

Exploring periodontitis misclassification mechanisms under partial-mouth protocols

Alshihayb, Talal; Sharma, Praveen; Dietrich, Thomas; Heaton, Brenda

DOI:
[10.1111/jcpe.13611](https://doi.org/10.1111/jcpe.13611)

License:
None: All rights reserved

Document Version
Peer reviewed version

Citation for published version (Harvard):
Alshihayb, T, Sharma, P, Dietrich, T & Heaton, B 2022, 'Exploring periodontitis misclassification mechanisms under partial-mouth protocols', *Journal of Clinical Periodontology*, vol. 49, no. 5, pp. 448-457.
<https://doi.org/10.1111/jcpe.13611>

[Link to publication on Research at Birmingham portal](#)

Publisher Rights Statement:

This is the peer reviewed version of the following article: Alshihayb, T. S., Sharma, P., Dietrich, T., & Heaton, B. (2022). Exploring periodontitis misclassification mechanisms under partial-mouth protocols. *Journal of Clinical Periodontology*, which has been published in final form at <https://doi.org/10.1111/jcpe.13611>. This article may be used for non-commercial purposes in accordance with Wiley Terms and Conditions for Use of Self-Archived Versions. This article may not be enhanced, enriched or otherwise transformed into a derivative work, without express permission from Wiley or by statutory rights under applicable legislation. Copyright notices must not be removed, obscured or modified. The article must be linked to Wiley's version of record on Wiley Online Library and any embedding, framing or otherwise making available the article or pages thereof by third parties from platforms, services and websites other than Wiley Online Library must be prohibited.

General rights

Unless a licence is specified above, all rights (including copyright and moral rights) in this document are retained by the authors and/or the copyright holders. The express permission of the copyright holder must be obtained for any use of this material other than for purposes permitted by law.

- Users may freely distribute the URL that is used to identify this publication.
- Users may download and/or print one copy of the publication from the University of Birmingham research portal for the purpose of private study or non-commercial research.
- User may use extracts from the document in line with the concept of 'fair dealing' under the Copyright, Designs and Patents Act 1988 (?)
- Users may not further distribute the material nor use it for the purposes of commercial gain.

Where a licence is displayed above, please note the terms and conditions of the licence govern your use of this document.

When citing, please reference the published version.

Take down policy

While the University of Birmingham exercises care and attention in making items available there are rare occasions when an item has been uploaded in error or has been deemed to be commercially or otherwise sensitive.

If you believe that this is the case for this document, please contact UBIRA@lists.bham.ac.uk providing details and we will remove access to the work immediately and investigate.

Title: Exploring Periodontitis Misclassification Mechanisms Under Partial-mouth Protocols

Running title: Periodontitis and partial-mouth protocol

Authors:

Talal S Alshihayb, DScD, BDS

College of Dentistry, King Saud bin Abdulaziz University for Health Sciences

Praveen Sharma, PhD, FDS (Restorative Dentistry) (RCS Edin.), FHEA, MJDF (RCS Edin.),
BDS

Primary: Birmingham Community Healthcare NHS Foundation Trust, Birmingham, UK

Secondary: Periodontal Research Group, University of Birmingham, Birmingham, UK

Email: Praveen.sharma@nhs.net

ORCID: 0000-0001-6435-4842

Thomas Dietrich, Dr. med., Dr. med. dent., MPH, FDS RCPS

Primary: Department of Oral Surgery, The School of Dentistry, University of Birmingham,
Birmingham, UK

Secondary: Birmingham Community Healthcare NHS Foundation Trust, Birmingham, UK

Email: T.Dietrich@bham.ac.uk

Brenda Heaton, PhD, MPH

Primary: Boston University Henry M. Goldman School of Dental Medicine

Secondary: Boston University School of Public Health

Email: brenda9@bu.edu

ORCID: 0000-0002-3097-4717

Corresponding Author:

Talal S Alshihayb, DScD, BDS

College of Dentistry, King Saud bin Abdulaziz University for Health Sciences

3rd floor, Office #73

Riyadh, 14611

Saudi Arabia

email: shihaybt@ksau-hs.edu.sa

ORCID: 0000-0001-5750-4144

Conflict of interest and source of funding: The authors have stated explicitly that there are no conflicts of interest in connection with this article. The National Health and Nutrition Examination Survey is a publicly available dataset which is supported by the National Center for Health Statistics from the Centers for Disease Control and Prevention.

Ethical approval: The National Health and Nutrition Examination Survey is a deidentified publicly available dataset. Original data collection protocols and data sharing methods received ethical approvals from the Ethical Review Board at the National Center for Health Statistics and the Centers for Disease Control and Prevention.

Author contributions: *Conception:* Sharma. P, Dietrich. T, and Heaton. B; *design:* T.S.

Alshihayb, Sharma. P, Dietrich. T, and Heaton; *data analysis:* T.S. Alshihayb; *data*

- 1 *interpretation:* T.S. Alshihayb, Sharma. P, Dietrich. T, and Heaton. B; *drafting and critically*
- 2 *reviewing the manuscript:* T.S. Alshihayb, Sharma. P, Dietrich. T, and Heaton. B. All authors
- 3 gave final approval and agreed to be accountable for all aspects of the work.
- 4 **Data availability:** Data is publicly available at <https://wwwn.cdc.gov/nchs/nhanes/Default.aspx>.

1 **Abstract**

2 **Aim:** To investigate the sources of periodontitis misclassification under partial-mouth protocols
3 and to explore possible approaches to enhancing protocol validity.

4 **Materials and Methods:** Using data from 10,680 adults with 244,999 teeth from the National
5 Health and Nutrition Examination Survey, we compared tooth-, site-, and quadrant-specific
6 periodontal parameters and case identification under full-mouth and partial-mouth protocols.
7 Separately, we utilized population measures of tooth-specific periodontal severity to generate
8 partial-mouth protocols with tooth selection based on the population ranking of clinical severity
9 and assessed the sensitivity of case identification.

10 **Results:** Symmetry of clinical severity was generally confirmed, with the exception of lingual
11 interproximal sites which yielded greater sensitivity in identifying periodontitis compared to
12 buccal sites due to more severe pocketing and attachment loss on average. Misclassification of
13 severe periodontitis occurred more frequently under commonly implemented partial-mouth
14 protocols compared to ranking-based selection of teeth which yielded sensitivity estimates of
15 70.1-79.4% with selection of eight teeth, and reached 90% with selection of only 14 teeth.

16 **Conclusions:** Clinical symmetry and sources of periodontitis misclassification were confirmed.
17 Proposed selection of teeth based on population rankings of clinical severity yielded optimal
18 sensitivity estimates for detection of severe periodontitis and may present a favorable alternative
19 to current options.

20 **Keywords:** Bias, Sensitivity and specificity, Periodontitis, Periodontal disease,
21 Misclassification.

22 **Clinical Relevance**

Scientific Rationale for study: Characterizing the potential for misclassification bias is important to use of partial-mouth protocols in epidemiologic studies. Prior investigations have been limited by the size and diversity of the sample. Additionally, there remains a need for the development of partial-mouth protocols that deliver greater sensitivity of case identification.

Principal findings: Misclassification of periodontitis was dependent on the selected site, tooth, and the severity of periodontal parameters. Our newly proposed ranking-based selection of teeth substantially outperform the existing partial-mouth protocol alternatives.

Practical Implications: Ranking-based-partial-mouth protocols may be a better substitute to the current partial-mouth protocols in estimating periodontitis.

Introduction

It is well known that full-mouth periodontal measurements of clinical attachment loss (CAL) and probing depth (PD) are the gold standard for ascertaining periodontitis (i.e., 6 sites per tooth on 28 teeth, excluding third molars) (Beck, Caplan, Preisser, & Moss, 2006; Kingman, Morrison, Löe, & Smith, 1988; Kingman, Susin, & Albandar, 2008; Susin, Kingman, & Albandar, 2005). However, a full-mouth periodontal exam may take up to 25-40 minutes to conduct per person (Owens, Dowsett, Eckert, Zero, & Kowolik, 2003; Preisser, Marks, Sanders, Akinkugbe, & Beck, 2017). Therefore, in research or surveillance settings where resources are often limited, partial-mouth protocols (PMPs) have been used to determine periodontal health status (Albandar, Brunelle, & Kingman, 1999; Page & Eke, 2007). They also carry the added benefit of reducing participant burden. However, the use of PMPs does come with some additional cost in that they underestimate the population prevalence of periodontitis (Tran et al., 2013). The effects of PMPs on estimates of periodontitis prevalence in the context of population

surveillance have been investigated in some detail and methods to correct prevalence estimates based on specific PMPs have been proposed (Botelho, Machado, Proença, & Mendes, 2020; Machado et al., 2018; Susin et al., 2005; Tran, Gay, & Waljil, 2016; Tran et al., 2014). However, much less attention has been given to the differential effects of PMPs on measures of periodontitis extent and severity and their impact on the validity of association studies through the introduction of misclassification bias.

Prior research on this topic has demonstrated that the degree to which the use of PMPs results in underestimation of periodontitis prevalence depends on both the PMP, as well as the case definition of periodontitis applied (Heaton, Sharma, Garcia, & Dietrich, 2018; Tran et al., 2013). We have previously investigated the mechanisms of disease misclassification under different PMPs using data from 640 participants in the VA Dental Longitudinal Study (DLS) (Heaton et al., 2018), where all periodontal exams were performed by a single examiner. In addition to limited generalizability, the DLS protocol used only two interproximal sites (i.e., mesiobuccal and distolingual) to measure CAL and PD. This made it impossible to separate the mesiodistal differences from buccolingual differences in comparisons of CAL and PD. The present study expands on our previous work by exploring periodontitis misclassification due to PMPs in a much larger sample of US adults with full-mouth CAL and PD measurements available on all six sites. Additionally, the large sample affords the opportunity to evaluate validation parameters against the population distributions of disease severity as a basis for speculating about optimal approaches to the implementation of PMPs.

The aims of this study were to i) compare the clinical periodontal measurements across sites, quadrants, and PMPs and ii) examine the misclassification mechanisms of periodontitis due to PMPs using the 2012 Centers for Disease Control/American Academy of Periodontology

(CDC/AAP) case definition (Eke, Page, Wei, Thornton-Evans, & Genco, 2012). To meet these aims, we compared full-mouth and PMP estimates among participants in the National Health and Nutrition Examination Survey (NHANES) (National Center for Health Statistics).

Methods

Data source and study population

Data from the NHANES cycles 2009-2014 were used in this study. NHANES is a nationally representative survey of the United States non-institutionalized population. NHANES began full-mouth clinical examinations for data collection cycles 2009-2014 which recorded CAL and PD on six sites per tooth for all 28 teeth (excluding third molars). In total, 30,468 people participated in the 2009-2014 cycles. For the purposes of this study, we included participants who underwent the periodontal exam protocol, were aged ≥ 30 years and who had at least one permanent tooth present (excluding third molars) with complete periodontal data. The resultant analytic sample totaled 10,680 people with 244,999 permanent teeth.

Periodontal clinical measurements and periodontitis case definition

Periodontal examination protocols for the NHANES 2009-2014 cycles have been described in detail elsewhere (Dye, Afful, Thornton-Evans, & Iafolla, 2019; Dye et al., 2014). Briefly, clinical periodontal measures were collected by two or more calibrated examiners and included gingival recession level as well as PD at six sites for 28 teeth (excluding third molars). CAL was calculated as the sum of the gingival recession and PD. For the purpose of this project, severe or moderate periodontitis is defined using the 2012 CDC/AAP criteria. Whole-mouth means of CAL and PD were calculated by dividing the sum of all measured sites by the total number of sites.

1 *Statistical analysis*

2 *Symmetry of CAL and PD*

3 Symmetry of clinical periodontal measures (CAL and PD) was assessed on a tooth level
4 across multiple aspects to formally evaluate the distribution of clinical disease parameters in the
5 whole mouth as a means to investigating potential sources of misclassification. We compared
6 CAL and PD between mesial and distal sites at the buccal and lingual sites (e.g., distobuccal-
7 mesiobuccal and distolingual-mesiolingual) as well as between buccal and lingual sites at mesial,
8 middle, and distal sites (e.g., mesiobuccal-mesiolingual, midbuccal-midlingual, and distobuccal-
9 distolingual). We stratified these comparisons by tooth type (anterior, premolar, or molar) and
10 periodontal disease status (none, mild, moderate or severe). We then compared the symmetry of
11 CAL and PD across the four quadrants (upper right, upper left, lower left, and lower right).

12 To evaluate CAL and PD across sites, we calculated the average difference between the
13 distobuccal and mesiobuccal sites, between distolingual and mesiolingual sites, between
14 mesiobuccal and mesiolingual sites, between midbuccal and midlingual sites, and between
15 distobuccal and distolingual sites. To compare CAL and PD between the right and left sides as
16 well as between the upper and lower jaws, we calculated the average difference in CAL and PD
17 values across teeth. Calculations were conducted on the tooth level and the standard error of the
18 mean difference was calculated accounting for the clustering of teeth within participants. The
19 complex design of NHANES was not incorporated in the analysis because it would force
20 analysis on a participant level instead of tooth level and thus, prohibit these comparisons.

21 *Partial-mouth protocols*

22 We determined periodontitis status based on common PMPs, including:

- 1 1. Random Half-Mouth (RHM) (Drury et al., 1996) where participants were randomly
2 assigned to a set of opposing contralateral quadrants (e.g., upper right/lower left or upper
3 left/lower right) , with selection repeated over 1000 iterations to account for random
4 error.
- 5 2. Community Periodontal Index for Treatment Needs protocol (CPITN) (Ainamo, 1982),
6 which includes teeth number 2, 3, 8, 14, 15, 18, 19, 24, 30, and 31
- 7 3. Ramfjord protocol (Ramfjord, 1959), which includes teeth number 3, 9, 12, 19, 25, and
8 28.

9 We also compared the right side vs left side (e.g., upper only, lower only, and both jaws),
10 maxilla vs mandible, and opposing contralateral quadrants.

11 *Periodontitis misclassification mechanisms*

12 To evaluate mechanisms of misclassification under PMPs, we compared different PMPs to the
13 full-mouth gold standard by applying the CDC/AAP periodontitis case definitions under both
14 protocols and calculated the sensitivity [total cases detected by the PMP ÷ total number of ‘true’
15 cases]. Further, we compared the whole-mouth means of number of permanent teeth, CAL, PD,
16 and number of permanent teeth with specific CAL/PD thresholds across the protocols (Eke,
17 Thornton-Evans, Wei, Borgnakke, & Dye, 2010; Heaton et al., 2018). To evaluate whether the
18 mechanism of periodontitis misclassification by PMP is random or not, we investigated how
19 misclassified and correctly classified periodontitis cases differed when using the RHM protocol.
20 Specifically, we compared number of teeth with thresholds of CAL and PD between concordant
21 (both full-mouth and PMP yielding the same diagnosis) and discordant (diagnosis of
22 periodontitis based on full-mouth but not PMP) pairs.

To further evaluate the mechanisms of misclassification, as well as to identify opportunity for minimizing misclassification in the face of PMPs, we utilized the population of teeth (N=244,999) to evaluate population patterns in tooth-specific severity of CAL and PD. Specifically, we ranked teeth according to the population mean value of the maximum interproximal site for CAL and PD. To explore the impact of the CDC/AAP case definition on misclassification by PMP, we additionally ranked each tooth according to the proportion of the tooth-specific population that had ≥ 5 mm of PD and ≥ 6 mm of CAL. We then employed a series of cumulative PMPs ranging from a single tooth to 27 teeth by iteratively selecting teeth in order of their population ranking of severity, moving from the most severe to the least. If a tooth indicated for selection in a given PMP was missing, it was replaced by selecting the next most severe tooth based on the population ranking such that each participant-specific implementation did not necessarily contain the same teeth. Once implemented, we then calculated and plotted the sensitivity of classifying a true case, as well as the population average of the difference in the full-mouth and partial-mouth means of CAL and PD.

Analyses were done using SAS software Version 9.4 (SAS Institute Inc., Cary, NC, USA). Statistical codes for the analyses are available here (<https://github.com/tshihayb/Exploring-Periodontitis-Misclassification-Mechanisms-Under-Partial-mouth-Protocols.git>).

Results

The mean age of the participants was 52.0 years, and around half of the sample were males (unweighted percent). On average, participants had 22.9 permanent teeth (maximum of 28, 0.06 standard error). The distribution of periodontitis under the full-mouth protocol consisted of

11.2% severe cases, 35.4% moderate cases, 4.6% mild, and nearly half the sample had no periodontitis (48.8%).

Symmetry of CAL and PD across sites and quadrants

Table 1 displays the average site-specific differences in clinical periodontal measurements. Overall, there were no clinically meaningful differences in CAL between distal and mesial sites (distobuccal-mesiobuccal or distolingual-mesiolingual), while lingual sites tended to have greater CAL, on average, compared to their respective buccal sites (mesiobuccal-mesiolingual, midbuccal-midlingual, and distobuccal-distolingual). Site-specific differences in CAL did not appear to depend on tooth type but differences in PD did, with lingual sites displaying deeper pockets on molars, compared to anterior teeth. Additionally, buccal-lingual differences in CAL and PD appeared to increase according to periodontitis severity.

Table 2 displays the average severity of periodontal parameters and number of teeth across the oral quadrants. There were no meaningful differences in mean CAL, mean PD, mean number of teeth, or mean number of teeth with thresholds of CAL and PD across the four quadrants.

Periodontitis misclassification mechanisms

Figure S1 displays the sensitivity of detecting severe periodontitis according to selected interproximal sites and/or quadrants. Sensitivity estimates for severe periodontitis ranged from 6.9% to 77.9%. Generally, the sensitivity of detecting severe periodontitis increased as the number of included interproximal sites, teeth, and or quadrants increased. Measurements at lingual sites yielded higher sensitivity compared to buccal sites, while measurements at mesial versus distal sites resulted in similar sensitivity estimates. There were no substantial differences

in sensitivity across all four quadrants when the sites measured were fixed (i.e., same sites were measured for each quadrant). The sensitivity of the RHM and CPITN protocols for the diagnosis of severe periodontitis were similar (63.8% for RHM and 63.0 for CPITN), while it was very low for the Ramfjord protocol (26%) (Figure S2 in appendix).

Table S1 in appendix compares the concordant and discordant periodontitis cases (e.g., mild, moderate, and severe) between the RHM and the full-mouth according to measures of clinical severity. In all scenarios, concordant cases had the highest mean CAL, mean PD, and mean number of teeth with CAL and PD thresholds, followed by the discordant cases and then the concordant non-cases. The difference in the mean number of teeth with CAL or PD between concordant cases and non-cases and discordant cases depended on the severity of periodontitis (Severe vs moderate vs mild) and the threshold applied for severity of CAL/PD (3 vs 4 vs 5 etc.).

Table 3 displays the mean number of teeth, mean CAL, mean PD, and the mean number of teeth with increasing levels of CAL/PD severity. The mean CAL and PD were comparable with respect to the mean number of teeth and mean number of teeth with thresholds of CAL/PD across the traditional PMPs except for the slight increase of CAL/PD using the CPITN. Differences in the mean number of teeth with a given level of CAL/PD between the PMPs decreased as the severity level increased. When comparing the bias of the mean CAL under the different PMPs, rank-based protocols resulted in overestimation: ≥ 0.06 for 14-teeth rank-based vs. -0.01 for RHM); ≥ 0.15 for 6-teeth rank-based vs. 0 for Ramfjord. However, the CPITN had more overestimation than some of the 10-teeth rank-based protocols (0.23 vs 0.04 - 0.27) (data not shown). Similar patterns were observed for mean PD.

Figure 1 displays the population means of maximum interproximal measures and the proportion of teeth with $CAL \geq 6mm$ and $PD \geq 5mm$ for each tooth and sorted according to the

value of the population value. With the exception of the proportion with $CAL \geq 6mm$, the top eight tooth populations according to the population values are the 1st and 2nd molars (2, 3, 14, 15, 18, 19, 30, and 31). The proportion with $CAL \geq 6mm$ tends to favor the 1st and 2nd molars in the maxilla (2, 3, 14, 15) and the central incisors of the mandible (24, 25, 26, 27).

Figure 2 shows the sensitivity of detecting severe periodontitis when we selected teeth according to the population ranking of periodontal severity and/or proportion of teeth with a given severity (e.g., $PD \geq 5mm$ and $CAL \geq 6mm$). Generally, the sensitivity of detecting severe periodontitis did not differ based on whether teeth were selected according to rankings based on CAL vs PD with the exception of rankings based on population proportion with $\geq 6mm$ CAL. The sensitivity of severe periodontitis for a PMP with eight teeth ranged from 70.1% (proportion $\geq 6mm$ CAL) to 79.4% (proportion $\geq 5mm$ PD). Once PMPs included selection of 14 or more teeth sensitivity values tended to exceed 90%.

Figure 3 displays the population average of the whole-mouth mean differences in clinical severity of CAL and PD. Selection of teeth based on population rankings of severity resulted in overestimation of the whole-mouth means that decreased according to increases in the numbers of teeth selected by the PMP, with some differences observed according to which measure the population rankings were based on. Specifically the differences in the whole-mouth means approached zero after the inclusion of eight teeth if selection was based on the proportion with $\geq 6mm$ CAL, whereas differences approached zero only after 20 teeth were selected based on other rankings.

Discussion

1 This study showed that PMPs performance depended on the sites measured, periodontitis
2 severity, the number of teeth selected, and the protocol under which they were selected. In
3 particular, the sensitivity of detecting true severe disease ranged substantially depending on the
4 approach taken for tooth selection under partial-mouth protocols. Specifically, standard PMPs
5 resulted in sensitivity estimates less than 70% under the CDC/AAP definition. However, a
6 ranking-based protocol as demonstrated here resulted in sensitivity estimates of 90% for as few
7 as 14 teeth. Lastly, selection of teeth in a PMP played an even bigger role when estimating the
8 whole-mouth means of CAL/PD.

9 The findings related to the symmetrical presentation of periodontal parameters in this
10 study are largely consistent with our previous work (Heaton et al., 2018). However, the use of six
11 sites per tooth in the present study afforded the ability to clarify that differences between
12 mesiobuccal and distolingual sites can be attributed to systematically deeper lingual pockets with
13 greater CAL, as was demonstrated here. We additionally observed increases in differences
14 between the buccal and lingual site-specific periodontal parameters with worsening periodontal
15 health (Table 1) which was not observed in our previous study (Heaton et al., 2018). Finally, we
16 did not observe the differences in the mean number of teeth and mean CAL between the
17 mandible and maxilla seen in the previous analysis (Heaton et al., 2018) which can plausibly be
18 explained by the role of random error, highlighting the potential strength of the sample size
19 utilized in this study. Ultimately, this study confirms that on average, the presentation of clinical
20 disease is symmetrical and that any differences in disease severity are systematic and predictable
21 (e.g., tooth- or site-specific).

22 The symmetrical and systematic differences in the presentation of clinical disease
23 observed here provide evidence as to the non-random source of misclassification of periodontitis

under PMPs. For example, the misclassification of severe cases by PMPs did not affect all individuals to the same extent based on the fact that concordant severe cases had the highest CAL and PD values compared to discordant cases, and concordant non-cases. However, this is only true when the case definition applied is categorical and tooth-based. If the periodontal condition was instead operationalized as the continuous, whole-mouth mean of CAL or PD, we confirm previous findings that some PMPs can closely approximate full-mouth measurements, regardless of true disease severity. Thus, if whole-mouth means of CAL or PD are to be used in studies of association, more time-efficient alternatives to full-mouth protocols could be considered without sacrificing accuracy.

In our view, the most novel and impactful contribution of this work is the population-level evaluation of tooth-specific distributions of periodontal severity and the development and implementation of population ranking-based partial-mouth protocols. This analysis showed that when we selected the most severely affected teeth according to the population distribution of CAL/PD, we could achieve a sensitivity of up to 80% for detecting severe periodontitis as defined by the CDC/AAP with as little as eight teeth. If as many as 14 teeth were selected, sensitivity estimates were as high as 90%, regardless of population-ranking measure used. While there was generally a narrow range in the differences of sensitivity estimates by which population ranked measure was used, selection based on the proportion of the tooth-specific population with ≥ 6 mm CAL resulted in the lowest sensitivities associated with detection of severe disease for protocols that utilized between 4 and 14 teeth. This finding highlights the dependency on and relationship to the case definition of periodontitis that is utilized as the gold standard. Specifically, the CDC/AAP definition applied here necessitates both PD and CAL at a given level to be classified as a severe case. Given that the ranking-based protocol can only

1 consider a single distribution (e.g., CAL or PD), it will favor only one aspect of the case
2 definition. Here, the teeth with the greatest population proportions of $CAL \geq 6mm$ represent only
3 a subset of those teeth that also have $PD \geq 5mm$ until you reach selection of 14 teeth. Once 14
4 teeth are selected under the protocol, there is sufficient enough overlap that differences in
5 sensitivity are minimized. It is important to note, however, that if selection was instead based on
6 population means, there are negligible differences in the sensitivity of detecting severe disease
7 regardless of number of teeth selected and regardless of which distribution (e.g. CAL or PD)
8 selection is based on.

9 While we are not the first to propose alternative approaches to the historically
10 implemented PMPs (Beck et al., 2006), we would argue that the approach taken here offers much
11 more practical implementation in the field compared to others, as the marginal gains in
12 sensitivity can be balanced against the resource required to increase the number of sites
13 measured. In practice, the most efficient choice of PMP will depend on the purpose of a specific
14 study. If the goal is to estimate disease prevalence based on a threshold based disease definition,
15 then a ranking based site/tooth selection as described here can be used to maximise sensitivity
16 for a given number of teeth to be included. The overestimation of mean CAL/PD by the rank-
17 based PMPs indicates that they might not work well for continuous definitions as the mean
18 CAL/PD due to the selection of the most severe teeth. Therefore, investigators should carefully
19 choose the PMP after consideration of the periodontitis definition that will be implemented.

20 We did consider the use of other case definitions, including the 2018 World Workshop
21 European Federation of Periodontology (EFP)/American Academy of Periodontology (AAP)
22 consensus classification (Papapanou et al., 2018; Tonetti, Greenwell, & Kornman, 2018).
23 However, these were not designed for research purposes and impose very low thresholds for

CAL and PD, rendering its use and value in this analysis questionable. In fact, we did calculate the prevalence using this data and found that approximately 99% were found to have periodontitis, similar to findings based on another study (Germen et al., 2021; Ghassib, Batarseh, Wang, & Borgnakke, 2021; Stødle, Verket, Høvik, Sen, & Koldsland, 2021).

The findings of this study provide corroborating evidence on the symmetry of periodontal parameters across the mouth. Further, it illustrates the potential sources and mechanisms of misclassification under PMPs when threshold-based disease definitions such as the CDC/AAP definition are applied. Results of this study offer a new insight into PMPs through selecting teeth based on their population ranking of periodontal clinical measures' severity. Ranking-based selection of PMPs may be used to maximize sensitivity when the goal is to estimate periodontitis prevalence.

References

- Ainamo, J. (1982). Development of the World Health Organization (WHO) community periodontal index of treatment needs (CPITN). *Int. dent. J.*, 32, 281-291.
- Albandar, J., Brunelle, J., & Kingman, A. (1999). Destructive periodontal disease in adults 30 years of age and older in the United States, 1988-1994. *Journal of periodontology*, 70, 13-29.
- Beck, J. D., Caplan, D. J., Preisser, J. S., & Moss, K. (2006). Reducing the bias of probing depth and attachment level estimates using random partial-mouth recording. *Community dentistry and oral epidemiology*, 34, 1-10.
- Botelho, J., Machado, V., Proença, L., & Mendes, J. J. (2020). The 2018 periodontitis case definition improves accuracy performance of full-mouth partial diagnostic protocols. *Scientific reports*, 10, 1-7.
- Drury, T. F., Winn, D. M., Snowden, C. B., Kingman, A., Kleinman, D. V., & Lewis, B. (1996). An overview of the oral health component of the 1988–1991 National Health and Nutrition Examination Survey (NHANES III-Phase 1). *Journal of Dental Research*, 75, 620-630.
- Dye, B. A., Afful, J., Thornton-Evans, G., & Iafolla, T. (2019). Overview and quality assurance for the oral health component of the National Health and Nutrition Examination Survey (NHANES), 2011–2014. *BMC oral health*, 19, 1-11.
- Dye, B. A., Li, X., Lewis, B. G., Iafolla, T., Beltran-Aguilar, E. D., & Eke, P. I. (2014). Overview and quality assurance for the oral health component of the National Health and

- 1 Nutrition Examination Survey (NHANES), 2009-2010. *Journal of public health*
2 *dentistry*, 74, 248-256.
- 3 Eke, P., Thornton-Evans, G., Wei, L., Borgnakke, W., & Dye, B. (2010). Accuracy of NHANES
4 periodontal examination protocols. *Journal of Dental Research*, 89, 1208-1213.
- 5 Eke, P. I., Page, R. C., Wei, L., Thornton-Evans, G., & Genco, R. J. (2012). Update of the case
6 definitions for population-based surveillance of periodontitis. *Journal of periodontology*,
7 83, 1449-1454.
- 8 Germen, M., Baser, U., Lacin, C. C., Firatlı, E., İşsever, H., & Yalcin, F. (2021). Periodontitis
9 Prevalence, Severity and Risk Factors: A Comparison of the AAP/CDC Case Definition
10 and the EFP/AAP Classification. *International Journal of Environmental Research and*
11 *Public Health*, 18, 3459.
- 12 Ghassib, I. H., Batarseh, F. A., Wang, H. L., & Borgnakke, W. S. (2021). Clustering by
13 periodontitis-associated factors: A novel application to NHANES data. *Journal of*
14 *periodontology*, 92, 1136-1150.
- 15 Heaton, B., Sharma, P., Garcia, R. I., & Dietrich, T. (2018). Evaluating periodontal disease
16 misclassification mechanisms under partial-mouth recording protocols. *Journal of*
17 *clinical periodontology*, 45, 422-430.
- 18 Kingman, A., Morrison, E., Löe, H., & Smith, J. (1988). Systematic errors in estimating
19 prevalence and severity of periodontal disease. *Journal of periodontology*, 59, 707-713.
- 20 Kingman, A., Susin, C., & Albandar, J. M. (2008). Effect of partial recording protocols on
21 severity estimates of periodontal disease. *Journal of clinical periodontology*, 35, 659-667.
- 22 Machado, V., Botelho, J., Mascarenhas, P., Cavacas, M. A., Alves, R., & Mendes, J. J. (2018).
23 Partial recording protocols performance on the assessment of periodontitis severity and
24 extent: Bias magnitudes, sensibility, and specificity. *Revista Portuguesa de*
25 *Estomatologia, Medicina Dentaria e Cirurgia Maxilofacial*, 59, 145-153.
- 26 National Center for Health Statistics (NCHS). *National Health and Nutrition Examination*
27 *Survey*. Retrieved from <https://www.cdc.gov/nchs/nhanes/index.htm>.
- 28 Owens, J. D., Dowsett, S. A., Eckert, G. J., Zero, D. T., & Kowolik, M. J. (2003). Partial-mouth
29 assessment of periodontal disease in an adult population of the United States. *Journal of*
30 *periodontology*, 74, 1206-1213.
- 31 Page, R. C., & Eke, P. I. (2007). Case definitions for use in population-based surveillance of
32 periodontitis. *Journal of periodontology*, 78, 1387-1399.
- 33 Papapanou, P. N., Sanz, M., Buduneli, N., Dietrich, T., Feres, M., Fine, D. H., . . . Graziani, F.
34 (2018). Periodontitis: Consensus report of workgroup 2 of the 2017 World Workshop on
35 the Classification of Periodontal and Peri-Implant Diseases and Conditions. *Journal of*
36 *periodontology*, 89, S173-S182.
- 37 Preisser, J. S., Marks, S. J., Sanders, A. E., Akinkugbe, A. A., & Beck, J. D. (2017). A new way
38 to estimate disease prevalence from random partial-mouth samples. *Journal of clinical*
39 *periodontology*, 44, 283-289.
- 40 Ramfjord, S. P. (1959). Indices for prevalence and incidence of periodontal disease. *The Journal*
41 *of Periodontology*, 30, 51-59.
- 42 Stødle, I. H., Verket, A., Høvik, H., Sen, A., & Koldsland, O. C. (2021). Prevalence of
43 periodontitis based on the 2017 classification in a Norwegian population. The HUNT
44 Study. *Journal of clinical periodontology*, 48, 1189– 1199.
- 45 Susin, C., Kingman, A., & Albandar, J. M. (2005). Effect of partial recording protocols on
46 estimates of prevalence of periodontal disease. *Journal of periodontology*, 76, 262-267.

1 Tonetti, M. S., Greenwell, H., & Kornman, K. S. (2018). Staging and grading of periodontitis:
2 Framework and proposal of a new classification and case definition. *Journal of*
3 *periodontology*, 89, S159-S172.

4 Tran, D. T., Gay, I., & Waljil, M. (2016). Partial-mouth periodontal examination protocols for
5 population-based surveillance of periodontitis. *Int J Oral Dent Health*, 2, 025.

6 Tran, D. T., Gay, I., Du, X. L., Fu, Y., Bebermeyer, R. D., Neumann, A. S., . . . Walji, M. F.
7 (2013). Assessing periodontitis in populations: a systematic review of the validity of
8 partial-mouth examination protocols. *Journal of clinical periodontology*, 40, 1064-1071.

9 Tran, D. T., Gay, I., Du, X. L., Fu, Y., Bebermeyer, R. D., Neumann, A. S., . . . Walji, M. F.
10 (2014). Assessment of partial-mouth periodontal examination protocols for periodontitis
11 surveillance. *Journal of clinical periodontology*, 41, 846-852.

Figure 1. Descending ranking of teeth based on the severity of the population mean maximum interproximal clinical attachment loss (CAL) (upper left panel), population mean maximum interproximal probing depth (PD) (upper right panel), population percentage of teeth with ≥ 6 mm of clinical attachment loss (lower left panel), and population percentage of teeth with ≥ 5 mm PD (lower right panel).

Figure 2. Sensitivity estimates for diagnosing severe periodontitis according to the Centers for Disease Control and Prevention with the American Academy of Periodontology (CDC/AAP) for the partial-mouth protocols (PMPs) where the most severe teeth based on different the ranking of population values were selected. CAL: clinical attachment loss, PD: probing depth, max: maximum, interproximal.

Figure 3. Population mean difference in the mean mouth CAL/PD between partial-mouth (PM) and full-mouth (FM) protocols where the most severe teeth based on different the ranking of population values were selected. CAL: clinical attachment loss, PD: probing depth, max: maximum, interprox: interproximal.