

Evaluating periodontal disease misclassification mechanisms under partial-mouth recording protocols

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TITLE PAGE

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ABSTRACT:

Aim. To evaluate the assumptions underlying the use of partial-mouth recording protocols and the associated mechanisms of potential misclassification of periodontal disease.

Methods. Using data from 640 participants in the Veterans Affairs Dental Longitudinal Study, we compared tooth-specific and site-specific clinical measures, and calculated sensitivity and specificity of different partial-mouth recording protocols by applying widely used surveillance case definitions for periodontitis as the full-mouth reference standard. Additionally, we evaluated alternative case definitions for partial-mouth recording protocols that accounted for the reduction in numbers of teeth under observation.

Results. In this cohort, periodontitis presented as a generalized condition in that measures of clinical severity did not differ meaningfully according to site measured, oral quadrant or jaw. Importantly, we found that the sensitivity of disease classification under partial-mouth recording protocols was a function of the number of teeth and sites under observation and the case definition applied. Sensitivity increased when case definitions were modified to account for the smaller number of teeth under observation with partial-mouth recording protocols. However, specificity estimates were reduced.

Conclusions. Misclassification of periodontal disease by partial-mouth recording protocols is not random, even if sites under observation are randomly selected. Partial-mouth recording protocols can be selected/modified to maximize sensitivity, but they do so at the expense of bias in mean measures of severity.

CLINICAL RELEVANCE:

Scientific Rationale for Study: Partial-mouth recording protocols have been widely implemented, often without proper vetting of the assumptions underlying their use. A better understanding of the assumptions behind the valid use of partial-mouth recording protocols and the relevance of proposed case definitions based on full-mouth examinations is currently needed.

Principal Findings: This paper provides an evaluation of the clinical manifestations of periodontitis, which underpin the valid use of partial-mouth approaches. Disease manifestation is fairly symmetric on average in that there appear to be no meaningful differences according to site, oral quadrant or jaw. Misclassification due to use of partial-mouth recording protocols is not random.

Practical Implications: Partial-mouth recording protocols that record all teeth in a half-mouth or quadrant will result in relatively unbiased estimates of average disease severity/extent scores, but will have reduced sensitivity for meeting disease thresholds for binary disease definitions. Partial-mouth recording protocols that sample selected teeth, such as Ramfjord or CPITN protocols, can increase sensitivity at the expense of bias in average severity/extent scores.

INTRODUCTION

Periodontal disease case definitions and recording protocols (e.g. full-mouth recording (FMR) vs. partial-mouth recording (PMR)) are two areas of periodontal research in which a diversity of opinion and approach exist, often barring the advancement of descriptive and analytic research from the perspectives of feasibility and validity. Standardized case definitions of periodontal disease have not been broadly proposed or accepted until recently (Mesch et al., 1999, Page and Eke, 2007, Eke et al., 2012). Even still, proposed case definitions have received continued criticism for a variety of reasons (Borrell and Papapanou, 2005, Demmer and Papapanou, 2010, Savage et al., 2009, Leroy et al., 2010, Tonetti and Claffey, 2005). PMR protocols have been proposed and utilized for decades, including the use of index teeth and sites (Ramfjord, 1959), half-mouth measurement with random selection of opposing quadrants (Drury et al., 1996), and randomized selection of teeth and sites (Beck et al., 2006), yet no alternative has received widespread acceptance (Eke et al., 2010, Kingman and Albandar, 2002, Kingman et al., 2008, Vettore et al., 2007, Susin et al., 2005, Beck et al., 2006). Although they are separate issues, case definitions and the use of PMR protocols are fundamentally related and share general criticism related to the potential for invalid estimation of disease prevalence and severity due to misclassification. The use of PMR protocols, specifically, has received notable attention related to underestimation of disease presence and severity and has even been suggested as a potential source of non-differential misclassification of periodontal disease (e.g., random misclassification), thereby biasing estimates of effect when used in studies of association (Kingman and Albandar, 2002, Akinkugbe et al., 2015). However, the extent to which periodontal disease is misclassified may be a result of the particular PMR protocol employed as well as the case definition applied. To date, the discussions and developments related to case definitions and alternatives to FMR protocols have largely gone on without mutual consideration, regardless of this important relationship between them.

PMR protocols have the obvious advantage of reducing the burden of measurement, and may be the only feasible option to include periodontal assessments in clinical studies where many other assessments are performed. Therefore, a better understanding of the assumptions behind the valid use of PMR protocols and the relevance of proposed case definitions based on full-mouth examinations is currently needed. For example, it has been suggested by some that periodontitis is not a generalized condition, evenly distributed throughout the mouth which, if true, should call the use of PMR protocols into question (Eke et al., 2010, Kingman and Albandar, 2002, Susin et al., 2005). However, to our knowledge, the distribution of clinical disease parameters and disease effects, such as tooth loss, has not been formally evaluated. Additionally, the discussion related to PMR protocols has overwhelmingly been focused on the resultant underestimation of disease burden in surveillance studies exclusively. This determination has most often been made by applying the same case definitions proposed for full-mouth examination data to data obtained from PMR protocols. Most case definitions used in these evaluations, such as the recently accepted case definitions developed by the Centers for Disease Control and Prevention in collaboration with the American Academy of Periodontology (CDC-AAP), are tooth-based definitions and therefore will inherently underestimate disease burden when fewer teeth are under observation. Specifically, given the same case definition applied to both FMR and PMR (regardless of protocol) data, the specificity of disease determination by PMR will always be 100% and the sensitivity less than 100%, resulting in underestimation.

We hypothesized that underestimation would not only be directly related to the number of teeth and sites under observation (PMR protocol), but also related to the case definitions applied and that the misclassification of periodontal disease would be ameliorated if the case definition used for a PMR protocol was adapted to reflect the smaller number of recorded sites. We also hypothesized that misclassification of periodontal disease due to the use of PMR

protocols would not be random, even if based on a random PMR protocol. These mechanisms of misclassification have yet to be fully understood or evaluated.

The specific aims of this paper were to (i) evaluate the assumption of symmetry of periodontal parameters at the mouth and tooth level that underpin many PMR protocols, (ii) determine the sensitivity and specificity of periodontitis case definitions under a variety of recording protocols, and (iii) evaluate potential mechanisms of misclassification of periodontal disease in these scenarios.

METHODS

Subject Population

Full-mouth examination data was obtained on 640 adult men participating in the Veterans Affairs Dental Longitudinal Study (DLS) during the years 1987-1997. The parent study for the DLS is the Veterans Affairs Normative Aging Study, an ongoing closed-panel prospective study of aging, which began in the 1960s (Bell et al., 1966). At baseline, 2,280 men aged 21 to 84 years who were free of chronic disease and lived in the greater Boston metropolitan area were enrolled. In 1968, 1,231 Normative Aging Study participants volunteered to enroll in its dental component (Kapur et al., 1972). Subjects were not Veterans Affairs patients and received both medical and dental care in the private sector. According to self-report of oral diagnoses and receipt of specialty treatment, few DLS subjects received comprehensive or definitive treatment for periodontitis. Beginning in 1987, periodontal examinations were conducted as part of the regular study follow-up visit by a single examiner following the then National Institute of Dental Research protocol, recording measurements of millimeters of clinical attachment loss (CAL) and pocket probing depth (PD) at four sites per tooth—disto-lingual, mid-lingual, mesio-buccal, mid-buccal. The present cross-sectional analysis uses data from full-mouth examinations, recording site-specific measures, that were done on all participants (n=640) active in the DLS at that time. Third molars were excluded from all analyses.

PMR Protocols Evaluated and Periodontitis Case Definitions Used

Table 1 provides detailed information regarding the protocols and definitions implemented in this investigation.

We evaluated mechanisms of misclassification by PMR protocol by applying three commonly used PMR protocols to the DLS dataset – Random Half-Mouth (RHM), Community Periodontal Index of Treatment Needs (CPITN), and the Ramfjord index teeth (Ramfjord, 1959, Ainamo and Ainamo, 1985). The RHM protocol was implemented through random selection of opposing oral quadrants, and included up to 14 teeth. RHM protocols were used for all PMR disease determinations unless otherwise specified.

The reference definition of periodontal disease presence and severity used for all full-mouth comparisons was the 2007 CDC-AAP definitions for no/mild, moderate and severe periodontitis (Page and Eke, 2007). This definition incorporates measures of PD and CAL obtained only from interproximal sites (see Table 1). In order to evaluate the potential impact of case definitions on misclassification of disease by PMR protocol, we also evaluated modifications to this definition for disease determinations under PMR protocols. Specifically, the CDC-AAP severe disease definition was modified to require that only one interproximal site with at least 6 mm CAL was present (instead of two). An additional alternative definition which eliminated the requirement for a site with 5+ mm PD was also assessed.

Symmetry of Clinical Periodontal Disease

Clinical measures of CAL and PD were obtained on 13,209 teeth and were used to assess the symmetry of clinical disease presentation according to a variety axes. Specifically, presentation of clinical disease was compared across sites (mesial vs. distal; mid-buccal vs. mid-lingual), across oral quadrants (upper right vs. upper left; lower right vs. lower left) and across jaws (upper vs. lower). Measures of clinical severity across each of the above-mentioned axes were also stratified according to tooth type (anterior, premolar, molar) and by categories of disease severity (none/mild, moderate, severe). In order to assess symmetry by site, differences

between site-specific clinical measures (PD, CAL) were calculated for each individual. Average differences and the associated standard errors were calculated accounting for the clustering of teeth within each individual. In order to assess symmetry by oral quadrant and jaw, we calculated mean PD, mean CAL, total number of teeth, number of teeth with CAL \geq 6mm and number of teeth with PD \geq 5mm within each oral quadrant. In line with the CDC-AAP case definitions for severe disease, only the maximum measurement of the interproximal sites on each tooth was included in the calculation of means.

Mechanisms of Misclassification

The sensitivity and specificity of different PMR protocols in the determination of disease status was assessed based on full-mouth determinations using the CDC-AAP definitions as the reference standard. Site-specific, quadrant-specific and half-mouth combination estimates of sensitivity were evaluated.

In order to assess differences in the overall severity and extent of disease for those whose disease status was misclassified as a result of implementing PMR protocols, we evaluated disease parameters according to whether disease determinations between FMR and PMR protocols were concordant. To determine concordance, the CDC-AAP definition was applied to each participant under both FMR and PMR conditions using the RHM protocol (see Table 1).. We then assessed the number of teeth in the mouth with CAL and PD above a certain threshold according to whether subjects' PMR determinations of severe or moderate disease were concordant or discordant with determinations made by the FMR protocol applying the standard CDC-AAP definitions.

Approvals to conduct human subject research were obtained from the Boston University Medical Campus and the Veterans Affairs Institutional Review Boards.

RESULTS

Subject Population

The analytic sample comprised 640 men with a mean age of 68 years. Of these, 15% (n=99) were found to have mild to no periodontal disease, 66% (n=425) had moderate/non-severe disease, and 18% (n=116) had severe disease, using the CDC-AAP definition. On average, men had approximately 21 teeth (excluding third molars).

Symmetry of Clinical Periodontal Disease

On average, mid-lingual sites had deeper pockets than mid-buccal sites and disto-lingual sites were deeper than mesio-buccal sites (Table 2). Mid-lingual sites exhibited less attachment loss on average than mid-buccal sites, whereas little difference was observed between mesio-buccal and disto-lingual attachment loss. No consistent differences were found according to tooth-type or periodontal disease status (Table 2).

No meaningful differences were observed between right and left quadrants in both the upper and lower jaw for mean PD, mean CAL, number of teeth, number of teeth with 6+mm CAL and number of teeth with 5+mm PD (Table 3). However, some minor differences between maxillary and mandibular quadrants were observed with somewhat higher numbers of teeth and more attachment loss in the mandible (Table 3).

Mechanisms of Misclassification

Table 4 displays the incremental increases in the sensitivity of 'severe' disease determinations according to the number of teeth and interproximal sites measured. Sensitivity increased as a function of the number of sites measured. PMR data limited to disto-lingual sites exhibited greater sensitivity than PMR data limited to mesio-buccal sites. Standard case definitions for FMR protocols produce 100% specificity when applied to data obtained from PMR protocols.

Using the RHM protocol (14 teeth), the sensitivity of diagnosing severe periodontitis was 54%. The CPITN protocol (10 teeth) achieved 53% sensitivity, while the use of the six Ramfjord index teeth achieved 16% sensitivity (Table 6).

When the standard definition of severe disease was modified to require that only one site with severe CAL and PD be present, the sensitivity of identifying true disease using the RHM protocol increased to 77%, while non-perfect specificity (96%) was introduced (Youden's Index = 0.73, Figure 1). The sensitivity of disease determination by PMR was additionally increased when an interproximal site with severe PD was not required. The resulting sensitivity was 94% and the specificity was further reduced to 80% (Youden's Index = 0.74). Both modified definitions resulted in improved discrimination compared to the standard definition (Youden's Index = 0.54).

Among those where the PMR protocol failed to identify the presence of 'moderate' or 'severe' disease according to the standard CDC-AAP definition (discordant), the number of sites above a certain disease threshold was always intermediate between those that were correctly classified by the PMR as either non-diseased or diseased (Table 5). The difference in periodontal disease severity and extent between those correctly identified by the PMR protocol as diseased and those that were misclassified appears to be a function of the disease definition (moderate or severe) and the site specific disease threshold used (Table 5).

The number of teeth under observation did not impact the means of clinical measures across PMR protocols aside from the CPITN protocol in which means of clinical measures were slightly increased due to the primary inclusion of molar teeth (see also Table 3). However, the number of teeth with severe clinical measures decreased according to the number of teeth under observation (Table 6).

DISCUSSION

The present work was primarily undertaken to provide insight into the clinical presentation of periodontitis and how it pertains to the classification of disease by PMR protocols. This work provides important foundational knowledge to the future investigation of case definitions under PMR protocols and even more importantly, the possibility of bias related to use of PMR protocols in studies of association.

This study suggested that at the mouth level (i.e., between quadrants) the presentation of clinical disease and disease severity is, on average, symmetric. However, clinical presentation varied somewhat depending on tooth type and sites measured. Specifically, periodontal pockets were deeper, on average, for lingual sites compared to buccal sites and for molars compared to non-molars. This finding confirms previous findings by other investigators (Beck et al., 2006, Kingman and Albandar, 2002). The symmetry of clinical disease parameters was also shown to have direct implications for the performance of different PMR protocols in that the sensitivity of PMR protocols is not only a function of the number of teeth or sites measured, but also the tooth type and location of the measured site (i.e., lingual vs. buccal site). Specifically, sensitivity would be maximized if lingual sites were chosen over buccal sites, or if more severely affected teeth such as molars are included in a PMR protocol. Many of the existing PMR protocols utilize buccal sites only, presumably due to easier access, resulting in reduced sensitivity (Susin et al., 2005). We showed that compared to a RHM protocol that utilizes both buccal and lingual sites (sensitivities range from 48% to 58%, Table 4), a PMR protocol that utilizes only lingual sites but on all teeth will exhibit higher sensitivity (68%), with the same number of measurement sites (28 sites, Table 4).

In addition to the symmetry of clinical disease presentation, this study highlighted the mechanisms of misclassification of clinical disease according to the number and type of teeth observed under varying PMR protocols and the relationships between them. We showed that the sensitivity of severe disease classification generally increased according to increases in the number of teeth under observation (Table 3). However, sensitivity estimates were similar for the RHM (54%) and the CPITN (53%) protocols, despite the fact that the CPITN protocol utilizes fewer teeth. The teeth used under the CPITN protocol include all eight molars which we have shown to display more severe disease and thereby produces increased sensitivity of disease identification under that protocol. The Ramfjord protocol which utilizes only six teeth to equally

represent the mouth (e.g. two molars, two premolars, two anteriors) produced minimal sensitivity (16%).

Given the relationship between the number of teeth observed and the underestimation of disease, we evaluated an alternative strategy to improve the sensitivity of PMR protocols by adapting the ‘case definition’ criteria for periodontal disease classification to reflect the reduced number of measurement sites. This approach has also been proposed by others (Tran et al., 2014). Reducing the threshold for diagnosis of severe disease to only one site with CAL of at least 6mm, resulted in a marked increase in sensitivity. Unsurprisingly, this came at the expense of reduced specificity (Figure 1). However, discrimination of severe disease markedly improved with either of the modified definitions.

In addition to effects on the sensitivity of disease identification, this study highlighted the relationship between sensitivity of disease classification and potential bias in the estimation of disease severity and/or extent. For example, as mentioned above, an RHM protocol that utilizes both buccal and lingual sites will reduce sensitivity, but exhibits no bias in mean severity measures (e.g., mean PD, mean CAL) (Beck et al., 2006). If, however, a PMR protocol was restricted to lingual sites or more severely affected teeth in order to maximize the sensitivity of disease classification, as mentioned above, this would come at the expense of an overestimate of disease severity (mean PD/CAL). In addition to the selected sites, the tooth type under observation will have similar results. We demonstrated that while the sensitivity of the RHM and CPITN protocols were similar, the average severity of the clinical measures assessed under the CPITN protocol resulted in an overestimate of disease severity compared to the FMR protocol due to the inclusion of teeth at higher risk for deeper pockets and greater attachment loss. In contrast, despite the marked reductions in sensitivity when using the Ramfjord teeth, the estimates of disease severity under that protocol revealed no bias.

The results of this study also demonstrate that the misclassification of periodontal disease is not random, even if PMR sites are randomly selected. To illustrate, if the same case

definition is applied, no subject classified as non-diseased under FMR protocols will be classified as diseased under any PMR protocol (100% specificity). Misclassification under PMR protocols can therefore only occur amongst those classified as diseased under FMR protocols. Hence, under the assumption of random misclassification, the severity and extent of periodontal disease would be expected to be distributed evenly between the concordant diseased and discordant subjects, i.e., between those who are classified as diseased under both FMR and PMR protocols (concordant diseased) and those who are truly diseased but classified as non-diseased under PMR protocols (discordant). Our results clearly indicate that misclassification by PMR is not random; in fact, depending on the disease definition and severity threshold used, periodontal parameters of misclassified subjects can be more similar to the truly non-diseased subjects than to the truly diseased subjects (Table 5). This makes intuitive sense given the observed symmetry of disease distribution, because amongst all subjects who are classified as diseased under FMR protocols, those with greater severity and extent will be more likely to be correctly classified under PMR than those who have ‘borderline’ severe disease. This has potentially important implications for association studies, as misclassification under PMR protocols may cause less bias than expected by random misclassification under the assumption of a causal exposure-disease association with periodontal disease severity (Heaton et al., 2017).

The employment of PMR protocols will undoubtedly continue to be used in the estimation of periodontitis prevalence and severity. Underestimation of disease prevalence is inevitable when the number of teeth observed is reduced and the same disease criterion as those used in FMR protocols are applied. Future work should consist of developing standardized options for PMR protocols that are grounded in the understanding related to the distribution of teeth, symmetry of disease and disease severity. Consideration should also be made for the relative ease of implementation. For example, random selection of teeth is infeasible in many settings and will not improve the sensitivity of estimates compared to other

PMR protocols utilizing the same number of teeth. Lastly, despite the fact that PMR protocols will consistently underestimate disease prevalence as a function of similarly applied tooth-based disease criterion, the same principles do not necessarily apply to studies of association. Similar work should be done to verify the influence of PMR protocols when periodontitis serves as either the exposure or outcome in an association study.

The present study is not without limitation. The DLS employed the 1987 National Institute of Dental Research examination protocol which prescribes measurement of only four sites per tooth, instead of six. As a result, estimates of disease severity, as well as the estimates of sensitivity, may be underestimates. Furthermore, any differences observed between mesial and distal sites are likely exaggerated since the comparison inherently incorporates some of the difference between buccal and lingual sites generally. For these same reasons, we were not able to compare buccal and lingual sites measured interproximally. However, in the absence of these limitations, we believe our conclusions would only be strengthened. This study also relied on a population of older, predominantly white men. Although we don't believe our findings to be dependent on the limited population with respect to age, gender and race, one may wish to exercise caution in determining the generalizability of the study. Lastly, it is important to emphasize that the misclassification of periodontitis by each PMR protocol is directly related to the case definition that is applied. We limited our evaluation to the 2007 CDC-AAP definition and therefore cannot comment on the particular impact of applying other periodontitis case definitions. However, such work could be informative and represents an opportunity for future research. Nevertheless, the mechanisms of misclassification with respect to the number and type of sites and teeth included in any definition would be similarly operational.

The field of periodontal research has greatly benefited from the development of a standardized case definition of periodontitis. Similarly, due consideration should be given to the development of standardized case definitions and measurement protocols for use in studies

which employ a PMR protocol. Specifically, future work should evaluate the appropriateness of tooth-based definitions in the presence of varying numbers of teeth.

REFERENCES

- AINAMO, J. & AINAMO, A. 1985. Partial Indexes as Indicators of the Severity and Prevalence of Periodontal-Disease. *International Dental Journal*, 35, 322-326.
- AKINKUGBE, A. A., SARAIYA, V. M., PREISSER, J. S., OFFENBACHER, S. & BECK, J. D. 2015. Bias in estimating the cross-sectional smoking, alcohol, obesity and diabetes associations with moderate-severe periodontitis in the Atherosclerosis Risk in Communities study: comparison of full versus partial-mouth estimates. *J Clin Periodontol*.
- 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 Dent Oral Epidemiol*, 34, 1-10.
- BELL, B., ROSE, C. L. & DAMON, A. 1966. The Veterans Administration longitudinal study of healthy aging. *Gerontologist*, 6, 179-84.
- BORRELL, L. N. & PAPAPANOU, P. N. 2005. Analytical epidemiology of periodontitis. *J Clin Periodontol*, 32 Suppl 6, 132-58.
- DEMMER, R. T. & PAPAPANOU, P. N. 2010. Epidemiologic patterns of chronic and aggressive periodontitis. *Periodontol 2000*, 53, 28-44.
- 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). *J Dent Res*, 75 Spec No, 620-30.
- EKE, P. I., PAGE, R. C., WEI, L., THORNTON-EVANS, G. & GENCO, R. J. 2012. Update of the case definitions for population-based surveillance of periodontitis. *J Periodontol*, 83, 1449-54.
- EKE, P. I., THORNTON-EVANS, G. O., WEI, L., BORGNAKKE, W. S. & DYE, B. A. 2010. Accuracy of NHANES periodontal examination protocols. *J Dent Res*, 89, 1208-13.
- HEATON, B., GARCIA, R. I. & DIETRICH, T. 2017. Simulation study of misclassification biases in association studies employing partial-mouth protocols.
- KAPUR, K. K., GLASS, R. L., LOFTUS, E. R., ALMAN, J. E. & FELLER, R. P. 1972. The Veterans Administration longitudinal study of oral health and disease. *Aging Hum Devel*, 3, 125-137.
- KINGMAN, A. & ALBANDAR, J. M. 2002. Methodological aspects of epidemiological studies of periodontal diseases. *Periodontol 2000*, 29, 11-30.
- KINGMAN, A., SUSIN, C. & ALBANDAR, J. M. 2008. Effect of partial recording protocols on severity estimates of periodontal disease. *J Clin Periodontol*, 35, 659-67.
- LEROY, R., EATON, K. A. & SAVAGE, A. 2010. Methodological issues in epidemiological studies of periodontitis--how can it be improved? *BMC Oral Health*, 10, 8.
- MESCH, D. J., MCGREW, J. H., PESCOLOLIDO, B. A. & HAUGH, D. F. 1999. The effects of hospital closure on mental health workers: an overview of employment, mental and physical health, and attitudinal outcomes. *J Behav Health Serv Res*, 26, 305-17.
- PAGE, R. C. & EKE, P. I. 2007. Case definitions for use in population-based surveillance of periodontitis. *J Periodontol*, 78, 1387-99.
- RAMFJORD, S. 1959. Indices for prevalence and incidence of periodontal disease. *J Periodontol*, 30, 51-59.
- SAVAGE, A., EATON, K. A., MOLES, D. R. & NEEDLEMAN, I. 2009. A systematic review of definitions of periodontitis and methods that have been used to identify this disease. *J Clin Periodontol*, 36, 458-67.
- SUSIN, C., KINGMAN, A. & ALBANDAR, J. M. 2005. Effect of partial recording protocols on estimates of prevalence of periodontal disease. *J Periodontol*, 76, 262-7.

- TONETTI, M. S. & CLAFFEY, N. 2005. 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*, 32 Suppl 6, 210-3.
- TRAN, D. T., GAY, I., DU, X. L., FU, Y., BEBERMEYER, R. D., NEUMANN, A. S., STRECKFUS, C., CHAN, W. & WALJI, M. F. 2014. Assessment of partial-mouth periodontal examination protocols for periodontitis surveillance. *J Clin Periodontol*, 41, 846-52.
- VETTORE, M. V., LAMARCA GDE, A., LEAO, A. T., SHEIHAM, A. & LEAL MDO, C. 2007. Partial recording protocols for periodontal disease assessment in epidemiological surveys. *Cad Saude Publica*, 23, 33-42.

TABLES

Table 1. Description of protocols and definitions used.

Partial-Mouth Recording Protocols (PMRs)		
Random Half-Mouth [RHM]:	Random selection of opposing oral quadrants	
Community Periodontal Index of Treatment Needs [CPITN]:	Evaluation of tooth numbers 2, 3, 8, 14, 15, 18, 19, 24, 30, 31 only	
Ramfjord Teeth:	Evaluation of tooth numbers 3, 8, 12, 19, 24, 28 only.	
Terminology		
Concordant:	Disease determinations based on FMR and PMR protocols were the same	
Discordant:	Disease determinations based on FMR and PMR protocols were not the same	
Sensitivity:	The probability of identifying true disease using a PMR protocol under the reference standard of FMR determinations. Calculated by taking the number of cases identified with disease under a PMR protocol (numerator) and dividing by the total number of cases identified under the gold standard FMR (denominator)	
Specificity:	The probability of ruling out the presence of disease using a PMR protocol under the reference standard of FMR determinations. Calculated by taking the number of non-cases identified under a PMR protocol (numerator) and dividing by the total number of non-cases identified under the gold standard FMR (denominator)	
2007 CDC - AAP Periodontitis Case Definitions		
Clinical Definition		
Disease Category	Clinical Attachment Loss [CAL]	Pocket Depth [PD]
Severe periodontitis	≥ 2 interproximal sites with CAL ≥ 6 mm (not on same tooth)	and ≥ 1 interproximal site with PD ≥ 5 mm
Moderate periodontitis	≥ 2 interproximal sites with CAL ≥ 4 mm (not on same tooth)	or ≥ 2 interproximal site with PD ≥ 5 mm
No or Mild periodontitis	Neither "moderate" nor "severe" periodontitis	
PMR Severe Periodontitis Adapted Case Definitions:		
	CAL	PD
Definition 1	≥ 1 interproximal site with CAL ≥ 6 mm	and ≥ 1 interproximal site with PD ≥ 5 mm
Definition 2	≥ 1 interproximal site with CAL ≥ 6 mm	

Table 2. Absolute comparisons of clinical measurement sites (mm) by tooth type and disease status.

	N	PD				CAL			
		Mesial – Distal ^a		Buccal – Lingual ^b		Mesial – Distal ^a		Buccal – Lingual ^b	
		Mean	Std Error	Mean	Std Error	Mean	Std Error	Mean	Std Error
Overall	13177	-0.76	0.02	-1.05	0.02	-0.02	0.03	0.29	0.03
Tooth Type									
Anterior	6570	-0.84	0.02	-0.91	0.02	-0.04	0.03	0.16	0.03
Pre-molar	3766	-0.66	0.02	-1.05	0.02	-0.15	0.03	0.58	0.04
Molar	2841	-0.72	0.03	-1.41	0.03	0.20	0.04	0.32	0.04
Disease Status^c									
No/Mild	2314	-0.71	0.03	-1.05	0.03	0.05	0.04	0.59	0.05
Moderate	8725	-0.77	0.02	-1.00	0.02	0.02	0.03	0.36	0.03
Severe	2138	-0.75	0.05	-1.25	0.06	-0.24	0.07	-0.23	0.08

^aDifferences in pocket depth (PD) measurements and clinical attachment loss (CAL) measurements for mesio-buccal and disto-lingual sites, measured in millimeters

^bDifferences in pocket depth (PD) measurements and clinical attachment loss (CAL) measurements for mid-buccal and mid-lingual sites, measured in millimeters

^cDifferences in pocket depth (PD) measurements and clinical attachment loss (CAL) measurements by site according to the 2007 CDC-AAP periodontitis case definitions

Table 3. Comparisons of average severity of clinical measures (mm) and teeth by oral quadrant.

	Upper Teeth				Lower Teeth			
	Right Quadrant		Left Quadrant		Left Quadrant		Right Quadrant	
	Mean	Std Error	Mean	Std Error	Mean	Std Error	Mean	Std Error
PD^a	2.81	0.03	2.88	0.03	2.64	0.03	2.61	0.03
Anterior	2.64	0.02	2.72	0.02	2.48	0.02	2.43	0.02
Premolar	2.82	0.03	2.79	0.03	2.44	0.03	2.55	0.02
Molar	3.05	0.04	3.14	0.04	3.23	0.05	2.98	0.04
CAL^b	2.83	0.05	2.84	0.05	3.33	0.05	3.24	0.05
Anterior	2.20	0.04	2.30	0.04	3.22	0.04	3.38	0.04
Premolar	2.80	0.05	2.58	0.05	2.59	0.05	2.46	0.05
Molar	3.58	0.07	3.67	0.07	3.44	0.05	3.51	0.05
Number of Teeth	4.91	0.09	4.91	0.09	5.43	0.06	5.46	0.06
No. of teeth with CAL ≥6mm ^c	0.29	0.03	0.27	0.03	0.43	0.04	0.37	0.03
No. of teeth with PD ≥5mm ^d	0.24	0.03	0.32	0.03	0.28	0.03	0.23	0.02

^aMean of the maximum interproximal pocket depths (PD) measured on each tooth in the population

^bMean of the maximum interproximal clinical attachment loss (CAL) measured on each tooth in the population

^cNumber of teeth with at least 6mm clinical attachment loss (CAL) at interproximal sites

^dNumber of teeth with at least 5mm pocket depth (PD) at interproximal sites

Table 4. Sensitivity (Se) estimates for identification of severe periodontitis cases according to clinical sites^a measured and teeth evaluated

	Mesial Sites Only		Distal Sites Only		Both Sites	
	Severe Cases ^b	Se ^c	Severe Cases	Se ^c	Severe Cases	Se ^c
Quadrant	(7 sites)		(7 sites)		(14 sites)	
Upper Right (UR)	8	6.9%	16	13.8%	27	23.3%
Upper Left (UL)	10	8.6%	16	13.8%	25	21.6%
Lower Left (LL)	13	11.2%	16	13.8%	27	23.3%
Lower Right(LR)	10	8.6%	21	18.1%	31	26.7%
Half-mouth	(14 sites)		(14 sites)		(28 sites)	
UR/LL ^d	20	17.2%	32	27.6%	67	57.8%
UL/LR ^d	23	19.8%	28	24.1%	56	48.3%
LR/LL ^d	27	23.3%	46	39.7%	64	55.2%
UR/UL ^d	23	19.8%	39	33.6%	62	53.4%
Full-mouth	(28 sites)		(28 sites)		(56 sites)	
	54	46.6%	79	68.1%	116	100.0%

^aSites measured were mesio-buccal and/or disto-lingual sites. Third molars were excluded from observation.

^bSevere cases were determined according to the 2007 CDC-AAP definition for 'severe' periodontitis

^c"Se" refers to Sensitivity

^d"UR" refers to Upper Right; "UL" refers to Upper Left; "LL" refers to Lower Left; "LR" refers to Lower Right

Table 5. Numbers of teeth with specified clinical severity according to concordance of disease determinations from RHM and FMR protocols

	SEVERE ^a		MODERATE ^a		
	Concordant Severe	Discordant	Concordant Severe	Concordant Moderate	Discordant
CAL^b					
≥ 4 mm	12.46	10.66	5.54	8.75	2.73
≥ 5 mm	9.03	6.23	2.38	4.54	0.90
≥ 6 mm	5.70	2.92	0.67	1.85	0.26
≥ 7 mm	3.29	1.38	0.22	0.85	0.08
PD^b					
≥ 4 mm	6.71	3.91	2.02	3.09	2.16
≥ 5 mm	4.10	2.11	0.59	1.35	0.60
≥ 6 mm	2.03	0.83	0.14	0.51	0.14
≥ 7 mm	1.00	0.38	0.03	0.22	0.02

^aStandard 2007 CDC-AAP case definitions were applied to both RHM and FMR protocols

^b"CAL" refers to clinical attachment loss; "PD" refers to pocket depth

Table 6. Comparisons of sensitivity and mean clinical severity across PMR protocols

Variable	PMR Protocols (max no. of teeth)			
	FMR (28)	RHM (14)	CPITN (10)	Ramfjord (6)
Mean No. of Teeth	20.7	10.34	6.16	4.29
Mean CAL	3.16	3.16	3.74	3.18
Mean PD	2.74	2.73	2.95	2.71
No. of teeth with CAL \geq 6mm	1.36	0.65	0.14	0.32
No. of teeth with PD \geq 5mm	1.07	0.53	0.10	0.20
Sensitivity of Severe Classification ^a	100%	54%	53%	16%

Abbreviations: FMR=Full-mouth recording; RHM=Random Half-mouth; CPITN=Community Periodontal Index for Treatment Needs; CAL=Clinical Attachment Loss; PD=Pocket Depth

^aStandard 2007 CDC-AAP case definitions were applied to both FMR and PMR protocols

FIGURE LEGENDS

Figure 1. Classification table for severe disease determinations according to multiple definitions applied to a PMR protocol

^aThree definitions were applied to data obtained using a random half-mouth PMR protocol and compared to determinations made by applying the standard 2007 CDC-AAP definition to data obtained from a FMR protocol: 1) The standard 2007 CDC-AAP definition for severe periodontitis (2 CAL/1 PD), 2) A modified definition for severe requiring one tooth with CAL of at least 6mm and one tooth with PD of at least 5mm, both measured interproximally, 3) A modified definition of severe periodontitis requiring only one site with CAL with at least 6mm, measured interproximally.