the prevalence of Stage III/IV periodontitis significantly increased ($r = 0.549$, $P < 0.01$). Of the subjects aged 15 to 24 years, 18.2% were diagnosed with Stage III, having no subjects in Stage IV. In the 25 to 34-year-old group, Stage III/IV was the most prevalent (60.9%). By the age of 35 and 44 years, the prevalence of Stage III/IV predominantly increased to 88.7%.

Overall, subjects that suffered from Stage III/IV periodontitis were more than those that suffered from Stage I/II. The prevalence of the localized form was higher than the generalized form (Table 2). Significantly more male subjects had Stage III/IV than female subjects ($P = 0.014$). Further, there were also more males with generalized periodontitis than females ($P = 0.035$).

3.3 | The change in prevalence and distribution from 1992 to 1996

The analysis in 1996 was based on the age groups at baseline in 1992. During the observation, 18 of 24 subjects were newly diagnosed with periodontitis (Figure 3E). Similarly, Stage III/IV showed high. The rate markedly reached 80.0% in 1996, which was notably higher than that at baseline ($P < 0.05$). However, Stage II dropped sharply from 35.9% to 18.3% in these 4 years. Despite the prevalence of

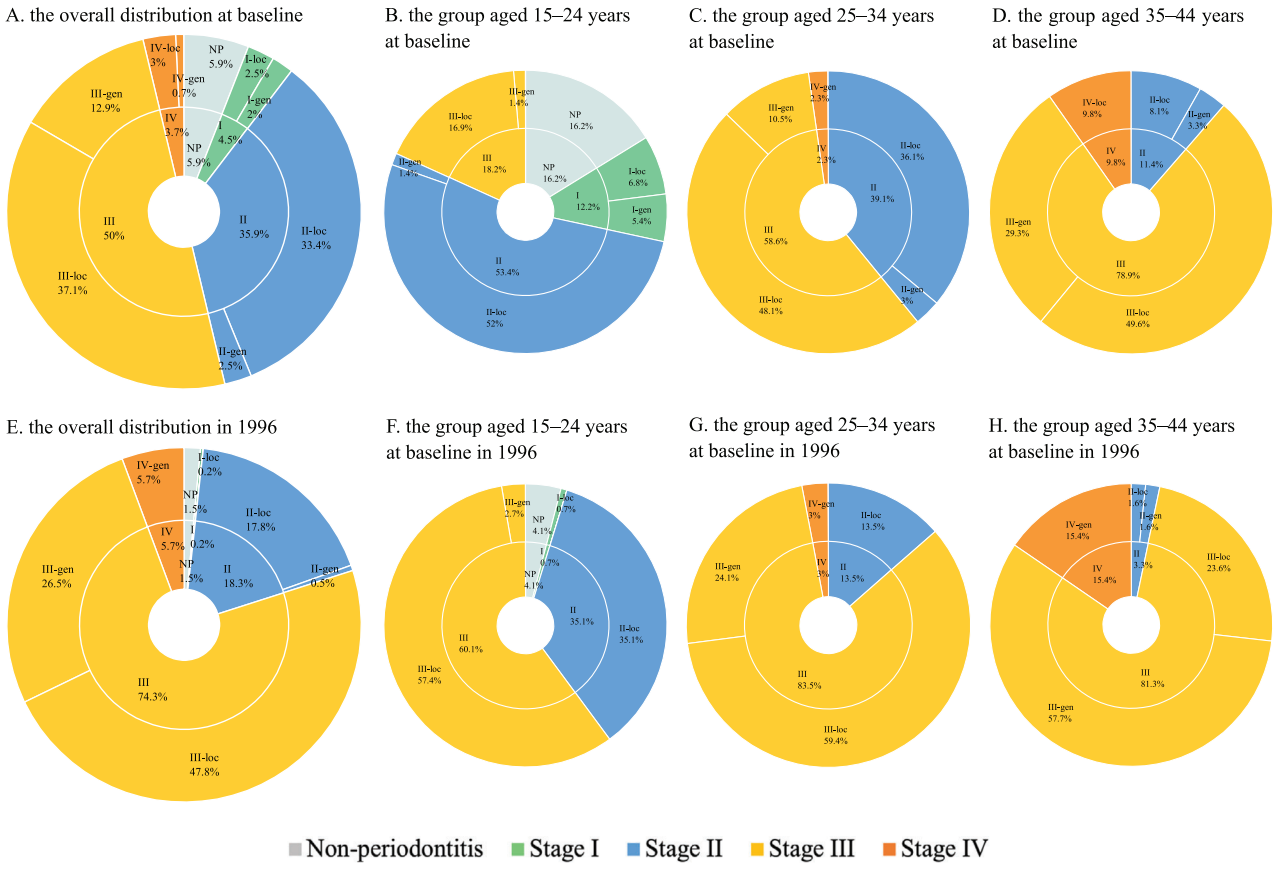

FIGURE 3 The prevalence (%) and the distribution of periodontitis in 1992 and 1996. (**A**) the overall distribution at baseline (1992); (**B**) the prevalence in the group aged 15-24 years at baseline; (**C**) the prevalence in the group aged 25-34 years at baseline; (**D**) the prevalence in the group aged 35-44 years at baseline; (**E**) the overall distribution in 1996; (**F**) the longitudinal change in the group aged 15-24 years at baseline in 1996; (**G**) the longitudinal change in the group aged 25-34 years at baseline in 1996; (**H**) the longitudinal change in the group aged 35-44 years at baseline in 1996; I-IV, Stage I to IV; loc/gen, localized or generalized form

localized cases still being predominant, the overall prevalence decreased from 76.0% at baseline to 65.8% in 1996 (total reduction rate: 13.4%). By contrast, the prevalence of generalized cases increased from 18.1% to 32.7% (total growth rate: 80.7%).

Among the three age groups, the stage distribution was also highly different (Figure 3F to H). Likewise, a steep increase in the prevalence of Stage III/IV was found with aging. Moreover, in 1996, the prevalence of Stage III/IV in all age groups was even greater than that at baseline. It was worth noting that in the 35 to 44-year-old group, III-gen became the most prevalent type after four years, showing a clear difference when compared with baseline, in which III-loc was the most prevalent.

The comparison of stage and extent between 1992 and 1996 is presented in Figure 4. Overall, 50.2% (203/404) of individuals shifted to a higher stage and/or extent, whereas 49.8% (201/404) retained the same classification as the baseline. Of the 18 newly occurred periodontitis cases, half of them developed into II-loc, and the other half developed into III-loc. Only six of 24 subjects remained as NP.

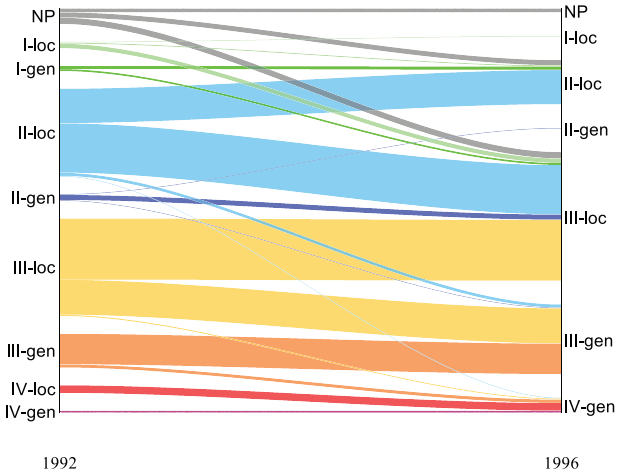

FIGURE 4 Disease progression in staging and extent. I-IV, Stage I to IV; loc/gen, localized or generalized form; NP, non-periodontitis

For Stage I, seven and 10 of the 18 new cases shifted upwards to II-loc and III-loc, respectively. Among the

TABLE 2 The prevalence and distribution of periodontitis in male and female

	N	1992, *n* (%)				1996, *n* (%)				Grading based on the longitudinal ΔCAL over the 4 y, n (%)								
		Stage		Extent		Stage		Extent		Threshold of 2 mm			Threshold of 3 mm			Threshold of 4 mm		
		I/II	III/IV	loc	gen	I/II	III/IV	loc	gen	0(A)	<2(B)	≥2(C)	0	<3	≥3	0	<4	≥4
M	182	65(35.7)	110(60.4)*	134(73.6)	41(22.5)**	25(13.7)**	156(85.7)*	108(59.3)**	73(40.1)**	4 (2.3)	8(4.6)	163 (93.1)	4 (2.3)	45(25.7)	126(72.0)	4 (2.3)	94(53.7)	77(44.0)
F	222	98(44.1)	107(48.2)	173(77.9)	32(14.4)	50(22.5)	167(75.2)	158(71.2)	59(26.6)	20 (9.8)	28 (13.7)	157 (76.6)	20 (9.8)	69(33.7)	116(56.6)	20 (9.8)	108(52.7)	77(37.6)
Total	404	163(40.3)	217(53.7)	307(76.0)	73(18.1)	75(18.6)	323(80.0)	266(65.8)	132(32.7)	24(6.3)	36(9.5)	320(84.2)	24(6.3)	114(30.0)	242(63.7)	24(6.3)	202(53.2)	154(40.5)

A-C, Grade A to C; F, female; loc/gen, localized or generalized form; M, male; N, number of subjects; n(%), number count (prevalence rate); ΔCAL, the greatest change of clinical attachment loss.

*$P < 0.05$ when compared male with female, using X^2-test.

**$P < 0.01$ when compared male with female, using X^2-test.

subjects with II-loc, 56.3% progressed moderately to III-loc, and 39.3% remained as II-loc. There was only a small number that shifted from II-loc to III-gen (3.7%). Regarding Stage III, 60% of localized cases showed that same stage as at baseline, along with the extent unchanged throughout the observation; 36.0% progressed from localized to generalized form; and merely 1.3% rapidly progressed into IV-gen. Differed from localized form, III-gen was relatively stable in sub-classification during the 4 years, with 90.4% showing no change in stage. Eventually, 9.6% of III-gen and 100% of IV-loc developed into IV-gen.

As mentioned in the methods, nine levels of disease were used to characterize the progression of periodontitis. After excluding the three baseline IV-gen subjects from the calculation, 49.4% (198/401) participants retained the original stage or extent, and 40.6% (163/401) progressed by one or two level(s). Only 9.0% (36/401) of the subjects exhibited three or more levels of transition during the 4 years.

For Stage I/II subjects, 66.8% (109/163) had disease progression. All subjects progressed from a lower stage to a higher stage. No subjects shifted from a localized to a generalized case. However, among subjects with Stage III/IV, 33.6% (73/217) had disease progression, of which 90.4% (66/73) shifted from a localized to a generalized case, and only 9.6% (7/73) progressed from a lower to a higher stage.

3.4 | Grading according to direct evidence over the 4 years

Of 380 periodontitis cases, 320 (84.2%) were subclassified as Grade C, namely a rapid rate of progression. 36 (9.5%) were in Grade B and 24 (6.3%) in Grade A. Among the three age groups, the prevalence of Grade A was comparable (4.9 to 6.8%, $P > 0.05$). In the 25 to 34 and 35 to 44-year-old groups, the prevalence of rapid progression was 88.7% and 92.7%, respectively, which was significantly higher than those of the 15 to 24 age group (59.5%, $P < 0.01$). However, the population aged between 15 and 24 years had significantly more moderate progression cases (17.6%) than the 25 to 34 age group (5.3%, $P < 0.01$) and the 35 to 44 age group (2.4%, $P < 0.01$). As for sex, the prevalence of Grade C in male subjects (93.1%) was significantly higher than in female subjects (76.6%, $P < 0.001$) (Table 2).

When the 3-mm threshold of ΔCAL was adopted, subjects with rapid progression decreased from 84.2% (320/380) to 63.7% (242/380) ($P < 0.001$). The reduction rate was 24.3%. When the threshold was further increased to 4 mm, the rate dropped significantly from 84.2% to 40.5% (154/380) ($P < 0.001$), with a reduction rate of 51.9%.

3.5 | Comparison between stage progress and progression of CAL, RBL, and tooth loss

Stage progress was divided into nine levels, as described earlier in the methods. The CAL or RBL progress of each individual was defined as the greatest ΔCAL or ΔRBL over 4 years.

In Stage I/II at baseline, there was a positive linear correlation between stage progress and mean ΔCAL, with Kendall's Tau B coefficient of 0.483 ($P = 0.014$) for Stage I and 0.207 for Stage II ($P = 0.003$) (Supplementary Figure S1 and Table S1). However, in subjects with Stage III/IV, there was no linear correlation between stage progress and mean ΔCAL. The correlation coefficients for Stages III and IV were 0.097 ($P = 0.107$) and 0.285 ($P = 0.217$), respectively. It was worth noting that 86.1% (124/144) of Stage III/IV subjects who showed no stage progression had at least one site with ΔCAL ≥2 mm during the 4-year period (Supplementary Table S1).

In terms of RBL, there was a positive linear correlation between stage progress and mean ΔRBL in subjects with Stage I/II at baseline. The Kendall's Tau B coefficient for Stage I was 0.476 ($P = 0.011$) and that for Stage II was 0.221 ($P = 0.001$). However, no related linear correlation was found in Stage III/IV, with the correlation coefficients of 0.154 ($P = 0.007$) for Stage III and 0.228 ($P = 0.312$) for Stage IV (Supplementary Figure S1).

Regarding tooth loss, only one subject with Stage I/II disease had tooth loss because of periodontitis in 4 years, and the stage progressed by five levels. As for subjects with Stage III/IV disease, 33.6% (73/217) had a stage progression of ≥1 level. Among them, the incidence rate of tooth loss because of periodontitis (17.8%, 13/73) was significantly higher than that of tooth loss without stage progression (4.9%, 7/144, $P = 0.002$).

4 | DISCUSSION

The newly proposed classification in 2018 provides a relatively precise diagnosis in clinical practice, which may be conducive to the formulation of personalized treatment plans and prognosis prediction.[45,46] For scientific research, a precise diagnosis with staging and grading subdivision facilitates the direct comparison among studies, making the comparison more meaningful. However, no related epidemiological studies have been reported thus far to our knowledge. Therefore, the current study was designed to determine the prevalence and distribution characteristics of periodontitis in the population, according to the 2018 classification system.

Through the new classification, this study showed that >90% of subjects without dental health care had periodontitis, with 53.7% having Stage III/IV at baseline. However, no other epidemiological studies using the new classification in populations without access to dental health care have been found. Only some researchers have studied periodontitis patients who actively seek periodontal treatment and maintenance based on the new classification system. In Germany, Graetz et al. reported that 68.1% of 251 patients (mean age: 45.1 ± 9.6 years, age range: 23 to 70 years) suffered from Stage III periodontitis.[47] A long-term retrospective study by Ravidà et al. showed that of 292 periodontitis patients in the US (mean age: 47.3 ± 12.1 years; age range: 17 to 76 years), 31 (10.6%) were classified as Stage I, 85 (29.1%) as Stage II, 146 (50.0%) as Stage III, and 30 (10.3%) as Stage IV.[46] Before the proposal of the new classification, based on the CDC-AAP classification,[25] the 2009 to 2014 National Health and Nutrition Examination Survey reported that an estimated 42% of dentate US adults ≥30 years had periodontitis, with only 7.8% having severe periodontitis.[18] Returning to our study, the state of the disease in villagers was more severe, showing 53.7% of Stage III/IV at baseline and 80.0% in 1996. In addition to the history of medical intervention, other possible factors such as oral hygiene habits, susceptibility, socioeconomic status, and geographical conditions may also have a significant impact on disease severity.

During the 4-year follow-up, the prevalence of periodontitis increased to 98.5%, in which Stage III/IV reached 80.0%. Notably, in the age group of 35 to 44 years, 96.7% had Stage III/IV periodontitis. At the patient level, 50.2% of 404 individuals progressed to a higher stage and/or extent. The rural Chinese population seemed to suffer from more severe stages and advanced periodontal destruction at a relatively younger age (mean age: 28.7 ± 8.9 years) than Graetz's (68.1% in Stage III and 30.7% in Stage IV) and Ravidà's (50.0% in Stage III and 10.3% in Stage IV) cohorts.[46,47]

In the current study, 79.5% of villagers presented with rapid progression, 11.3% with moderate progression, and 9.2% with slow progression. In 1986, a related study by Löe et al. reported that ≈8% and 81% of individuals showing rapid and moderate progress of periodontal diseases during a 15-year observation, with only 11% having no progress.[19] One major reason for these discrepancies could be attributed to the use of different evaluation methods. In our 4-year longitudinal study, we based the disease progression analysis on direct grading evidence, which was a 2-mm change in CAL. Although in Löe's survey, disease progression was based on age, attachment level, number of affected teeth, sites, and tooth type.

Under the 2018 classification, the direct evidence for grading is judged based on ≥5 years longitudinal change

of CAL. The 2 mm is the threshold for distinguishing between Grade B and Grade C patients. Based on a 4-year longitudinal change in CAL, this study found that 84.2% of villagers were in Grade C, that is, subjects had at least one site showing rapid periodontal progression. In 1997, a 10-year survey by Baelum et al. reported that among the 30 to 39-year-old Chinese villagers with untreated periodontal diseases, the prevalence of progressive disease was almost 90% (defined as AL progression ≥2 mm in a site with pre-existing ≥2 mm of AL). With the increasing threshold of 3 mm, the prevalence decreased to 42%. When the threshold was further increased to 4 mm, only 16% of subjects presented with progressive disease.[48] The threshold of 2 mm seemed to be less able to distinguish Grade B from Grade C patients in the rural Chinese population. Likewise, in this study, when we increased the threshold to 3 and 4 mm, subjects with rapid progression were more likely to be differentiated. Recently, following the AAP-EFP classification, the British Society of Periodontology recommended using 0.5 of the %bone loss/age ratio as the threshold to distinguish Grade A from Grade B.[37,38] It remains to be understood whether the increment of ΔCAL threshold for grading better reflects differences in the progression of periodontal diseases in population-based epidemiological studies. Furthermore, it is also not clear whether grading has the ability to predict patients' progression and demonstrate these progressive characteristics based on the greatest ΔCAL at one site. Further research is therefore worthwhile, and the implementation of the 2018 classification might need to be explored.

This study shows that a linear correlation between stage progression and progression of CAL and RBL was found only in subjects with Stage I/II disease. As Stage III/IV is the highest stage of periodontitis, no additional room exists for further upward progression, thus ensuring a ceiling effect. In the present study, more than half of the population had Stage III/IV disease at baseline. Most of them did not show stage progression during the 4 years. However, among these subjects without stage progression, 86.1% had at least one site with ΔCAL ≥2 mm, along with RBL and even periodontal tooth loss. This indicates that periodontal disease among villagers with Stage III/IV periodontitis continued to progress, but the progression could not be captured by the staging system because of the ceiling effect. Therefore, it is valuable to identify more parameters to determine disease progression in patients with Stage III/IV periodontitis. Tooth loss may be a potential candidate for this determination. In the Stage III/IV group of this study, the incidence of tooth loss because of periodontitis in subjects with stage progression was significantly higher than that in those without stage progression. Recently, Ravidà et al. reported that patients with Stage IV periodontitis showed a significantly higher periodontal-related tooth loss.[46] Therefore, the periodontal-related tooth loss might be a helpful parameter to directly reveal disease progression among patients with Stage III/IV periodontitis.

Our study has some limitations. CAL was collected from two random diagonal quadrants in each subject; this may likely under- or overestimate disease progression.[47,48] The lack of information on systemic diseases may also limit the analysis of the impact of these factors on disease. If these factors are taken into account, more villagers may be diagnosed with Grade C periodontitis.

5 | CONCLUSIONS

Based on 2018 classification, over 90% of villagers without access to dental care suffered from periodontitis, and Stage III/IV was highly prevalent. With aging, the prevalence of Stage III/IV increased. Male villagers had more advanced, generalized, and Grade C periodontitis than female villagers. During the 4 years, 50.2% of individuals shifted to a higher stage and/or extent. The great majority of subjects presented with rapid periodontal progression. Stage progression correlated significantly with CAL and RBL progression in Stage I/II, but this association was not found in Stage III/IV. Among subjects with disease progression in Stage III/IV, 90.4% shifted from localized to generalized cases. Furthermore, ceiling effects were observed in Stage III/IV.

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AUTHOR CONTRIBUTIONS

All authors have made substantial contributions to the conception of the study. Siniong Iao and Xiyan Pei contributed equally to this manuscript (co-first authors). Xiangying Ouyang, Xiyan Pei, and Siniong Iao were involved in project design, data collection, data analysis and interpretation, manuscript drafting, and critical revisions. Caifang Cao designed the project of natural

periodontal progression and collected the data. Jianru Liu and Wenyi Liu were involved in data collection, data analysis and interpretation, and critical revisions. All authors discussed the results and approved the final version to be published.

REFERENCES

1. Susin C, Haas AN, Valle PM, Oppermann RV, Albandar JM. Prevalence and risk indicators for chronic periodontitis in adolescents and young adults in south Brazil. *J Clin Periodontol*. 2011;38:326-333.
2. Gaio EJ, Haas AN, Carrard VC, Oppermann RV, Albandar J, Susin C. Oral health status in elders from South Brazil: a population-based study. *Gerodontology*. 2012;29:214-223.
3. Figueiredo A, Soares S, Lopes H, et al. Destructive periodontal disease in adult Indians from Northeast Brazil: cross-sectional study of prevalence and risk indicators. *J Clin Periodontol*. 2013;40:1001-1006.
4. Wang QT, Wu ZF, Wu YF, Shu R, Pan YP, Xia JL. Epidemiology and preventive direction of periodontology in China. *J Clin Periodontol*. 2007;34:946-951.
5. Sun XY, Yuan C, Wang XZ, et al. Report of the National Investigation of Resources for Oral Health in China. *Chin J Dent Res*. 2018;21:285-297.
6. Zhang Q, Li Z, Wang C, et al. Prevalence and predictors for periodontitis among adults in China. *Glob Health Action*. 2010;7:24503.
7. Yu HC, Su NY, Huang JY, Lee SS, Chang YC. Trends in the prevalence of periodontitis in Taiwan from 1997 to 2013: a nationwide population-based retrospective study. *Medicine (Baltimore)*. 2017;96:e8585.
8. Zhan Y, Holtfreter B, Meisel P, et al. Prediction of periodontal disease: modelling and validation in different general German populations. *J Clin Periodontol*. 2014;41:224-231.
9. Schützhold S, Kocher T, Biffar R, et al. Changes in prevalence of periodontitis in two German population-based studies. *J Clin Periodontol*. 2015;42:121-130.
10. Holtfreter B, Schwahn C, Biffar R, Kocher T. Epidemiology of periodontal diseases in the Study of Health in Pomerania. *J Clin Periodontol*. 2009;36:114-123.
11. Bhat M, Do LG, Roberts-Thomson K. Risk indicators for prevalence, extent and severity of periodontitis among rural Indian population aged 35-54 years. *Int J Dent Hyg*. 2018;16:492-502.
12. Aimetti M, Perotto S, Castiglione A, Mariani GM, Ferrarotti F, Romano F. Prevalence of periodontitis in an adult population from an urban area in North Italy: findings from a cross-sectional population-based epidemiological survey. *J Clin Periodontol*. 2015;42:622-631.
13. Botelho J, Machado V, Proença L, et al. Study of Periodontal Health in Almada-Seixal (SoPHiAS): a cross-sectional study in the Lisbon Metropolitan Area. *Sci Rep*. 2019;9:15538.
14. Machado V, Botelho J, Amaral A, et al. Prevalence and extent of chronic periodontitis and its risk factors in a Portuguese subpopulation: a retrospective cross-sectional study and analysis of clinical attachment loss. *PeerJ*. 2018;6:e5258.
15. Hugoson A, Sjödin B, Norderyd O. Trends over 30 years, 1973-2003, in the prevalence and severity of periodontal disease. *J Clin Periodontol*. 2008;35:405-414.
16. Norderyd O, Koch G, Papias A, et al. Oral health of individuals aged 3-80 years in Jönköping, Sweden during 40 years (1973-2013). II. Review of clinical and radiographic findings. *Swed Dent J*. 2015;39:69-86.
17. Eke PI, Borgnakke WS, Genco RJ. Recent epidemiologic trends in periodontitis in the USA. *Periodontol 2000*. 2020;82:257-267.
18. Eke PI, Thornton-Evans GO, Wei L, Borgnakke WS, Dye BA, Genco RJ. Periodontitis in US Adults: national Health and Nutrition Examination Survey 2009-2014. *J Am Dent Assoc*. 2018;149:576-588.
19. Löe H, Anerud A, Boysen H, Morrison E. Natural history of periodontal disease in man. Rapid, moderate and no loss of attachment in Sri Lankan laborers 14 to 46 years of age. *J Clin Periodontol*. 1986;13:431-445.
20. Preus HR, Anerud A, Boysen H, Dunford RG, Zambon JJ, Löe H. The natural history of periodontal disease. The correlation of selected microbiological parameters with disease severity in Sri Lankan tea workers. *J Clin Periodontol*. 1995;22:674-678.
21. Timmerman MF, Van der Weijden GA, Armand S, et al. Untreated periodontal disease in Indonesian adolescents. Clinical and microbiological baseline data. *J Clin Periodontol*. 1998;25:215-224.
22. van der Velden U, Amaliya A, Loos BG, et al. Java project on periodontal diseases: causes of tooth loss in a cohort of untreated individuals. *J Clin Periodontol*. 2015;42:824-831.
23. Tonetti MS, Claffey N. European Workshop in Periodontology group C. Advances in the progression of periodontitis and proposal of definitions of a periodontitis case and disease progression for use in risk factor research. Group C consensus report of the 5th European Workshop in Periodontology. *J Clin Periodontol*. 2005;32(Suppl 6):210-213.
24. Eke PI, Page RC, Wei L, Thornton-Evans G, Genco RJ. Update of the case definitions for population-based surveillance of periodontitis. *J Periodontol*. 2012;83:1449-1454.
25. Page RC, Eke PI. Case definitions for use in population-based surveillance of periodontitis. *J Periodontol*. 2007;78:1387-1399.
26. Morelli T, Moss KL, Beck J, et al. Derivation and validation of the periodontal and tooth profile classification system for patient stratification. *J Periodontol*. 2017;88:153-165.
27. Morelli T, Moss KL, Preisser JS, et al. Periodontal profile classes predict periodontal disease progression and tooth loss. *J Periodontol*. 2018;89:148-156.
28. Holtfreter B, Albandar JM, Dietrich T, et al. Standards for reporting chronic periodontitis prevalence and severity in epidemiologic studies: proposed standards from the Joint EU/USA Periodontal Epidemiology Working Group. *J Clin Periodontol*. 2015;42:407-412.
29. Caton JG, Armitage G, Berglundh T, et al. A new classification scheme for periodontal and peri-implant diseases and conditions – introduction and key changes from the 1999 classification. *J Clin Periodontol*. 2018;45(suppl 20):S1-S8.
30. Papapanou PN, Sanz M, Buduneli N, et al. Periodontitis: consensus report of workgroup 2 of the 2017 World Workshop on the Classification of Periodontal and Peri-Implant Diseases and Conditions. *J Periodontol*. 2018;89(suppl 1):S173-S182.
31. Miyamoto T, Kumagai T, Khan S, Reddy MS. Application of 2017 new classification of periodontal diseases and conditions to localized aggressive periodontitis: case series. *Clin Adv Periodontics*. 2019;9:185-191.

32. Wadia R, Walter C, Chapple ILC, et al. Periodontal diagnosis in the context of the 2017 classification system of periodontal diseases and conditions: presentation of a patient with periodontitis localised to the molar teeth. *Br Dent J*. 2019;226:180-182.
33. Walter C, Chapple ILC, Ower P, et al. Periodontal diagnosis in the context of the BSP implementation plan for the 2017 classification system of periodontal diseases and conditions: presentation of a pair of young siblings with periodontitis. *Br Dent J*. 2019;226:23-26.
34. Walter C, Chapple ILC, Ower P, et al. Periodontal diagnosis in the context of the BSP implementation plan for the 2017 classification system of periodontal diseases and conditions: presentation of a patient with severe periodontitis following successful periodontal therapy and supportive periodontal treatment. *Br Dent J*. 2019;226:411-413.
35. Walter C, Chapple ILC, Ower P, et al. Periodontal diagnosis in the context of the BSP implementation plan for the 2017 classification system of periodontal diseases and conditions: presentation of a patient with a history of periodontal treatment. *Br Dent J*. 2019;226:265-267.
36. Walter C, Ower P, Tank M, et al. Periodontal diagnosis in the context of the 2017 classification system of periodontal diseases and conditions: presentation of a middle-aged patient with localised periodontitis. *Br Dent J*. 2019;226:98-100.
37. Dietrich T, Ower P, Tank M, et al. Periodontal diagnosis in the context of the 2017 classification system of periodontal diseases and conditions – implementation in clinical practice. *Br Dent J*. 2019;226:16-22.
38. Milward M, Roberts A. Assessing periodontal health and the british society of periodontology implementation of the new classification of periodontal diseases 2017. *Dental Update*. 2019;46:918-929.
39. Cao CF, Yang XY, Yang S, Hao MX, Hasegawa K. A longitudinal survey on periodontal disease in Chinese villagers – preliminary report. *Chinese J Dent Res*. 1998;1:7-16.
40. Suda R, Cao C, Hasegawa K, Yang S, Sasa R, Suzuki M. 2-year observation of attachment loss in a rural Chinese population. *J Periodontol*. 2000;71:1067-1072.
41. Pei X, Ouyang X, He L, Cao C, Luan Q, Suda R. A 4-year prospective study of the progression of periodontal disease in a rural Chinese population. *J Dent*. 2015;43:192-200.
42. Xie JX, Cao CF, Zou ZJ, Wang ZF. Radiographic analysis of normal periodontal tissues. *Zhonghua Kou Qiang Yi Xue Za Zhi*. 1991;26(6):339-341.
43. Tonetti MS, Sanz M. Implementation of the new classification of periodontal diseases: decision-making algorithms for clinical practice and education. *J Clin Periodontol*. 2019;46:398-405.
44. Tonetti MS, Greenwell H, Kornman KS. Staging and grading of periodontitis: framework and proposal of a new classification and case definition. *J Periodontol*. 2018;89(suppl 1):S159-S172.
45. Greenwell H, Wang H-L, Kornman KS, Tonetti MS. Biologically guided implant therapy: a diagnostic and therapeutic strategy of conservation and preservation based on periodontal staging and grading. *J Periodontol*. 2019;90:441-444.
46. Ravidà A, Qazi M, Troiano G, et al. Using periodontal staging and grading system as a prognostic factor for future tooth loss: a long-term retrospective study. *J Periodontol*. 2020;91(4):454-461.
47. Chu Y, Ouyang X. Accuracy of partial-mouth examination protocols for extent and severity estimates of periodontitis: a study in a Chinese population with chronic periodontitis. *J Periodontol*. 2015;86:406-417.
48. Heaton B, Garcia RI, Dietrich T. Simulation study of misclassification bias in association studies employing partial-mouth protocols. *J Clin Periodontol*. 2018;45:1034-1044.
49. Graetz C, Mann L, Krois J, et al. Comparison of periodontitis patients' classification in the 2018 versus 1999 classification. *J Clin Periodontol*. 2019;46:908-917.
50. Baelum V, Luan WM, Chen X, Fejerskov O. Predictors of destructive periodontal disease incidence and progression in adult and elderly Chinese. *Community dentistry and oral epidemiology*. 1997;25:265-272.

SUPPORTING INFORMATION

Additional supporting information may be found online in the Supporting Information section at the end of the article.

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