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A longitudinal assessment of chronic periodontitis in Australian adults

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Abstract

Aim: The study aimed to estimate the incidence/progression and reversal of chronic periodontitis and to identify factors associated with chronic periodontitis in Australian adults over a 12-year period.

Materials and Methods: Data were obtained from the longitudinal component of the National Study of Adult Oral Health (NSAOH) in 2004–2006, and repeated data, among the same adults, in 2017–2018. NSAOH 2004–2006 was a population-based study of Australian adults aged 15+ years. The American Academy of Periodontology/European Federation of Periodontology case definitions were used, and then compared with two other case definitions. Multivariable Poisson regression models were used to estimate incidence rate ratios (IRRs) and reversal rate ratio (RRRs) of periodontitis.

Results: A total of 775 dentate Australian adults had dental examinations at both times. The proportion of incidence/progression and reversal among Australian adults was 56.4% and 11.0%, respectively. Tobacco smokers presented with more than three times higher incidence (IRR: 3.32, 95% CI: 1.50–7.60) and lower reversals (RRR: 0.94, 95% CI: 0.39–0.98) than those who had never smoked. Cessation of smoking was positively associated with periodontitis reversal. The total incidence/progression was 471.7/10,000 person-years, with reversal being 107.5/10,000 person-years. The average number of teeth lost due to periodontal disease was 1.9 in 2017–2018. Being male and not having periodontal treatment were significant risk markers for the incidence/progression of periodontitis.

Conclusion: Smoking is a risk factor for periodontitis. Cessation of smoking is an effective means of reducing the incidence and progression of chronic periodontitis, to reduce the risk of tooth loss, and to improve overall periodontal health.

KEYWORDS
case definitions, chronic periodontitis, incidence, tooth loss

Clinical Relevance

Scientific rationale for study: Chronic periodontitis is highly prevalent in adult populations in Australia and worldwide and a potential risk factor for systemic diseases. There are few

longitudinal studies of periodontal disease at a national level. It is imperative to estimate the incidence and progression of periodontitis to understand, at a population level, how disease patterns change over time, and the risk factors associated with the condition, to propose interventions to prevent and manage periodontal disease and associated conditions.

Principal findings: Tobacco smokers had more than three times higher incidence rate ratio and lower reversal rate ratio than those who had never smoked. Cessation of smoking was positively associated with periodontitis reversal, especially among those with mild/moderate periodontitis.

Practical implications: Smoking is a risk factor for periodontitis. Cessation of smoking is an effective means of reducing the incidence and progression and increasing the reversal of chronic periodontitis, to reduce the risk of tooth loss, and to improve overall periodontal health.

1 | INTRODUCTION

Chronic periodontitis is highly prevalent in adult populations worldwide and characterized by non-reversible periodontal tissue destruction. This results in progressive clinical attachment loss (CAL), leading to eventual tooth loss (Tonetti et al., 2015). According to the Global Burden of Disease 2015, more than 7% of the world's population (approximately 540 million people) has severe chronic periodontitis (Kassebaum et al., 2017). In Australia, the National Study of Adult Oral Health (NSAOH) found that the prevalence of moderate or severe chronic periodontitis increased from 20.5% in 2004–2006 to 30.1% in 2017–2018 (Roberts-Thomson & Do, 2007; Ha et al., 2020).

Chronic periodontitis is one of the major causes of tooth loss. Evidence suggests that more than 30% of tooth extractions are attributed to periodontitis (Eke et al., 2020). Tooth loss reduces the ability to chew and causes masticatory dysfunction. This, in turn, decreases the intake of nutrients, which impacts the immune system, resulting in certain systemic diseases, and even death (Romandini et al., 2021). Oral health-related quality of life, including physical, psychological, and social (Slade et al., 2014; Schierz et al., 2021), and life expectancy (Roberts-Thomson & Do, 2007; Slade et al., 2014) are significantly affected by tooth loss in adults.

Chronic periodontitis is a complex disease with multiple potential contributing factors. Smoking is an important risk factor impacting the progression of periodontitis (Niciti et al., 2015). Others factors such as systemic conditions (Monsarrat et al., 2016) and socio-economic status (SES) (Poulton et al., 2002; Vettore et al., 2013) are also associated with the initiation and progression of chronic periodontitis. However, to date the majority of studies examining periodontitis have been cross-sectional in design. Longitudinal data on the incidence and progression of chronic periodontitis are scarce (Thomson et al., 2013; Haas et al., 2014; Rios et al., 2020). It is necessary to estimate the incidence and progression, or reversal of chronic periodontitis, to understand, at a population level, how disease patterns change over time, and the risk factors associated with the condition, to propose interventions to prevent and manage periodontal disease and associated conditions. The aims of this study were to (1) calculate the incidence, progression, and reversal of chronic periodontitis, and (2) identify risk and/or protective factors for the incidence, progression, and reversal of chronic periodontitis in Australian adults over a 12-year period.

2 | METHODS

This study is reported according to STROBE (Strengthening the Reporting of Observational Studies in Epidemiology) guidelines.

2.1 | Study design and sample selection

The study utilized a cohort study design. Data were obtained from the longitudinal component of the NSAOH in 2004–2006, and repeated data, among the same adults, in 2017–2018. NSAOH 2004–2006 was a population-based study of Australian adults aged 15+ years, in which representative samples of adults were drawn using a three-stage, stratified sample design within metropolitan and regional areas in each state/territory. The first stage selected a sample of postcodes from all in-scope postcodes in Australia. The second stage selected households within sampled postcodes, with adults aged 15 years and over being randomly selected from each sample household to participate in the final stage.

Individuals who participated in the examination component of NSAOH 2004–2006 and who had agreed to be re-contacted for future studies formed the sampling frame for the longitudinal NSAOH ($n = 5424$). Considering those lost to follow-up ($n = 2861$), the effective sample for the longitudinal NSAOH was 2563 individuals, who were contacted and invited to participate in the 2017–2018 computer-assisted telephone interview (CATI) and examination. A total of 1707 responded to the CATI and 775 participants received a complete periodontal assessment.

The longitudinal component of NSAOH was reviewed and approved by the University of Adelaide Human Research Ethics Committee (HREC Number: H-2016-182).

Participants received an information sheet explaining the study and provided informed consent. Participants signed a consent form prior to undergoing a dental examination.

2.2 | Data collection

Self-reported information about oral health and related characteristics was collected using CATI in 2004–2006, and with the alternative

option of an online questionnaire in 2017–2018. Dentate participants were invited to receive a standardized oral epidemiological examination. Information about dental clinical status was collected during examinations, which were conducted by registered, trained, and calibrated oral health professionals. All examiners were tested in the field against a gold standard examiner to estimate inter-examiner reliability.

The periodontal assessment included gingival recession (GR) and probing pocket depth (PPD) measurements at three sites, namely mesio-buccal, mid-buccal, and disto-buccal, of all teeth present except wisdom teeth. CAL was calculated by the sum of GR and PPD. The intra-class correlation coefficient (ICC) for the number of sites with gingival recession in NSAOH 2004–2006 and 2017–2018 was 0.92 and 0.90, respectively, and with periodontal pocket depth 0.56 and 0.73 respectively, indicating medium to excellent reliability.

2.3 | Variables

2.3.1 | Outcome variables

The outcome variable was chronic periodontitis. Individuals' severity of chronic periodontitis at baseline (2004–2006) and 12-year follow-up (2017–2018) were based on the European Federation of Periodontology/American Academy of Periodontology (EFP/AAP) case definition/classification (Tonetti et al., 2018):

i. Stage I: 1 mm ≤ CAL ≤ 2 mm at the site of greatest loss, and no tooth loss due to periodontitis;
ii. Stage II: 3 mm ≤ CAL ≤ 4 mm at the site of greatest loss, and no tooth loss due to periodontitis;
iii. Stage III: CAL ≥5 mm at the site of greatest loss, and/or at least one site PPD ≥6 mm or tooth loss due to periodontitis of ≤4 teeth;
iv. Stage IV: CAL ≥5 mm at the site of greatest loss, and/or at least one site PPD ≥6 mm or tooth loss due to periodontitis of ≥5 teeth.

The outcome was measured as incidence and progression, which were combined into a single measure (henceforth, incidence/progression), and reversal of chronic periodontitis. These were based on the following definitions:

1. The incidence/progression of chronic periodontitis from baseline to12-year follow-up:

- The incidence of periodontitis (new cases) was defined as chronic periodontitis status changing from no indication of periodontitis ("No disease") to some indication of periodontitis, such as from no periodontitis or gingivitis to Stage I, II, III, or IV under the EFP/AAP case definition.
- The progression of periodontitis was defined as (i) from Stage I to Stage II, III, or IV; (ii) Stage II to Stage III or IV; (iii) Stage III to Stage IV under the EFP/AAP case definition, or (iv) at least one tooth lost due to periodontitis.

2. Reversal of periodontitis was defined from baseline to 12-year follow-up as change in chronic periodontitis status from severe to mild/medium, such as from Stage IV to Stage III, II, I, or No periodontitis/gingivitis; Stage III to Stage II, I, or No periodontitis/gingivitis; or Stage II to Stage I or No/gingivitis; or Stage I to No/gingivitis.

2.3.2 | Covariates

Combined baseline and 12-year follow-up socio-demographic characteristics were included in multivariable modelling as covariates.

Socio-demographic characteristics included age groups (based on the age provided at baseline [NSAOH 2004–2006] and grouped into 15–34, 35–54, 55–74, or 75+ years); sex (Male vs. Female); country of birth (Australia or Overseas); language spoken at home (English vs. Others); residential location (Outer/Remote, Inner region, or Major city); highest education qualification (Secondary school, Trade to Diploma degree, or Tertiary/University); difficulty paying a $200 dental bill (yes vs. no); and equivalized household income (low [<AU$ 20,000], medium [AU$ 20,000–50,000], or high [>AU$ 50,000]). Equivalized household income was derived by calculating an equivalence factor according to the "modified OECD (the Organization for Economic Cooperation and Development)" equivalence scale, and then dividing the income by that factor. The equivalence factor was built up by allocating points to each person in a household (1 point to the first adult, 0.5 point to each additional person who was 15 years and over, and 0.3 point to each child under the age of 15), and then summing the equivalence points of all household members (Australian Bureau of Statistics, 2022). Equivalized household income was grouped into three approximately equal tertiles (tertile 1 being low and tertile 3 being high).

Oral/general health and related behaviours included tobacco smoking status (current smoker, ex-smoker, or never smoker); gum disease treatment (yes vs. no); diabetes status (diabetes vs. no diabetes), and regular dental visiting (twice a day or more) (yes vs. no).

2.4 | Statistical analyses

Data files were managed and summary variables were computed using SAS software version 9.4 (SAS 9.4, SAS Institute Inc., Cary, NC, USA).

Participants who had periodontal assessment at baseline and 12-year follow-up were included in the analysis. Basic descriptive analyses were conducted to ascertain sample characteristics. The proportion and rate (10,000 person-years) of periodontal incidence/progression, no change, and reversal of periodontitis were estimated. Statistically significant differences were denoted by 95% confidence intervals that did not overlap. Multivariable Poisson regression models with robust standard error estimation were generated. Crude and

TABLE 1 Sample characteristics and association with incidence/progression, no change, and reversal of chronic periodontitis among Australian adults under the EFP/AAP case definition

	Number (*n*)	Percentage (95% CI)	Incidence/progression (%, 95% CI)	No change (%, 95% CI)	Reversal (%, 95% CI)
Total	775	100	56.6 (53.1–60.1)	30.5 (27.2–33.7)	12.9 (10.5–15.3)
Age group (baseline)					
75+	7	**0.9 (0.2–1.6)**	57.1 (20.4–93.9)	28.6 (0.0–62.1)	14.3 (0.0–40.3)
55–74	338	43.6 (40.1–47.1)	56.8 (51.5-62.1)	26.0 (21.3–30.7)	17.2 (13.1–21.2)
35–54	342	44.1 (40.6–47.6)	57.0 (51.8–62.3)	33.0 (28.0–38.0)	9.9 (6.8–13.1)
15–34	88	**11.4 (9.1–13.6)**	54.5 (44.1–65.0)	37.5 (27.4–47.6)	8.0 (2.3–13.6)
Sex					
Male	341	44.0 (40.5–47.5)	58.4 (53.1–63.6)	**24.9 (20.3–29.5)**	16.7 (12.7–20.7)
Female	434	56.0 (52,5–59.5)	55.3 (50.6–60.0)	**34.8 (30.3–39.3)**	9.9 (7.1–12.7)
Country of birth					
Overseas	155	20.0 (17.2–22.8)	62.6 (54.9–70.2)	22.6 (16,0–29.2)	14.8 (9.2–20.4)
Australia	620	80.0 (77.2–82.8)	55.2 (51.2–59.1)	32.4 (28.7–36.1)	12.4 (9.8–15.0)
Language					
Others	42	5.4 (3.8–7.0)	57.1 (42.1–72.1)	35.7 (21.2–50.2)	7.1 (0.0–14.9)
English	733	94.6 (93.0–96.2)	56,6 (53.0–60.2)	30.2 (26.8–33.5)	13.3 (10.8–15.7)
Location					
Outer/remote	103	13.3 (10.9–15.7)	**63.1 (59.8–72.4)**	24.3 (16.0–32.6)	12.6 (6.2–19.0)
Inner region	205	26.5 (23.3–29.6)	57.1 (50.3–63.9)	33.2 (26.7–39.6)	**9.8 (5.7–13.6)**
Major city	467	60.3 (56.8–63.7)	**55.0 (50.5–59.6)**	30.6 (26.4–34.8)	**14.3 (13.8–17.5)**
Educational level					
Second school or less	288	37.2 (33.8–40.6)	**49.3 (43.5–55.1)**	37.2 (31.6–42.7)	13.5 (9.6–17.5)
Trade to Diploma	308	39.7 (36.3–43.2)	59.7 (54.3–65.2)	26.9 (22.0–31.9)	13.3 (9.5–17.1)
University or above	179	23.1 (20.1–26.1)	**63.1 (56.0–70.2)**	25.7 (19.3–32.1)	11.2 (6.5–15.8)
Equivalized income					
Low	269	35.3 (31.9–38.8)	59.1 (53.2–65.0)	25.7 (20.4–30.9)	15.2 (10.9–19.5)
Medium	236	31.0 (27.7–34.3)	52.1 (45.7–58.5)	34.3 (28.3–40.4)	13.6 (9.2–17.9)
High	256	33.6 (30.3–37.0)	58.2 (52.1–64.3)	32.0 (26.3–37.8)	9.8 (6.1–13.4)
Difficult to pay AU$200					
Yes	428	55.5 (52.0–59.0)	59.6 (54.9–64.2)	28.5 (24.2–32.8)	11.9 (8.8–15.0)
No	343	44.5 (41.0–48.0)	52.8 (47.5–58.1)	32.9 (28.0–37.9)	14.3 (10.6–18.0)
Smoking status					
Current smoker	36	4.6 (3.2–6.1)	**77.8 (64.2–91.4)**	**11.1 (0.8–21.4)**	11.1 (0.8–21.4)
Ex-smoker	289	37.3 (33.9–40.7)	**57.1 (51.4–62.8)**	**28.4 (23.2–33.6)**	14.5 (10.5–18.6)
Never smoker	450	58.1 (54.6–61.5)	**54.7 (50.1–59.3)**	**33.3 (29.0–37.7)**	12.0 (9.0–15.0)
Had gum treatment					
No	655	87.7 (85.3–90.0)	**60.9 (59.0–70.9)**	29.3 (20.0–38.7)	**9.8 (3.7–10.9)**
Yes	92	12.3 (10.0–14.7)	**56.3 (52.5–58.1)**	30.8 (27.3–34.4)	**12.8 (11.3–15.4)**
Diabetes status					
Diabetes	71	9.2 (7.2–11.3)	60.6 (49.2–72.0)	22.5 (12.8–32.3)	16.9 (8.2–25.6)
No diabetes	698	90.8 (88.7–92.8)	56.3 (52.6–60.0)	31.2 (27.8–34.7)	12.5 (10.0–14.9)
Regular dental visit					
No	396	51.1 (47.6–54.6)	56.8 (51.9–61.7)	31.1 (26.5–35.6)	12.1 (8.9–15.3)
Yes	379	48.9 (45.4–52.4)	56.5 (51.5–61.5)	29.8 (25.2–34.4)	13.7 (10.2–17.2)
		Mean (95% CI)			
Number of teeth (2004–2006)		25.0 (24.6–25.4)			
Number of teeth lost (2017–2018)		1.9 (1.6–2.2)			

Note: Bold values are statistically significant.

Abbreviations: CI, confidence interval; EFP/AAP, European Federation of Periodontology/American Academy of Periodontology.

adjusted incidence/progression rate ratios (IRRs) and reversal rate ratio (RRRs) of periodontitis were estimated. The RRR exclude participants with no change in the outcome. Blocks of covariates were entered into multivariable models in four steps. Model 1 was the crude model. Participants' demographic characteristics were entered in Model 2. Socio-economic factors were added in Model 3, and oral and general health-related factors, number of teeth at baseline, and teeth lost in 2017–2018 were added in Model 4.

2.5 | Sensitivity analyses

Sensitivity analyses were undertaken to (1) compare case definitions for the incidence/progression, no change, and reversal of chronic periodontitis under the U.S. Centres for Disease Control and Prevention and the American Association of Periodontology and (CDC/AAP) case definition (Page & Eke, 2007; Botelho et al., 2020); (2) calculate the mean site of CAL/PPD by extracted and non-extracted teeth; (3) estimate CAL progression (Thomson et al., 2013) (in two steps): (i) change in CAL was determined for each site by subtracting the later CAL (2017–2018) from that of the earlier CAL (2004–2006), and (ii) CAL progression was defined as CAL increasing by at least 3 mm; and (4) estimate and compare incidence/progression and reversal of periodontitis stratified by severity of chronic periodontitis (Stage I and II vs Stage III and IV) at baseline (in 2004–2006).

3 | RESULTS

A total of 1707 dentate Australian adults completed interviews in both 2004–2006 and 2017–2018. Of those, 24 persons (1.4%) had become edentulous and 775 persons (45.4%) had a periodontal assessment at both time points.

The characteristics of those re-examined and who were not re-examined at the 12-year follow-up are summarized in Table S2. Compared to the re-examined participants, a higher proportion of participants who were not re-examined were in the middle to older age group (35–74 years), had received high school or less education, and were current or ex-smokers.

Table 1 shows sample characteristics and the incidence/progression, no change, and reversal of chronic periodontitis from 2004–2006 to 2017–2018. A higher proportion of participants were in the middle age group (35–74 years) (over 80%), were female (56%), born in Australia (over 80%), spoke English at home (nearly 95%), and resided in major cities (80%). A higher proportion had Trade to diploma as the highest level of educational attainment (approximately 40%), were from low-income households (more than 35%), reported difficulty paying a $200 dental bill (56%), had never smoked (58%), did not have diabetes (91%), had not received gum treatment (88%), and were irregular dental attenders (nearly 50%).

Under the EFP/AAP case definition, incidence/progression of chronic periodontitis was approximately 57%, no change was approximately 30%, and reversal was 13%. Incidence/progression of chronic periodontitis was higher among males (nearly 60%), those living in outer/remote locations (63%), those with tertiary qualification (63%), current smokers (78%), and not having received gum treatment (61%). No change of chronic periodontitis was higher among those who never smoked (33%) than current smokers. Reversal of chronic periodontitis was higher among those residing in major cities (14%) compared with those in inner regions (10%) and among those who had had gum treatment (13%) (Table 1). Under the CDC/AAP case definition (Table S3), the incidence/progression of chronic periodontitis was more than 20%, no change was more than 65%, and reversal was 11%. Incidence/progression of chronic periodontitis was higher among the 35–54-year age group (approximately 30%), males (more than 25%), and those with self-reported diabetes (approximately 35%). No change of chronic periodontitis was higher among participants who did not have diabetes (68%). Reversal of chronic periodontitis was higher among ex-smokers (13%) and those who had received gum treatment (19%).

The average number of teeth was 25 at baseline (2004–2006) and the average number of teeth lost due to periodontal disease was 1.9 in 2017–2018 (Table 1).

Table 2 presents the incidence/progression and reversal rate during the 12-year follow-up.

The total incidence/progression rate was more than 470/10,000 person-years, with the reversal rate being more than 100/10,000 person-years under the EFP/AAP case definition. The total incidence/progression rate was more than 195/10,000 person-years, with the reversal rate being approximately 90/10,000 person-years under the

TABLE 2 Incidence/progression and reversal rate of periodontitis among Australian adults over 12 years

	Incidence/progression Rate (95% CI)[a]	Reversal Rate (95% CI)[a]
EFP/AAP case	471.7 (442.5–500.8)	107.5 (87.5–127.5)
CDC/AAP case[b]	195.8 (167.5–224.2)	89.2 (68.3–110.0)
CAL progression[c]	332.5 (295.0–369.2)	-

Abbreviations: CAL, clinical attachment loss; EFP/AAP, European Federation of Periodontology/American Academy of Periodontology.
[a]Unit = per 10,000-person years.
[b](1) The U.S. Centres for Disease Control and Prevention and the American Association of Periodontology and (CDC/AAP) case definition (Page & Eke, 2007): (i) Moderate periodontitis is the presence of either two sites between adjacent teeth where 4 mm ≤ CAL ≤ 6 mm or at least two such sites have PD ≥5 mm. (ii) Severe periodontitis is at least two sites between adjacent teeth where CAL ≥6 mm and there is at least one site PPD ≥5 mm. (2) The incidence of periodontitis (new cases) was defined from no indication of periodontitis ("No disease") to some indication of periodontitis, such as from none to mild, moderate, or severe periodontitis; the progression of periodontitis was from mild to moderate or severe, or from moderate to severe to tooth loss due to periodontitis.
[c]CAL progression estimation (two steps): (i) The change of CAL was determined for each site by subtracting the later CAL (2017–2018) from that of the earlier one (2004–2006). (ii) CAL progression was defined as CAL increase by at least 3 mm.

TABLE 3 Association between incidence and progression of chronic periodontitis and risk factors among Australian adults under the EFP/AAP case definition

	Model 1 IRR (95% CI)	Model 2 IRR (95% CI)	Model 3 IRR (95% CI)	Model 4 IRR (95% CI)
Age group (baseline)				
75+	0.99 (0.97–1.02)	1.04 (0.37–2.89)	0.94 (0.33–2.64)	0.74 (0.25–2.13)
55–74	1.02 (0.99–1.03)	0.99 (0.72–1.37)	0.94 (0.67–1.32)	0.92 (0.63–1.34)
35–54	1.05 (0.76–1.44)	1.01 (0.73–1.39)	0.95 (0.69–0.32)	0.94 (0.66–1.34)
15–34	Ref.	Ref.	Ref.	Ref.
Sex				
Male	**1.36 (1.05–1.97)**	**1.34 (1.05–1.96)**	**1.32 (1.03–1.86)**	**1.23 (1.03–1.88)**
Female	Ref.	Ref.	Ref.	Ref.
Country of birth				
Overseas	**1.31 (1.05–2.00)**	**1.32 (1.03–2.18)**	**1.32 (1.01–2.12)**	**1.56 (1.08–3.06)**
Australia	Ref.	Ref.	Ref.	Ref.
Language				
Others	0.87 (0.66–1.52)	0.85 (0.37–1.87)	0.97 (0.63–1.59)	0.79 (0.40–2.15)
English	Ref.	Ref.		Ref.
Location				
Outer/remote	1.47 (0.87–1.94)	1.62 (0.93–3.05)	1.55 (0.82–3.04)	1.43 (0.72–2.85)
Inner region	1.35 (0.86–2.06)	1.30 (0.85–1.94)	1.20 (0.76–1.95)	1.25 (0.75–2.06)
Major city	Ref.	Ref.	Ref.	Ref.
Educational level				
Secondary school or less	0.78 (0.61–1.00)		0.40 (0.22–1.01)	0.45 (0.24–1.02)
Trade to Diploma	0.95 (0.78–1.19)		0.63 (0.37–1.06)	0.59 (0.34–1.01)
University or above	Ref.		Ref.	Ref.
Equivalized income				
Low	0.70 (0.40–1.11)		0.50 (0.30–1.10)	0.46 (0.24–1.19)
Medium	0.89 (0.71–1.14)		0.54 (0.29–1.06)	0.51 (0.30–1.01)
High	Ref.		Ref.	Ref.
Difficulty paying AU$200				
Yes	1.12 (0.93–1.36)			1.12 (0.73–1.72)
No	Ref.			Ref.
Smoking status				
Current smoker	**4.32 (1.25–9.41)**			**3.32 (1.50–7.60)**
Ex-smoker	1.04 (0.85–1.63)			1.24 (0.78–1.78)
Never smoker	Ref.			Ref.
Had gum treatment				
No	**1.18 (1.04–2.56)**			**1.32 (1.03–2.43)**
Yes	Ref.			Ref.
Diabetes status				
Diabetes	1.08 (0.79–1.47)			**1.18 (1.09–2.06)**
No diabetes	Ref.			Ref.
Regular dental visit				
No	1.17 (0.83–1.92)			1.13 (0.78–1.83)
Yes	Ref.			Ref.
	***β* (95% CI)**	***β* (95% CI)**	***β* (95% CI)**	***β* (95% CI)**
Number of teeth	.01 (−0.02, 0.03)			−.01 (−0.01. 0.03)

Note: Model 1: crude model; Model 2: adjusted for sample characteristics; Model 3: model 2 plus adjusting for socio-economic factors; Model 4: model 3 plus adjusting for number of teeth (in 2004–2006), oral/general health, and related behavioural factors. Bold values are statistically significant.
Abbreviations: CI, confidence interval; EFP/AAP, European Federation of Periodontology/American Academy of Periodontology; IRR, incidence rate ratio.

TABLE 4 Association between reversal of chronic periodontitis and risk factors among Australian adults under the EFP/AAP case definition

	Model 1 RRR (95% CI)	Model 2 RRR (95% CI)	Model 3 RRR (95% CI)	Model 4 RRR (95% CI)
Age group (baseline)				
75+	1.80 (0.22–14.6)	1.92 (0.23–15.8)	2.18 (0.26–18.6)	5.6 (0.6–52.4)
55–74	2.16 (0.98–4.73)	2.11 (0.95–4.67)	2.32 (0.97–5.53)	3.23 (1.20–8.71)
35–54	1.25 (0.55–2.82)	1.28 (0.56–2.90)	1.56 (0.65–3.75)	1.55 (0.58–4.12)
15–34	Ref.	Ref.	Ref.	Ref.
Sex				
Male	1.69 (0.93–2.51)	1.60 (0.89–2.38)	1.64 (0.88–2.49)	1.57 (0.80–2.42)
Female	Ref.	Ref.	Ref.	Ref.
Country of birth				
Overseas	1.19 (0.75–2.60)	1.22 (0.75–2.50)	1.21 (0.74–1.98)	1.40 (0.83–2.53)
Australia	Ref.	Ref.	Ref.	Ref.
Language				
Others	0.54 (0.17–1.70)	0.49 (0.15–1.62)	0.47 (0.14–1.54)	0.45 (0.12–1.66)
English	Ref.	Ref.	Ref.	Ref.
Location				
Outer/remote	0.88 (0.49–1.59)	0.78 (0.26–1.49)	0.68 (0.27–1.29)	0.70 (0.31–1.61)
Inner region	0.68 (0.41–1.12)	0.66 (0.24–1.61)	0.65 (0.39–1.11)	0.72 (0.26–1.20)
Major city	Ref.	Ref.	Ref.	Ref.
Educational level				
Secondary school or less	1.41 (0.71–2.08)		1.46 (0.81–2.07)	1.41 (0.75–2.09)
Trade to Diploma	1.19 (0.70–2.03)		1.15 (0.65–2.01)	1.16 (0.91–2.07)
University or above	Ref.		Ref.	Ref.
Equivalized income				
Low	1.56 (0.95–2.57)		1.54 (0.86–2.62)	1.82 (0.87–2.80)
Medium	1.39 (0.82–2.34)		1.40 (0.91–3.98)	1.42 (0.92–4.45)
High	Ref.		Ref.	Ref.
Difficulty paying AU$200				
Yes	0.83 (0.56–1.93)			0.98 (0.51–1.86)
No	Ref.			Ref.
Smoking status				
Current smoker	**0.93 (0.34–0.97)**			**0.94 (0.39–0.98)**
Ex-smoker	**1.21 (1.01–2.01)**			**1.18 (1.06–1.99)**
Never smoker	Ref.			Ref.
Had gum treatment				
No	**0.76 (0.31–0.96)**			**0.70 (0.25–0.98)**
Yes	Ref.			Ref.
Diabetes status				
Diabetes	1.06 (0.74–2.47)			1.04 (0.48–2.27)
No diabetes	Ref.			Ref.
Regular dental visit				
No	0.88 (0.60–1.31)			0.83 (0.67–1.60)
Yes	Ref.			Ref.
	β (95% CI)	β (95% CI)	β (95% CI)	β (95% CI)
Number of teeth	.02 (−0.03, 0.06)			.06 (0.00–0.11)

Note: Model 1, crude model; Model 2, adjusted for sample characteristics; Model 3, model 2 plus adjusting for socio-economic factors; Model 4, model 3 plus adjusting for the number of teeth (in 2004–2006), oral/general health, and related behavioural factors. Bold values are statistically significant.
Abbreviations: CI, confidence interval; EFP/AAP, European Federation of Periodontology/American Academy of Periodontology; RRR, reversal rate ratio.

CDC/AAP case definition. The progression of CAL was more than 300/10,000 person-years under the CAL progression definition.

Both the mean site of CAL and PPD at baseline (2004–2006) were higher (1.89 and 1.52 mm, respectively) among participants in the "extracted teeth" group than their counterparts in the "non-extracted teeth" group (1.54 and 1.42 mm, respectively) (see Table S2).

Table 3 presents the incidence/progression of chronic periodontitis by risk indicators under the EFP/AAP case definition. The risk indicators for incidence/progression of chronic periodontitis included being male, being born overseas, being a current smoker and not having received gum treatment, and having diabetes. After adjusting for all covariates and the baseline number of teeth in multivariable analysis, current smokers had more than three times higher incidence/progression than those who had never smoked. Higher estimates were also observed among males, those born overseas, those with diabetes, and those who had not received gum treatment.

A similar pattern was observed under both the CDC case definition and CAL progression measurement (Tables S4 and S5). After adjusting for all covariates, the baseline number of teeth, and the mean number of teeth lost at follow-up, current smokers had a higher incidence/progression of chronic periodontitis and CAL progression than those who had never smoked. Under the CDC/AAP case definition, the middle to older age group (35–74 years at baseline), males, those with diabetes, and those who had not received gum treatment had higher incidence/progression of chronic periodontitis or CAL progression. The greater the number of teeth, the higher the incidence/progression of periodontitis or CAL progression observed (Tables S4 and S5).

Table 4 shows the associations between the reversal of chronic periodontitis and risk/protective factors under the EFP/AAP case definition. Lower reversal of periodontitis was observed among participants who were current smokers and who had not received gum treatment. After adjusting for all covariates and baseline number of teeth, the same result was observed. Under the CDC/AAP case definition (see Table S6), periodontitis reversal was lower among those who had not received gum treatment and higher among ex-smokers and those with diabetes. After adjusting for all covariates, baseline number of teeth, and mean number of teeth lost at follow-up, those who had not received gum treatment had lower RRR and ex-smokers had around three times the RRRs of their counterparts who had received gum treatment and were current smokers, respectively.

Table S7 presents the associations between the incidence/progression of chronic periodontitis and risk indictors by the severity of chronic periodontitis at baseline. Among those with mild/medium (≤Stage II) or severe (Stage III and IV) periodontitis at baseline, those who were male, were current smokers, who had not received gum treatment, and were irregular dental attenders had higher IRRs than their counterparts. Among those with severe periodontitis at baseline, higher estimates were also observed among those who spoke a language other than English at home, were ex-smokers, reported difficulties paying a $200 dental bill, and were with type 2 diabetes.

Table S8 presents the associations between chronic periodontitis reversal and risk indictors by the severity of chronic periodontitis at baseline. Among those with mild/moderate periodontitis at baseline, those born overseas and those with Trade to Diploma educational attainment had higher RRRs than their counterparts who were born in Australia and those with university or above as the highest level of educational attainment, respectively. Lower estimates were observed among those living in inner regional areas, current smokers, and who had not received gum treatment. Among the participants with severe periodontitis at baseline, lower estimates were observed among those living in inner regional areas, current and ex-smokers, and those who had not received gum treatment. Participants in the medium household income tertile had higher RRRs than their counterparts in the high household income tertile.

4 | DISCUSSION

To the best of our knowledge, this is the first study to examine the incidence, progression, and reversal of chronic periodontitis in Australian adults over a 12-year period. Our findings indicate that tobacco smoking was positively associated with the incidence/progression of periodontitis under all definitions, and cessation of smoking was positively associated with periodontitis reversal. Meanwhile, being male, born overseas, speaking a language other than English at home, diabetes, and not having received gum treatment were positively associated with the reversal of chronic periodontitis using different definitions.

Tobacco smoking has negative impacts on periodontal health. Smoking is the most significant risk factor (Thomson et al., 2013; Niciti et al., 2015; Chikte et al., 2019; Ke et al., 2022) but is modifiable across all levels of chronic periodontitis (Eke et al., 2016; Alexandridi et al., 2018). Our findings show that smoking is positively associated with the incidence/progression of chronic periodontitis and CAL progression and negatively associated with periodontitis reversal. Smoking cessation was positively associated with the reversal of chronic periodontitis, especially among those with mid/medium chronic periodontitis at baseline, which provides evidence to inform and guide smoking-control strategies.

Periodontal therapy is an important step to prevent further disease progression, to reduce the risk of tooth loss, and to improve overall periodontal health. Previous studies (Loos, 2005; Sanz et al., 2020; Sanz-Sánchez et al., 2020; Vivek et al., 2021) have shown that periodontal treatment can control plaque, reduce probing depth and attachment loss, and contribute to overall control of oral and systemic inflammation (such as decreasing the level of C-reactive protein and increasing the levels of IL-1, IL-6, and TNF-α in blood). Our findings indicate that no treatment was associated with less reversals and greater incidence/progression.

The difference in incidence/progression, no change, and reversal of periodontitis between the two case definitions was considerable, particularly for incidence/progression (more than 2 times higher under the EFP/AAP than under the CDC/AAP case definition). The possible reason may be the number of teeth lost having been included in EFP/AAP case definition. Therefore, the number of teeth lost at follow-up was not adjusted in multivariable analysis under the EFP/AAP case definition.

Interestingly, a higher reversal rate was observed among participants in the medium household income tertile with more severe baseline periodontitis in comparison with their more affluent counterparts. This could be a methodological shortcoming, in that there is a higher probability of reversal in any group with more severe baseline periodontal disease to begin with.

4.1 | Strengths and limitations

The strengths of the study include the following: (1) This is the first time in Australia that the incidence/progression and reversal of chronic periodontitis have been estimated using FEP/AAP case definition on a large sample of the adult population. (2) Sensitivity analyses using CDC/AAP case definition, CAL progression, and associations between baseline periodontal condition and periodontitis status were estimated and compared, which enriched and increased the reliability of our findings and provided more evidence to clinicians and policy makers. Limitations of the study include the following: (1) There is inevitable loss to follow-up in longitudinal studies, which might lead to biased estimates. (2) Self-reported gum treatment relies on recall, so this may be over- or under-estimated. (3) The possibility for misclassification error exists for the reason why teeth were extracted.

In future, a causal effect modelling approach to estimate risk factors associated with periodontitis should be conducted to provide evidence to emphasize, at a policy level, the importance of preventive and treatment strategies of chronic periodontitis for adults both in Australia and elsewhere.

5 | CONCLUSION

Our findings indicate that tobacco smoking is an important risk factor for periodontitis progression. Cessation of smoking was an effective means of reducing the incidence and progression of chronic periodontitis in a large cohort of Australian adults. Being male, having been born overseas, not having received gum treatment, and having diabetes were significant risk indicators for the incidence and progression of periodontitis.

AUTHOR CONTRIBUTIONS

Xiangqun Ju and Lisa Jamieson conceived and designed the study. Sergio Chrisopoulos and LL investigated the data. Xiangqun Ju did the statistical analyses. Xiangqun Ju and Gloria Mejia interpreted the data and contributed to writing manuscript drafts. Lisa Jamieson, Gloria Mejia, Sergio Chrisopoulos, and Liana Luzzi are guarantors for this article. All authors contributed to data acquisition and interpretation, and critically reviewed and approved the manuscript.

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CONFLICT OF INTEREST

The authors declare no conflict of interests.

DATA AVAILABILITY STATEMENT

The data that support the findings of this study are available on request from the corresponding author. The data are not publicly available due to privacy or ethical restrictions.

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SUPPORTING INFORMATION

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

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