INVITED RESPONSE TO SLADE AND BECK PAPER

Periodontal Disease Estimates in NHANES III: Clinical Measurement and Complex Sample Design Issues

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Abstract

Objective: *This paper evaluates the possibility that examiner bias or other factors contributed to an observed decline in pocket depth and gingivitis between the two three-year sequential periods of time (or phases) covered by the Third National Health and Nutrition Examination Survey (NHANES III).* ***Methods:*** *Prevalences of periodontal conditions were analyzed using data from two sets of repeat oral health examinations by examining dentists of NHANES III sample persons. The first set includes sample persons who were examined twice by the same examining dentist at an interval of one to six weeks. The second set includes sample persons who were assessed on the same day by both an examining dentist and a reference dentist. Other possible sources of error also were evaluated.* ***Results:*** *Overall kappa statistics measuring agreement between or within dental examiners were within the range observed for other periodontal disease surveys. While differences were found among dentists in the prevalence of pocket depth of 4 mm or more, for each group of sample persons assessed by a reference examiner–examining dentist pair, the reference examiner's periodontal measurements closely corresponded to measurements made by the examining dentists.* ***Conclusions:*** *Differences between dental examiners in prevalences of periodontal conditions may be due in part to the fact that examinees were not randomly assigned to examiners. As a result, the sample persons examined by each dentist may not have been alike in characteristics thought to affect periodontal disease status. These findings suggest that the observed declines in periodontal health status between phases is not due to examiner bias. This unexplained decline may be the result of sampling variation. It is recommended that combined six-year survey results be presented whenever possible. [J Public Health Dent 1999;59(2):73-78]*

Key Words: periodontal diseases, epidemiology, examiner reliability, survey sampling, NHANES III.

Drs. Slade and Beck have written an excellent paper in this issue on the periodontal disease status of Americans (1). Their work is based on data from the Third National Health and Nutrition Examination Survey (NHANES III). NHANES III was conducted by the National Center for Health Statistics (NCHS) of the Centers for Disease Control and Prevention and was designed to provide estimates of oral health and many other health and nutritional characteristics from a nationally representative sample of the US civilian noninstitutionalized population. The oral health assessments were made by dentists on the health examination team in mobile examination centers that traveled to 89 separate geographic locations. The NHANES III was designed as a six-year survey (1988–94), divided into two phases for data collection. The first three years (1988–91) were denoted "phase 1" and the second three years (1991–94) "phase 2."

The periodontal assessments in NHANES III were made at two surfaces (mesial and mid-buccal) of each tooth in two randomly selected quadrants in the mouth. Slade and Beck observed an apparent large decline in the prevalences of gingival bleeding and pocket depth between the phases. They did not find a large decline in attachment loss prevalence. They note that the occurrence of this magnitude of difference within the time frame covered by the NHANES III is unlikely to reflect true secular trends. The decline appears too rapid and precipitous and there have been no major changes in the extent of preventive oral health practices or treatment for periodontal disease. They conclude that one or both of the phase estimates must be biased and suggest that variation in how dental examiners made their periodontal disease assessments may have contributed to this difference.

To determine the potential for bias in NHANES III estimates of the occurrence of periodontal disease in the US population, we will first outline some potential sources of both sampling and measurement error in oral health surveys in general and the periodontal assessments in NHANES III in particular, and second, address whether these possible sources of error may have influenced the ability of NHANES III to measure the "true" prevalence of periodontal disease in the United States.

Clinical Measurement Issues

Potential sources of error in the measurement of oral health status in sample surveys include intrasubject (within subject) variation and intra- or interexaminer (within or between examiner) variations in measurements. Within-subject variation could occur

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due to changes in the underlying disease process between periodontal examinations resulting from physiological, inflammatory, immunological, diurnal, or other biological factors. Because gingival bleeding and, to some extent, pocket depth reflect inflammation (2), short-term physiologic changes possibly could be responsible for within-subject differences in these parameters at two points in time and large variances for these measurements. However, this physiologic variability could not result in the appearance of a decline in periodontal health status between NHANES III survey phases.

Lack of adherence to the protocol by examiners is a potential source of intra- or interexaminer error that, if present, could have led to an artifactual decline in periodontal disease over the NHANES survey period. Even small changes in procedures, which themselves have only a small impact, when coupled with other small impact changes in the same direction, can cause differences in survey estimates at two points in time. Specific potential sources of variation by dental examiners could include the placement by the examiner of the periodontal probe in the periodontal pocket. Other studies have found that variations in angulation can influence probing depths (3). Although the protocol states that the probe is to be kept parallel to the long axis of the tooth, it is possible that examiners exhibited some variation in how they manipulated the probe. The NHANES III protocol called for examiners to round down to the nearest millimeter their measurements using the color-coded NIDR (National Institute of Dental Research) periodontal probe, which is graduated at 2, 4, 6, 8, 10, and 12 millimeters. Examiners might have varied in how they applied the scoring rules for the periodontal assessments. In addition, some parts of the periodontal pockets may include irregularities, making repeated measurements even at the same tooth site problematic.

The National Center for Health Statistics and the National Institute for Dental and Craniofacial Research employ a number of methods for reducing and assessing measurement error from sources such as those described in the previous paragraph (4,5). First, NCHS produces detailed protocols for the conduct of the entire survey. In addition, specific quality assurance practices were employed in the oral health survey subcomponent. These practices included extensive initial training and periodic retraining of dentists and recorders; visits by a "reference" examiner to each Mobile Examination Center every six months to evaluate the oral health subcomponent and retrain as necessary; a requirement that the dentist be licensed; detailed field procedures, including equipment and supply maintenance and replacement; and second repeat examinations on a subset of survey participants. NCHS maintains a policy of disseminating the questionnaire, examination, and laboratory data in public use form, as well as procedure manuals and other information useful in assessing data quality. As Slade and Beck point out (1), the extensive information available on study participants can make it possible to detect and evaluate measurement error in ways that are often not possible or available for other published studies.

Inter- and intraexaminer differences, if present, could have contributed to the appearance of a decline in periodontal disease over the NHANES III survey period. Differences between and within NHANES III examiners were computed to evaluate this possibility. Estimates of inter- and intraobserver measurement error in NHANES III are similar to those typical for studies in the literature of periodontal disease (6-11); however, detailed examination of NHANES III measurement error estimates may be instructive. Intraobserver measurement error will be discussed first.

In NHANES III, approximately 5 percent of the examined survey sample was recalled for repeat second examinations that were identical to the first. These second examinations took place from one to six weeks after the initial examination. (The data from the repeat examinations from NHANES III currently are not available as public use electronic data sets; however, NCHS plans to make these data available for research purposes.) Intraexaminer reliability can be assessed for each examiner by comparing results of that examiner's initial and repeat second examinations of the same sample persons. At the subject level, the intraobserver differences in mean attachment loss and probing pocket depth values by examiner ranged from 0.25 to 0.55 mm (12), which is considered acceptable.

Data from the sample persons who were examined by both the dental examiner and the reference examiner can provide insights into potential interexaminer differences. The reference examiner is a highly trained dentist with extensive experience in conducting national surveys of oral health status. During his visits to the mobile examination centers, the reference examiner and the dental examiner both examined the same sample persons within the same four-hour period on the same day, providing an opportunity to assess interobserver reliability and to retrain the dental examiner, if necessary. For attachment loss and pocket depth, interexaminer exact kappa statistics (within plus or minus 1 mm) were good (0.25–0.50), as were the weighted kappa statistics (0.55–0.89) (12).

In addition, prevalences of periodontal conditions were calculated based on paired examining dentist and reference dentist examinations for each of the three dentists (referred to as A, B, and C) with the largest numbers of survey examinations using data provided to the National Institute of Dental and Craniofacial Research by the National Center for Health Statistics. Figure 1 shows that the prevalence of 4 mm of pocket depth is different for the three groups of sample persons assessed by the reference examiner/dental examiner pairs. The prevalence of at least one tooth site with 4 mm or more is nearly 50 percent based on the examinees evaluated by the reference examiner and examiner B, but about 30 percent for the examinees assessed by the reference examiner and examiner A or examiner C.

This variation by examiner would be suspicious if subjects had been randomly assigned to examiners. However, this was not the case. Two mobile examination centers were in operation at any one time, each containing one dental examiner among other staff. During NHANES III, one of the examining dentists worked for all six years of the survey, while five other dentists substituted for her on rare occasions or held the second examiner position for different durations over the years of the survey. Because the employment periods were unrelated to survey sampling considerations, it is not surprising that there are differences in estimates by examiner. It cannot be as-

FIGURE 1
Prevalence of Pocket Depth for Dental Examiners and Reference Examiner, 1988–94

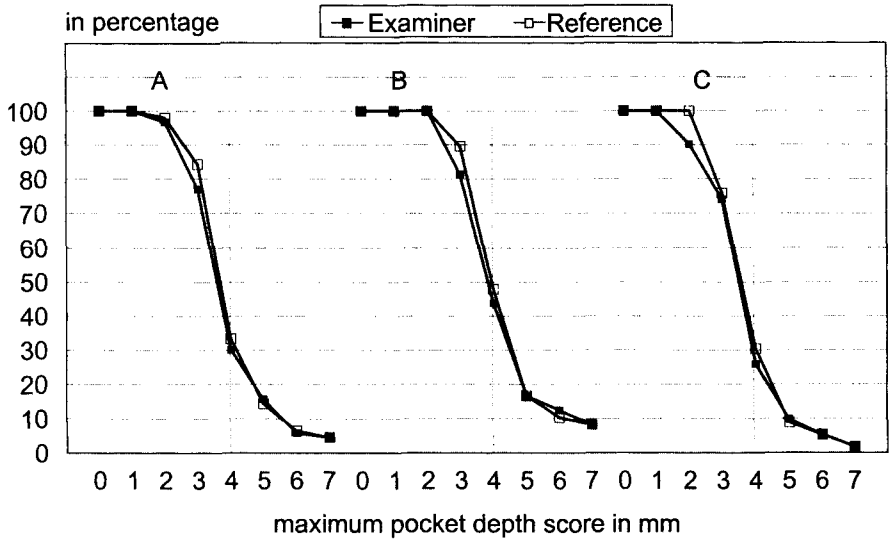
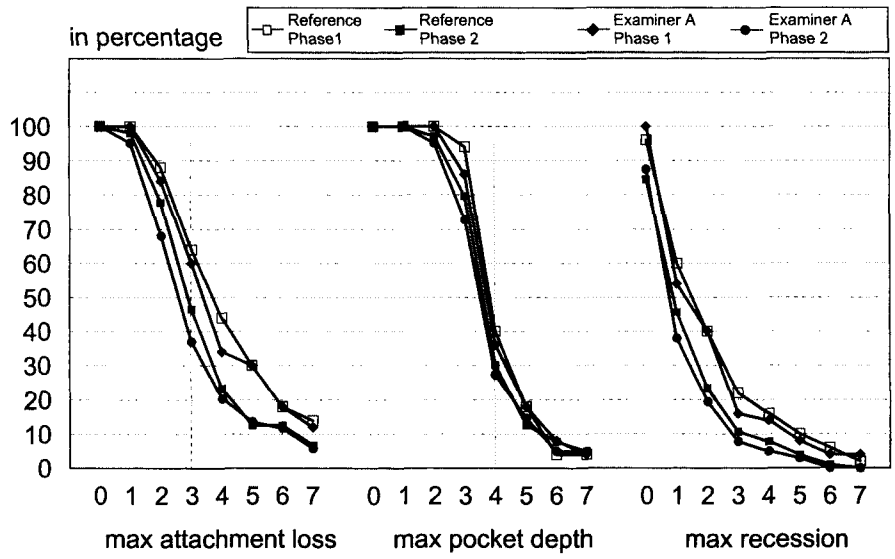


FIGURE 2
Prevalence of Periodontal Measures by Phase of Survey: Examiner A vs Reference Examiner, 1988–94



sumed that the group of sample persons examined by each NHANES III dental examiner would have similar periodontal, demographic, and other characteristics.

In Figure 1 the nearly identical prevalences of at least one tooth surface with 1 mm to 7 mm of pocket depth for each reference examiner/dental examiner pair show a close correspondence between the examiners' calls and the reference examiner's calls for each of the three examiners.

Examiner A conducted exams for the entire six years and was the only examiner with substantial numbers of pairs of examinations with the reference examiner in each of the two phases. Prevalences estimated from examiner A's examinations and the reference examiner's examinations on the same persons are shown by survey phase in Figure 2. Each examiner's prevalences for attachment loss, pocket depth, and recession are clearly lower in phase 2 than in phase 1. In addition, the reference examiner's scores were slightly higher than examiner A's scores in both of the phases. However, there was a close correspondence in both phase 1 and phase 2 between examiner A and the reference examiner at each millimeter level and for each of the three indicators of periodontal conditions: attachment loss, pocket depth, and recession. Thus, examiner A, who conducted 54 percent of the examinations over the six-year period, found prevalences of loss of attachment, pocket depth, and recession very similar to that found by the reference examiner.

The close correspondence of prevalences for each reference examiner/dental examiner pair suggests that interexaminer reliability was high during NHANES III and that the observed decline in prevalences of periodontal conditions is probably not due to examiner biases over time. Of course, it is possible that the close correspondence between the reference examiner and the dental examiners occurred because they all experienced identical drifts over time in the way they applied the protocol. However, this is extremely unlikely. Thus, examiner performance is not the major contributor to the difference over time in periodontal estimates.

Survey Sampling Issues

NHANES has been conducted periodically by the National Center for Health Statistics (NCHS) of the Centers for Disease Control and Prevention (CDC). NHANES III (1988–94) was the seventh in a series of these surveys based on a complex multistage sample design. The survey was designed to provide national estimates of health and nutritional status. Details of the survey design and questionnaires are available (4).

Sample surveys use a systematic sampling of people to estimate the prevalence or extent of a characteristic of the population in lieu of studying an entire population. Sample persons for NHANES III were selected through a multistage, probability cluster sampling process of primary sampling units composed of counties in the first stage, followed by sampling of clusters of housing units (called "segments"), sampling of households, and finally sampling of persons within households. Some population groups

are oversampled so that more precise estimates of their health characteristics can be obtained. This sampling strategy (4), coupled with the appropriate statistical analysis, is considered to provide health findings representative of the civilian, noninstitutionalized US population. Changes in survey design and the probabilities of selection were minimal over the course of the survey.

Because the entire population is not sampled in a sample survey, sample survey estimates will be affected by undercoverage of some subpopulations, by nonresponse, by deliberate exclusions from survey subcomponents, and by the inherent sampling error always present in sample surveys. The NHANES surveys have very good response rates—78 percent to the examination for NHANES III, for example—and the response rates were similar for the two phases (4). Persons were excluded from the periodontal portion of the examination if they had one of several conditions for which the periodontal probing could constitute a health hazard. Over the course of the survey, 7.7 percent (8.9% in phase 1 and 6.5% in phase 2) of persons aged 13 years and older who were eligible for the periodontal assessment were excluded for medical reasons. Because the rules for medical exclusion remained the same throughout the survey and the between-survey phase difference in the proportion of persons excluded from the examination was small, it seems unlikely that medical exclusions could account for the differences in periodontal estimates by phase of the survey.

To help researchers understand the complex nature of the NHANES III sample design and the most appropriate procedures to use to analyze the survey data, NCHS provided a set of "Analytic and Reporting Guidelines" with the public release data files (4). Slade and Beck (1) refer to the "Analytic and Reporting Guidelines" in their discussion and in particular to what they described as potentially contrasting statements within the guidelines. Parts of these guidelines refer to analytic issues that arise when researchers compare results from "phase 1" and "phase 2" of NHANES III. As stated in the analytic guidelines,

> ... unbiased national estimates of health and nutrition characteristics can be independently produced for each phase as well as for both phases combined. Computation of national estimates from both phases combined (i.e., the total NHANES III) is the preferred option; individual phase estimates may be highly variable. In addition, individual phase estimates are not statistically independent. It is also difficult to evaluate whether differences in individual phase estimates are real or due to methodological differences. That is, differences may be due to changes in sampling methods or data collection methodology over time.

To understand the basis for these statements, key aspects of the sample design for NHANES III will be reviewed. Sample design typically involves a series of trade-offs among various design options to meet multiple analytic objectives. The primary goal of the NHANES was to provide national estimates with an adequate degree of precision—that is, an acceptably small sampling error. For many of the desired estimates, especially for specific subpopulations, sample size considerations require the full six years of the study. The final sample design was established to minimize the sampling error for the six-year estimates, not to make comparisons across phases.

However, an accommodation was made so that some analysis could be done with the first three years of data. For the NHANES, the country was divided into primary sampling units (PSUs), and these PSUs were grouped into strata. The full six-year survey used a sample design that selected two PSUs per stratum. It was recognized that a national design could have been constructed by sampling one PSU per stratum. Therefore, one of the two PSUs in each stratum was randomly assigned to phase 1, and the remaining PSU was assigned to phase 2, yielding 44 survey locations in the first phase and 45 in the second phase. This approach created a phase 1 sample that was a nationally representative sample. With this selection, phase 2 also became a nationally representative sample. However, this particular sample design feature was never intended to produce estimates in order to test possible differences between phase 1 and phase 2.

Several statistical issues are raised when trying to compare phase 1 and phase 2 estimates because the survey was NOT designed to test these differences. If comparisons are made, a very conservative test would be advisable. Clearly, each phase estimate is based on only one-half the full sample, so one would expect the relative sampling errors to be larger than those based on the full sample. One statistical issue is how to estimate the larger sampling errors for each phase. A one-PSU-per-stratum design does not easily allow for the usual sampling error approximations, such as balanced repeated replication or linearization (13). To get a variance estimate for phase 1, the stratum must be combined to simulate a two-PSU-per-stratum design. This approach typically introduces a between-PSU component of variation that really did not exist in the actual design and, therefore, increases the sampling error. The number of collapsed strata is smaller, so the estimate of sampling error is based on fewer degrees of freedom, as well. In addition, because of the original six-year design, phase 1 and phase 2 estimates are not statistically independent. Recognition of the imprecise estimate of sampling variability for each phase estimate and the unknown correlation structure between phase 1 and phase 2 resulted in the statement that was inserted into the analytic guidelines that reads "at this time, there is no valid statistical test for examining differences...."

Are the Periodontal Findings Unique?

It is important to explore whether substantial differences between phases occurred for other health assessments, as this knowledge could help identify basic survey biases, if they exist, that would affect multiple health components. Few published analyses from the survey compare findings by phase, as the analytic guidelines produced by NCHS discourage this. However, two recent papers describe differences in estimates by phase. One of the papers described a decline of 22 percent in the geometric mean and 48 percent in the prevalence of elevated blood lead levels between phase 1 and phase 2 of NHANES III (14). It has been suggested that these differences represent "true" changes

over time due to results of regulatory and voluntary bans of lead in products (15). The general direction and magnitude of the trend also had been clearly evident in previous National Health and Nutrition Examination Surveys (16).

On the other hand, analyses of some other NHANES III components have shown similar results to those found by Slade and Beck (1). That is, there are differences between results from phase 1 and phase 2 of the survey in the absence of major trends in the determinants of those health characteristics (e.g., major changes in habits or major public health interventions), although not to the extent observed for periodontal disease. For these health assessments, it is difficult to determine whether the changes are true time trends, sampling variation, or due to methodologic issues.

Femur bone mineral levels (bone density, mineral content, and bone area) among adults were assessed for the first time in a national survey in NHANES III (17). As part of an overall assessment of data quality, the authors evaluated multiple indicators of potential differences between phases in bone mineral levels including percentage differences in the means, standard deviations, and interquartile ranges (difference between the 75th and 25th percentile estimates). They found that, among white women, the standard deviations were larger in phase 2 than phase 1, and the interquartile ranges were all larger. To address whether this difference was likely to be systematic or likely to reflect random sampling variation, they looked for differences in estimates by phase for four other health characteristics: hemoglobin, serum cholesterol, body weight, and height. Body weight and height measurements did have higher standard deviations in phase 2. Because they noted that the average height of Americans has been stable for decades, this difference seems likely due to sampling variation. They also were able to rule out an impact of sampling fraction changes between phases that were made to accommodate changes in population composition over the two phases. The authors concluded that these differences in estimates were not sufficient to suggest major secular trends or sampling differences between phases; they recommended making health estimates using the full six-year survey data.

The consistency of findings from contemporaneous surveys using different designs or the existence of data on trends up to the time of the current survey sometimes can help in evaluating the significance of trends in health characteristics. For example, tobacco use estimates from NHANES III can be compared with other contemporaneous surveys such as the National Health Interview Surveys conducted during those years. The only national survey of periodontal health using comparable clinical methods was the NIDR Survey of Employed Adults conducted in 1985–86 (18). However, the sampling frame was sufficiently different and the time between that survey and phase 1 of NHANES III was so short that it would be difficult to use changes between those two survey periods to help interpret the drop in periodontal estimates between phase 1 and 2 of NHANES III.

The periodontal findings may be unique due to features of the index used to measure prevalence that make the index unusually sensitive to examiner variation in procedures. Prevalence estimates are based on making a large number of tooth surface-specific measurements. A single surface with a measurement that meets the prevalence criteria counts that person as a prevalent case. A subject in NHANES III is considered to be a prevalent "case" of periodontal disease if at least one site, out of the 28 possible sites, has a periodontal pocket depth of a specified number of millimeters or more. As shown in Figures 1 and 2, the slopes for pocket depth prevalences between 3 mm and 4 mm—depths considered of clinical relevance—are quite steep. These features of the periodontal assessments suggest that subtle variations in measurement by an examiner across tooth sites or between examiners could impact prevalence estimates significantly.

In summary, it may not be possible to determine definitively whether there is any bias in the measurement of pocket depth or loss of attachment in the population or whether a decline in periodontal disease actually occurred. The "truth" may remain elusive. It appears that differences among examiners is not the major factor in the differences observed between the two phases of NHANES III. In addition, changes in survey design and probabilities of selection were minimal over the course of the survey. Ruling out these potential sources of bias leaves sampling variation as possibly the primary explanation for the observed findings. Sampling variation is explained as "Since the inclusion of individuals in a sample is determined by chance, the results of analysis of two or more samples will differ, purely by chance" (19). Comparisons that are statistically significant may, 5 percent of the time, be due to sampling variation. Sampling variation can result by chance in wide differences between estimates that are each unbiased. Statistical comparisons between phase 1 and phase 2 of NHANES III are complicated by the inability to calculate precise standard errors. However, even if making these comparisons were not a problem, it is possible that sampling variability alone could result in the seemingly large observed differences between the two phases of NHANES III.

It is not ideal to conduct a six-year cross-sectional survey, which is why NHANES has modified the sampling to be a continuous survey with an annual national probability sampling design. Yet, these issues concerning differences in results by survey years could loom even larger in a continuous survey. NCHS has embarked on a research program to address these questions.

Some Recommendations

The National Institute for Dental and Craniofacial Research and the National Center for Health Statistics recommend the following approaches to the analysis of NHANES III oral health data:

1. Use both data phases to create combined point estimates. The sample was designed to provide estimates from the combined data. NIDCR published provisional findings on most of the oral health indices from the first phase of NHANES III in a supplement to the *Journal of Dental Research* in 1996. These were provisional in that all of the necessary cross-checks with the main survey were not yet available at that time, nor were any of the phase 2 data. However, it was necessary to publish findings at that time to meet NIDCR commitments regarding data to support policy and program evaluation. Now that all of the data from both phases are available in final form,

there is no need to rely solely on one of the phases.

2. Recognize that multiple sources of measurement and sampling variation will exist in any sample survey and use the maximum amount of data available to evaluate the likelihood or extent of such measurement problems. Publish those evaluations whenever possible, as this will assist interpretation of the data and perhaps identify future improvements in survey measurement.

3. Access the extensive documentation available from NCHS about the NHANES III survey (4,5) and monitor the literature for NHANES III findings. Some analytic approaches used in other substantive areas may provide valuable insights into analysis and interpretation of oral health data.

Pocket depth is the measure for which Slade and Beck(1) found the greatest NHANES III phase differences. Pockets of 3 mm or more may be reflective of inflammation rather than chronic periodontal disease and, therefore, may be more variable over time. Attachment level may be the more meaningful measure of periodontal destruction. However, as Slade and Beck (1) point out, pocket depth remains the recommended measurement in clinical practice according to the American Academy of Periodontology (20). To provide a translation among the national survey findings, research studies, and clinical practice, it is important to provide findings of both pocket depth and periodontal loss of attachment in publications.

Efforts should be made to develop improved indices to accurately assess active periodontal disease or to define its consequences (e.g., bone loss) in ways that reflect the most current thinking about the etiology and biology of the disease and about the assessment of its impact (21-23). If these advancements can be accomplished using methods less susceptible to measurement error or more amenable to assessment of error, it will help considerably in understanding the determinants and burden of disease in populations.

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