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# Using Dental Register Information and Questionnaire Data to Assess Periodontitis in Large Cohort Studies

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**Keywords:** Dental Health Register | epidemiology | periodontitis | self-reported | Swedish Quality Register for Caries and Periodontal Disease

## ABSTRACT

**Aim:** Periodontitis proxy variables enable an expansion of periodontal research. The study aimed to estimate the validity of questionnaire items and registry data in relation to Stage III–IV periodontitis and having 50% bone loss.

**Methods:** Malmö Offspring Dental Study (MODS) participants (995) filled out questionnaires and underwent periodontal and panoramic radiography examinations. The questionnaire items, number of periodontal treatment procedures (PTP) in the Dental Health Register (DHR), and number of teeth with ≥6 mm probing depth in the Swedish Quality Register for Caries and Periodontal Disease (SKaPa) were evaluated as proxies for severe periodontitis. Stage III–IV periodontitis was the primary reference standard.

**Results:** For PTP-based severe periodontitis proxy in DHR, positive predictive value (PPV) was 88% and negative predictive value (NPV) 87% for Stage III–IV. The SKaPa-based proxy showed poor positive predictive values (PPVs, < 70%), but similar area under the curve (AUC), 0.74, compared with the DHR data (AUC 0.76). Sensitivity was < 70%, and specificity > 90% for the DHR and SKaPa proxies. Identification of cases with periodontitis by questionnaire combined with the demographic variables age, sex, smoking habits and education yielded good discriminatory ability (AUC > 0.75).

**Conclusion:** Register-based data can effectively identify individuals with severe periodontitis in large cohort studies, thereby advancing periodontal research.

[Correction made on 08 September 2025, after first online publication: Table 2 has been updated in this version.]

## 1 | Introduction

Periodontitis is a common disease, with moderate periodontitis reportedly affecting about 30% and severe periodontitis about 6%–10% of adults, depending on the cohort age (Eke et al. 2012; Kocher et al. 2023; Papapanou 2012). Large-scale epidemiologic studies of periodontitis are essential for high-quality investigations of its genetic foundations and connections to systemic diseases.

Sweden has extensive medical registers available for epidemiological research. The National Board of Health and Welfare manages several registers, including the Dental Health Register (DHR). Quality health registers are also available, one of which is the Swedish Quality Register for Caries and Periodontal Disease (SKaPa). The caries and periodontal data in SKaPa have been validated in children (Mensah et al. 2021), and our group recently validated the caries data in adults, using the Malmö Offspring Dental Study (MODS) cohort (Haworth et al. 2024). Although these registers are Swedish, they can serve as models for other countries, promoting global advancement in the field.

To enable comprehensive and reliable population-level periodontal research, the aim of the study was to evaluate whether procedure-based data—including history of periodontitis surgery and tooth extractions from the DHR, periodontal probing depth (PPD) data from SKaPa (≥ 6 mm) and questionnaire-based periodontitis—can be used as proxies for clinical assessments of severe periodontitis. The primary reference standard is the Application of the 2018 periodontal status Classification to Epidemiological Survey data (ACES) (Holtfreter et al. 2024), and the secondary is bone loss assessment.

## 2 | Materials and Methods

### 2.1 | MODS—Study Design and Population

For this validation study we compared three proxy variables (DHR—periodontal treatment procedures, SKaPa—teeth with PPD ≥ 6 mm and MODS—questionnaire items) to assess periodontitis with two reference standards (primary: ACES Stage III–IV; and secondary: having 50% bone loss on panoramic radiographs). We used data from the population-based MODS cohort, linking the DHR and SKaPa registers via the Swedish 12-digit Personal Identity Number (PIN). MODS participants were recruited from 2013 to 2020. Upon MODS finalization, register data were collected from 2008 to 2020.

MODS is the dental arm of the Malmö Offspring Study (MOS), which includes adult children and grandchildren of participants in the cardiovascular arm of the Malmö Diet and Cancer Study (Brunkwall et al. 2021). The rationale for the present validation study was to estimate periodontitis status within the remaining MOS cohort, which was not included in MODS.

MOS participants were informed about MODS and recruited primarily by phone and sometimes via postal mail. MODS participants underwent full-mouth periodontal exams, bitewings and panoramic radiographs. At the end of MODS, 176 participants were recruited for only panoramic radiographic examination. All participants that had a panoramic radiograph taken with or without additional clinical examination are referred to as the MODS panoramic radiograph cohort (Figure 1). The Ethics Review Board of Lund University approved MOS (Dnr. 2012/594) and MODS (Dnr. 2013/761).

### 2.2 | MODS—Health Questionnaire and Clinical Examination

Participants visiting MODS were initiated with the completion of one questionnaire on dental health and a comprehensive questionnaire that included questions on smoking habits (never, former, occasional or daily smoker) and education—(i) up to 9 years or completed 9 years of compulsory education, (ii) completed 12 years education corresponding to high school or gymnasium or (iii) completed university or university college education.

Periodontal exams were performed using a 1-mm graded probe (Hu-Friedy PCPUNC157) to record PPD > 2 mm at six sites per tooth, categorical clinical attachment loss (CAL) and bleeding upon probing. Inter-examiner agreement among five dentists was set at ≥ 90% of measurements agreeing within ±1 mm of PPD. The two-way mixed intraclass correlation coefficient with absolute agreement for inter-examiner PPD was 0.79 between the PI and three observers, and 0.75 between the PI and one observer. The actual percentage of agreement (±1 mm) was 90% between the PI and three observers, and 88% between the PI and one observer. Due to the extensive timespan of the study, not all examiners were available through the entirety of the study.

### 2.3 | MODS—Radiographic Examination

Panoramic radiograph examinations were performed using Morita 3De-CP and Morita Veraviewepocs 3D F40 machines to assess alveolar bone height, furcation involvement, vertical defects and missing teeth. All assessments were conducted by two calibrated observers. If overlapping teeth made surfaces uninterpretable on panoramic radiographs, complementary intraoral radiographs were used. Among 1170 panoramic radiographs, 118 required complementary intraoral radiographs for accurate periodontitis classification; however, bone loss classification changed after assessing intraoral radiographs in only 3 cases.

For each approximal tooth surface, the bone loss percentage was estimated using the ratio of the distances from the alveolar bone crest to the root apex and from the cementoenamel junction to the root apex. Interobserver agreement had an unweighted kappa of 0.78 (95% confidence interval [CI] 0.77–0.79).

Bone loss was stratified into four categories based on the level (15%, 33%, 50% or 66%) at ≥ 2 non-adjacent approximal teeth, excluding third molars and distal sites of second molars. The 15% and 33% cut-offs were chosen based on the 2018 classification (Holtfreter et al. 2024; Papapanou et al. 2018); 50% was

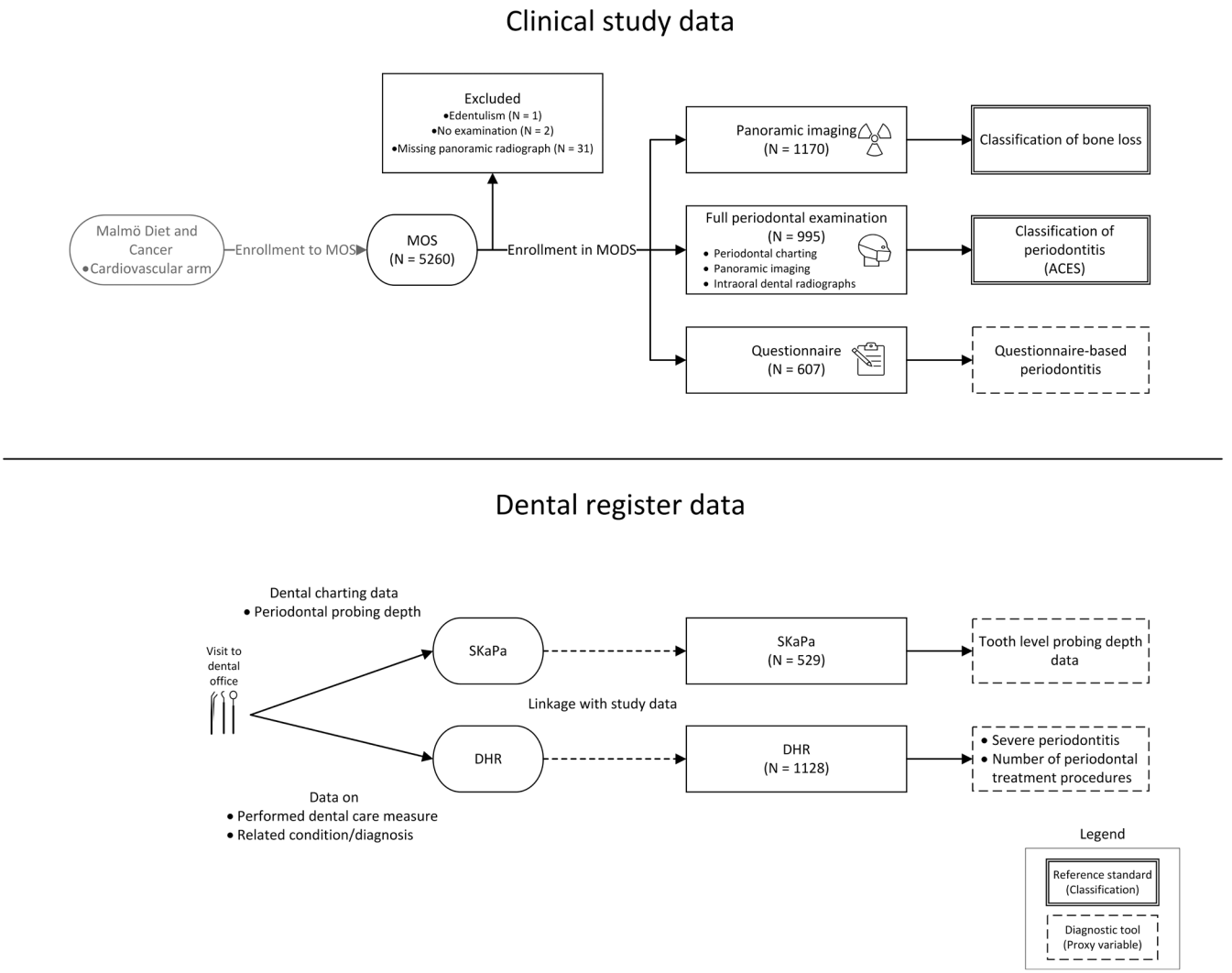


**FIGURE 1** | Study design flowchart of clinical, questionnaire and register data. Boxes with double-line frames represent reference standards, and boxes with dashed lines indicate proxy variables. ACES, Application of the 2018 periodontal status Classification to Epidemiological Survey data; DHR, Dental Health Register; MODS, Malmö Offspring Dental Study; MOS, Malmö Offspring Study; SKaPa, Swedish Quality Register for Caries and Periodontal Disease.

added due to the great leap in prevalence between 33% and 66% and has been mentioned in the literature (McGuire and Nunn 1996); and 66% was included based on the Jönköping studies (Hugoson et al. 2008). Having 50% bone loss was selected as a cut-off to identify cases of severe periodontitis corresponding to advanced periodontitis that may or may not meet the criteria for Stage IV.

## 2.4 | MODS—Periodontitis Classification

Following the ACES framework (Holtfreter et al. 2024), the cases were classified as Stage II if 15%–32% bone loss was measured on panoramic radiograph. Participants who met the bone loss requirements for Stage II and also had two teeth with PPD ≥ 6 mm (excluding third molars and distal sites of second molars), vertical bone loss of ≥ 3 mm or obvious furcation involvement on radiograph were upgraded to Stage III. Participants were also classified as Stage III if showing radiographic bone loss of > 33%. Stage III cases with ≥ 5 tooth gaps (excluding 3rd molars) were classified as Stage IV. Stage III–IV was used to identify severe periodontitis.

## 2.5 | Severe Periodontitis Variables From Dental Registers and Questionnaire

### 2.5.1 | Dental Health Register

The DHR is based on the Swedish dental care subsidy and records all dental procedures submitted to the social insurance agency by dental practitioners. Each procedure is registered with a condition code; for example, 3043 for periodontitis and 4011 for secondary caries. DHR data were collected in 2008–2020 from individuals over 23 years old, as at the time of this study Swedish citizens received free dental care until turning 24. Figure S1 and Table S1 present procedural codes that can be combined with the periodontitis condition code.

From the DHR, we extracted the sum of all periodontitis-related treatment procedures (PTPs) (condition 3043). A PTP-based proxy for identifying severe periodontitis was defined by having ≥1 periodontitis-related dental surgical procedures, including extractions (codes starting with '4') plus ≥2 extensive or very extensive non-surgical periodontal treatments (codes 342 or 343) within the same interval.

### 2.5.2 | Swedish Quality Register for Caries and Periodontal Disease

SKaPa is based on digital dental charts, primarily from public dental clinics in Sweden. It also collects data from citizens <23 years old, who are not included in DHR, resulting in higher coverage for children. Each tooth is classified based on the deepest PPD: ≤3, 4, 5 and ≥6 mm. We retrieved data from 3 years before MODS examination. The chart showing the greatest number of PPD recordings during this period was used for analysis, treating the 3 years as a single time-point. This approach excluded partial entries mistakenly recorded as full entries by SKaPa. The collected data were based on charts allowing registration of 4 or 6 sites per tooth. The number of teeth with PPD ≥6 mm was counted. Severe periodontitis was defined as having at least two teeth with PPD ≥6 mm (Trullenque-Eriksson et al. 2023). MODS examinations were not recorded in SKaPa or DHR.

### 2.5.3 | MODS Questionnaire

MODS participants were asked to complete the questionnaire for self-reported dental health in the waiting room before their visit. The questionnaire was added to the MODS protocol in 2017 and was then completed by all consecutive participants. The questions were a modified version of a previous publication (Buhlin et al. 2002) and were formulated as follows:

- Do you usually have tartar on your teeth? *Yes/No/Don't know*
- Are your gums sore or do they bleed? *Yes/Only when I brush my teeth/No/Don't know*
- Has anyone told you that you have deep periodontal pockets? *Yes/No/Don't know*
- Do your teeth feel loose? *Yes/A bit/No/Don't know*

All four questionnaire items are included in the questionnaire-based analysis.

The answers to the questionnaire items were dichotomized, and the response 'don't know' was treated as missing. Logistic regression models were then used to estimate the predicted probabilities of having periodontitis according to the respective reference standard derived from clinical examinations in MODS. The dichotomized questionnaire items were used as the independent variables. Receiver operating characteristic (ROC) curves were then constructed from the predicted probabilities. In a subsequent step, the model was expanded to include the variables of age, sex, education and smoking status.

To select an optimal classification cut-off, we identified the threshold that minimized the absolute difference between sensitivity and specificity.

**TABLE 1** | Malmö Offspring Dental Study (MODS) characteristics and periodontitis classification.

| Characteristic | Main MODS cohort ($N=995$) | MODS PR cohort ($N=1170$) |
|---|---|---|
| Age (years) | 45.3 ± 14.1 | 45.7 ± 14.1 |
| Sex (female) | 488 (49.0%) | 573 (49.0%) |
| Education attainment | | |
| Compulsory education | 59 (5.9%) | 67 (5.7%) |
| High school/ Gymnasium | 559 (56.2%) | 662 (56.8%) |
| University/ University college | 377 (37.9%) | 437 (37.5%) |
| Unknown | | 4 |
| Smoking status | | |
| Daily | 71 (7.1%) | 80 (6.9%) |
| Occasional | 72 (7.2%) | 85 (7.3%) |
| Former | 286 (28.7%) | 344 (29.5%) |
| Never | 566 (56.9%) | 657 (56.3%) |
| Unknown | | 4 |
| Available data in DHR | 962 (96.7%) | 1128 (96.4%) |
| Available data in SKaPa | 452 (45.4%) | 529 (45.2%) |
| Periodontitis (ACES) | | |
| Healthy/Stage I | 616 (61.9%) | |
| Stage II | 228 (22.9%) | |
| Stage III | 143 (14.4%) | |
| Stage IV | 8 (0.8%) | |
| Answered questionnaire | 607 (61.0%) | |
| Bone loss classification | | |
| <15% bone loss | | 764 (65.3%) |
| 15%–32% bone loss | | 257 (22.0%) |
| 33%–49% bone loss | | 112 (9.6%) |
| 50%–65% bone loss | | 29 (2.5%) |
| ≥66% bone loss | | 8 (0.7%) |

*Note:* Bone loss variables were based on at least 2 non-adjacent teeth, excluding assessment of distal surfaces on second molars. Categorical data are presented as *N* (%), and continuous data as mean ± standard deviation.
Abbreviations: ACES, Application of the 2018 periodontal status Classification to Epidemiological Survey data; DHR, Dental Health Register; PR, panoramic radiograph; SD, standard deviation; SKaPa, Swedish Quality Register for Caries and Periodontal Disease.

## 2.6 | Statistics

Non-normally distributed data were compared using the Mann–Whitney *U* test, and frequencies were compared using the chi-squared test. Interobserver agreement for radiographic assessments was evaluated using Cohen's kappa for categorical assessments. To compare register and questionnaire variables to reference standards, we determined the positive predictive value (PPV) and negative predictive value (NPV) (probabilities that individuals with or without a positive test result have or do not have the condition, respectively), sensitivity and specificity (ability of a test to correctly identify those with or without the condition, respectively) and ROC. Area under the curve (AUC) was interpreted as indicating acceptable (≥0.70), good (≥0.75) or excellent (≥0.90) performance (de Hond et al. 2022). We performed variance inflation factor analysis of the models that generated ROC curves; they revealed no evidence of multicollinearity between each question in the questionnaire, with values in the range of 1–1.10.

ROC curves were generated, and bootstrapping with 1000 repetitions was performed to obtain CIs for the AUC. DeLong's test was used to compare ROC curves. Analyses were performed using IBM SPSS Statistics 28 (SPSS Inc., Chicago, IL, USA) and R-4.4.0 (R Core Team 2021). There was no imputation of missing data.

## 3 | Results

Among the 1029 individuals in the full MODS protocol, 995 had both a clinical periodontal examination and a panoramic

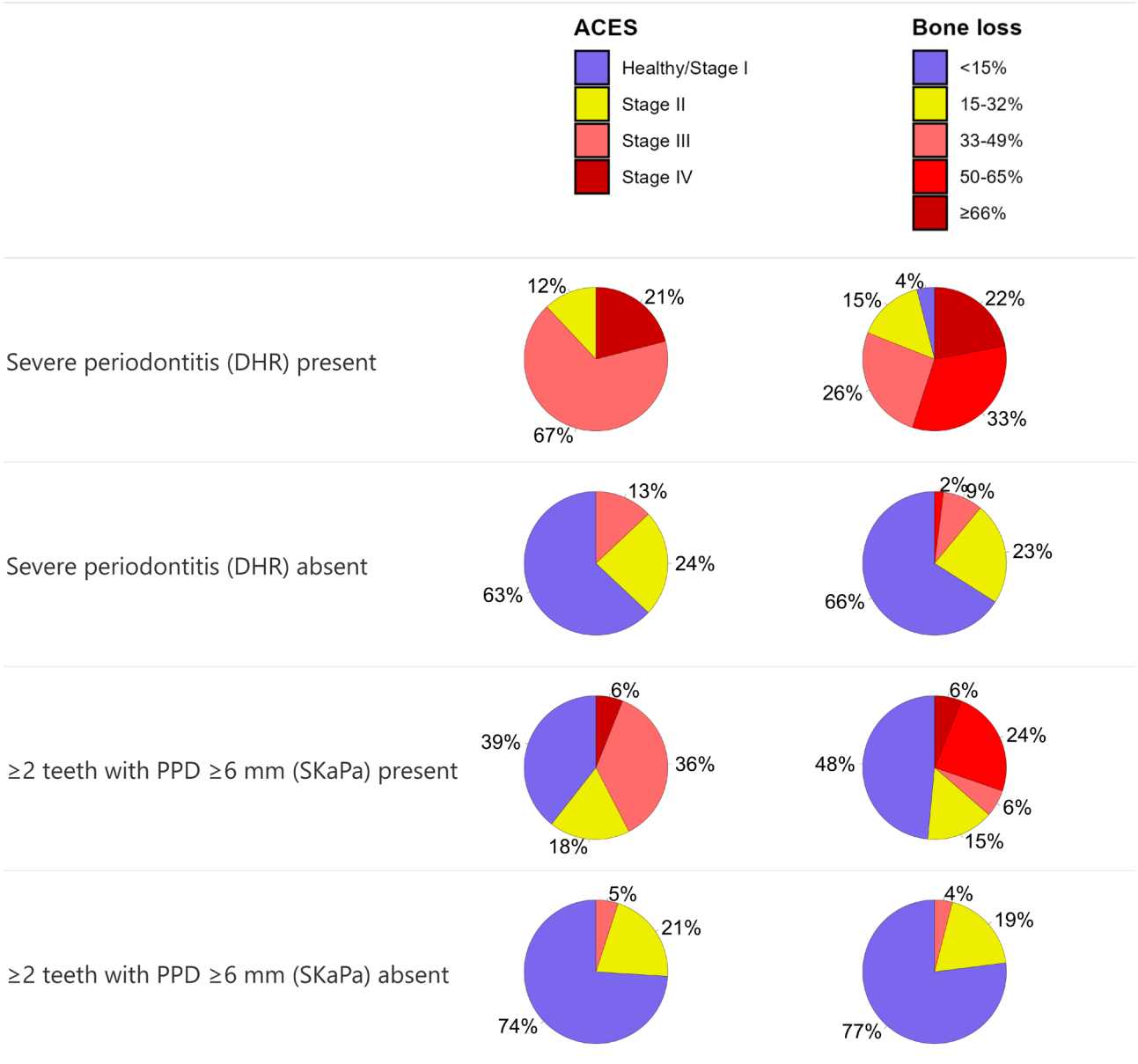


**FIGURE 2** | The distribution of periodontitis stages (ACES) and degree of alveolar bone loss among subjects with (top row) and without (second row) PTP-based severe periodontitis, and subjects with (third row) or without (bottom row) ≥2 teeth with ≥6 mm periodontal probing depth (PPD) in the SKaPa register. ACES, Application of the 2018 periodontal status Classification to Epidemiological Survey data; DHR, Dental Health Register; PTP, periodontal treatment procedure; SKaPa, Swedish Quality Register for Caries and Periodontal Disease.

**TABLE 2** | (A) Positive predictive values (PPV), negative predictive value (NPV), sensitivity and specificity of the PTP-based proxy for detecting severe periodontitis in the DHR and ≥2 teeth with PPD ≥6 mm in the SKaPa, for the weighted questionnaire with and without demographic variables (age, sex, smoking and education); (B) ROC curve analysis with AUC and 95% confidence interval (CI), evaluating the diagnostic ability of the number of periodontal treatment procedures in DHR, the number of teeth with PPD ≥6 mm in SKaPa and the weighted questionnaire crude and with demographic variables (age, sex, smoking and education) in relation to periodontitis reference standards (Stage III–IV periodontitis [ACES] and having 50% bone loss).

**2A**

| Reference standard | Variable | PPV | NPV | Sensitivity | Specificity | *N* |
|---|---|---|---|---|---|---|
| Primary<br>Stage III–IV (ACES) | Severe periodontitis (DHR) | 87.5 | 86.8 | 14.5 | 99.6 | 962 |
| | ≥2 teeth with PPD ≥6 mm (SKaPa) | 42.4 | 95.5 | 42.4 | 95.5 | 452 |
| | Questionnaire items (crude) | 26.1 | 88.9 | 56.3 | 68.6 | 529 |
| | Questionnaire items (added variables) | 33.7 | 93.0 | 72.4 | 71.9 | 529 |
| Secondary<br>Having 50% bone loss | Severe periodontitis (DHR) | 55.6 | 98.1 | 41.7 | 98.9 | 1128 |
| | ≥2 teeth with PPD ≥6 mm (SKaPa) | 30.8 | 99.8 | 92.3 | 94.8 | 529 |
| | Questionnaire items (crude) | 5.4 | 98.8 | 71.4 | 65.8 | 529 |
| | Questionnaire items (added variables) | 9.6 | 99.3 | 78.6 | 79.8 | 529 |

**2B**

| Reference standard | Variable | AUC (95% CI) | *N* |
|---|---|---|---|
| Primary<br>Stage III–IV (ACES) | Periodontal treatment procedures (DHR) | 0.76 (0.72–0.81) | 962 |
| | Number of teeth with PPD ≥6 mm (SKaPa) | 0.74 (0.64–0.83) | 452 |
| | Questionnaire items (crude) | 0.68 (0.62–0.74) | 529 |
| | Questionnaire items (added variables) | 0.80 (0.75–0.85) | 529 |
| Secondary<br>Having 50% bone loss | Periodontal treatment procedures (DHR) | 0.90 (0.84–0.96) | 1128 |
| | Number of teeth with PPD ≥6 mm (SKaPa) | 0.98 (0.97–1.00) | 529 |
| | Questionnaire items (crude) | 0.75 (0.58–0.90) | 529 |
| | Questionnaire items (added variables) | 0.90 (0.80–0.97) | 529 |

*Note:* All 4 questions are included in the weighted questionnaire model. Added variables are age, sex, education and smoking. Reference standards are Stage III–IV and having 50% bone loss.
Abbreviations: ACES, Application of the 2018 periodontal status Classification to Epidemiological Survey data; AUC, area under the curve; DHR, Dental Health Register; NPV, negative predictive value; PPD, periodontal probing depth; PPV, positive predictive value; ROC, receiver operating characteristic; SKaPa, Swedish Quality Register for Caries and Periodontal Disease.

radiograph and were thus eligible for periodontitis classification. Panoramic radiographs were obtained for 1171 participants, of whom 1170 underwent bone level assessment (one participant was edentulous).

Table 1 presents the cohort characteristics. In the main MODS cohort, the mean age was 45 years, 49.0% were women, 7.1% were daily smokers, 15.2% had Stage III–IV periodontitis and 3.2% had ≥50% bone loss on at least two non-adjacent teeth.

### 3.1 | Dental Health Register

Among the 995 participants, 96.7% had available data in the DHR. The prevalence of PTP-based severe periodontitis was 2.4% within the entire MODS cohort and 4.1% among MODS participants ≥50 years old. The PPV for PTP-based severe periodontitis was 87.5% when using Stage III–IV as the reference standard. The PPVs and NPVs for PTP-based severe periodontitis based on the pie charts in Figure 2 are presented in Table 2A.

To perform ROC curve analysis, the number of PTPs was extracted from the DHR. AUCs were 0.76 (95% CI 0.72–0.81) for PTPs with Stage III–IV as reference standard, and 0.90 (95% CI 0.84–0.96) for having 50% bone loss as reference standard (Table 2B and Figure 4A).

To determine whether the number of PTPs was affected by recruitment to MODS, in addition to aging, we stratified PPs based on 3-year intervals: 4–6 and 1–3 years prior to MODS recruitment and 1–3 years after MODS recruitment. The mean number of PTPs was 0.28 (SD 1.05) at 4–6 years prior to recruitment, 0.42 (SD 1.30) at 1–3 years before recruitment and 0.54 (SD 1.75) at 1–3 years post-recruitment (Figure 3). The number of visits at 4–6 years pre-recruitment was significantly lower than at 1–3 years pre-recruitment (Mann–Whitney *U* test, $p = 0.0012$). However, no significant difference was

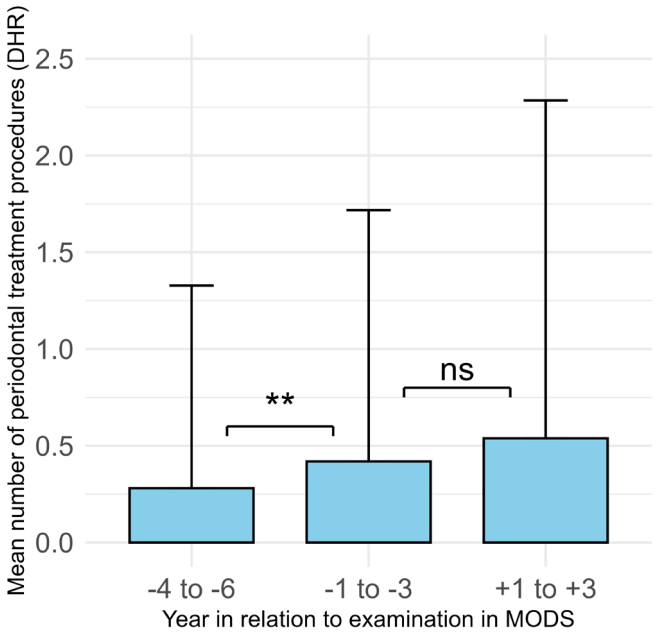


**FIGURE 3** | Mean number of periodontal treatment procedures (PTP) in the Dental Health Register (DHR), and the standard deviation (SD), during 3-year increments relative to time of recruitment into the Malmö Offspring Dental Study (MODS). The mean number of PTPs was significantly higher at 1–3 years than at 4–6 years prior to MODS examination, but did not differ between 1 and 3 years before MODS examination and 1–3 years after MODS examination (Mann–Whitney *U* test).**$p < 0.01$; ns, $p > 0.05$.

observed at 1–3 years pre-recruitment versus 1–3 years after recruitment.

Among the MODS participants with available DHR data, 64.4% had no PTPs registered, similar to the entire MOS cohort's 65.3%. Figure S2 shows a sensitivity analysis displaying PPV, NPV, sensitivity and specificity per full year in the DHR, showing a plateau after about 6 years. Among the 33 participants with no available DHR data, 19 were 18–23 years of age and thus not included in the DHR, and the remaining 14 had no registered dental visits in 2008–2020.

### 3.2 | Swedish Quality Register for Caries and Periodontitis

Periodontitis data from SKaPa were available for 45.4% of MODS participants. The use of 2 teeth with ≥ 6 mm as a cut-off yielded a poor PPV (< 70%) in all comparisons, including Stage II-IV periodontitis (Figure 2). However, the sensitivity and specificity were excellent (> 90%) compared with having 50% bone loss (Table 2A). For the number of teeth with ≥ 6 mm PPD, the AUC was 0.74 (95% CI 0.64–0.83) with stage III–IV and 0.98 (0.97–1.00) with having 50% bone loss as reference standard, as shown in Table 2B and ROC curves in Figure 4B.

### 3.3 | Questionnaire-Based Periodontitis

Among the 995 MODS participants who underwent periodontal examination, 607 completed the questionnaire on periodontitis-related questions, although some chose the answer 'Don't know' for some questions (Table S2). The distribution of the question responses is stratified by periodontitis stages in Table S2, and by PPV, NPV, sensitivity and specificity in Table S3. All questions had low PPV (Table S3).

For the crude questionnaire item model, the AUC was 0.68 (95% CI 0.62–0.74) for Stage III–IV, and 0.75 (95% CI 0.56–0.90) for having 50% bone loss as primary and secondary reference standards, respectively. The questionnaire-based model additionally including age, sex, education and smoking improved the AUC to 0.80 (95% CI 0.75–0.85) for Stage III–IV and 0.90 (95% CI 0.80–0.97) for having 50% bone loss (Table S3, Figure 4C).

Leave-one-out analysis revealed that the question about deep periodontal pockets significantly impacted the model for Stage III–IV (Figure 5), and the tartar question had a significant impact on the model for having 50% bone loss. However, due to its low prevalence, having 50% bone loss generated wide CIs and should be interpreted with caution.

## 4 | Discussion

To enable large cohort studies of periodontitis, it is crucial to identify register-based variables with high PPV. Here we demonstrated that a PTP-based proxy for identifying severe periodontitis effectively identifies Stage III–IV periodontitis cases with high PPV. Additionally, the SKaPa variable yielded high AUC when used as a continuous variable in ROC curve analysis, and it showed excellent sensitivity and specificity compared with having 50% bone loss, but not high PPV. The low PPV and NPV of dichotomized SKaPa variables are likely due to PPV and NPV being highly dependent on the selected threshold for classification and the condition's prevalence within the population.

Questionnaire-based periodontitis yielded high AUCs, particularly with the addition of variables that are often available in large cohort studies; for example, age, sex, education level and smoking habits. However, a questionnaire-based model is limited by the absence of an intuitive cut-off—particularly since individual questions showed low PPVs (Table S3). However, a constructed cut-off is presented in Table 2A and yielded good (> 75%) sensitivity and specificity and excellent NPV with 50% bone loss as the reference standard.

It may seem conceptually paradoxical that the DHR proxy variables are based on treatment for the very condition they aim to identify; this reflects the pragmatic use of clinical data in register-based research. Notably, in the current ACES framework, missing teeth due to periodontitis—a common consequence of periodontitis treatment—is a defining criterion for Stage IV periodontitis and most surgeries due to periodontitis were in fact extractions (Figure S1). Importantly, DHR includes information on whether extractions were due to periodontitis, addressing a common limitation in epidemiological studies (Holtfreter et al. 2024). Given the chronic nature of periodontitis and the low proportion of patients achieving 'stable periodontitis' (Chapple et al. 2018) in clinical

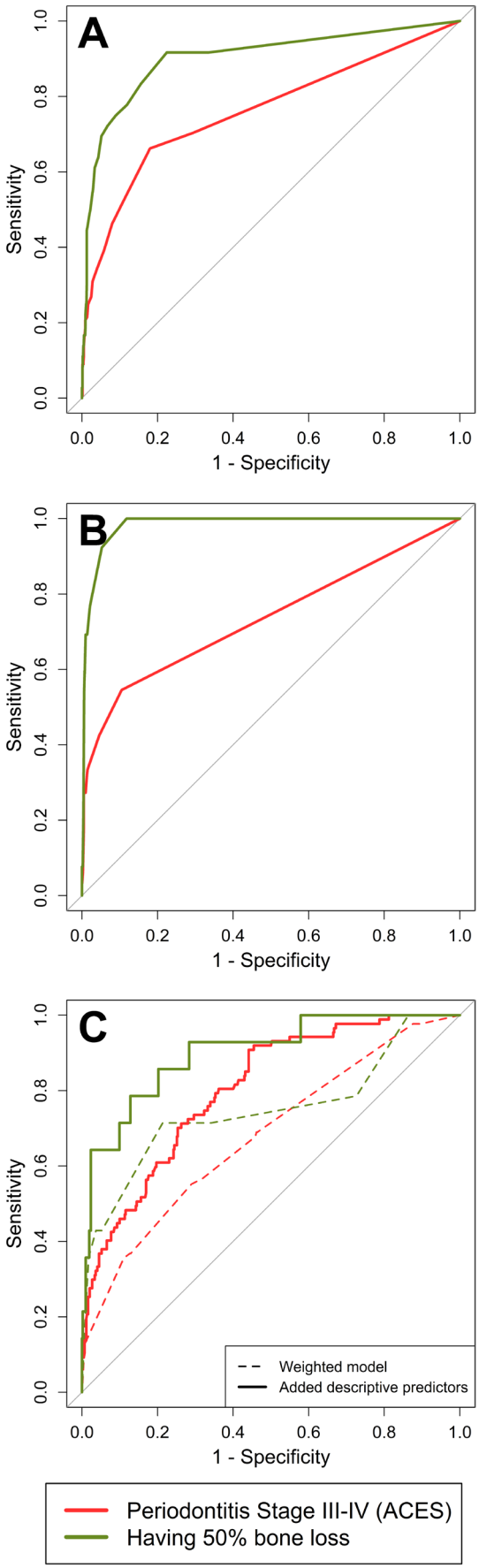


**FIGURE 4** | ROC curves for (A) the number of periodontal treatment procedures (PTPs) (taken from the Dental Health Register; DHR), (B) the number of teeth with PPD ≥6 mm (SKaPa) and (C) questionnaire items without or with addition of age, sex, education and smoking (MODS) in diagnosing periodontitis, as defined by Stage III–IV periodontitis (ACES) and having 50% bone loss. ACES, Application of the 2018 periodontal status Classification to Epidemiological Survey data; DHR, Dental Health Register; MODS, Malmö Offspring Dental Study; ROC, receiver operating characteristic; SKaPa, Swedish Quality Register for Caries and Periodontal Disease.

trials (Rattu et al. 2023), treatment often reflects ongoing disease. Moreover, treatment does not substantially alter key classification parameters such as attachment levels. Thus, periodontitis treatment recorded in DHR remains a valid proxy for periodontitis. To reduce false positives, we applied a stricter criterion requiring at least two extensive non-surgical treatments.

Large cohort studies have included both questionnaire-based periodontitis and genetic proxies. The UK Biobank questionnaire includes questions regarding bleeding gums and loose teeth; the latter correlates well with genetic data, suggesting that it may serve as a proxy for periodontitis (Shungin et al. 2019). However, in our data set, this question did not perform as well relative to the main reference standard. The CDC/AAP developed a dental questionnaire (Eke et al. 2013), which has been validated using a model incorporating age, education, smoking status and tooth loss, achieving an AUC of 0.76 for severe periodontitis per the CDC/AAP classification (Montero et al. 2020). This questionnaire does not include the UK Biobank questions, which are now relevant in European cohort studies. The CDC/AAP questionnaire also includes an inquiry about bone loss, while Scandinavian dental practitioners emphasize periodontal pockets. Wright et al. (2021) developed a 22-item periodontitis questionnaire based on psychological and functional factors, which showed a good model fit. A German validation study was performed using the SHIP-0 cohort and the Fourth German Oral Health Study (DMS IV) (Zhan et al. 2014). That study's model included demographic variables and showed good predictability in the SHIP-0 cohort and acceptable predictability in the DMS IV cohort. A French study demonstrated that a 12-item periodontitis questionnaire exhibited acceptable discriminatory capacity (Carra et al. 2018). A Dutch study (Nijland et al. 2021) tested a periodontitis questionnaire in an outpatient medical setting and reported acceptable discriminatory capacity. Compared with these previous studies, our questionnaire performed well, showing acceptable predictive capacity with only questions, and good predictive capacity with added demographic variables. These relatively good results are based on a different classification of periodontitis but could be due to the particular questions, a self-aware population or both.

### 4.1 | Strength and Limitations

One limitation of using register data is the time shift. This is inconsequential when comparing register data with genetic

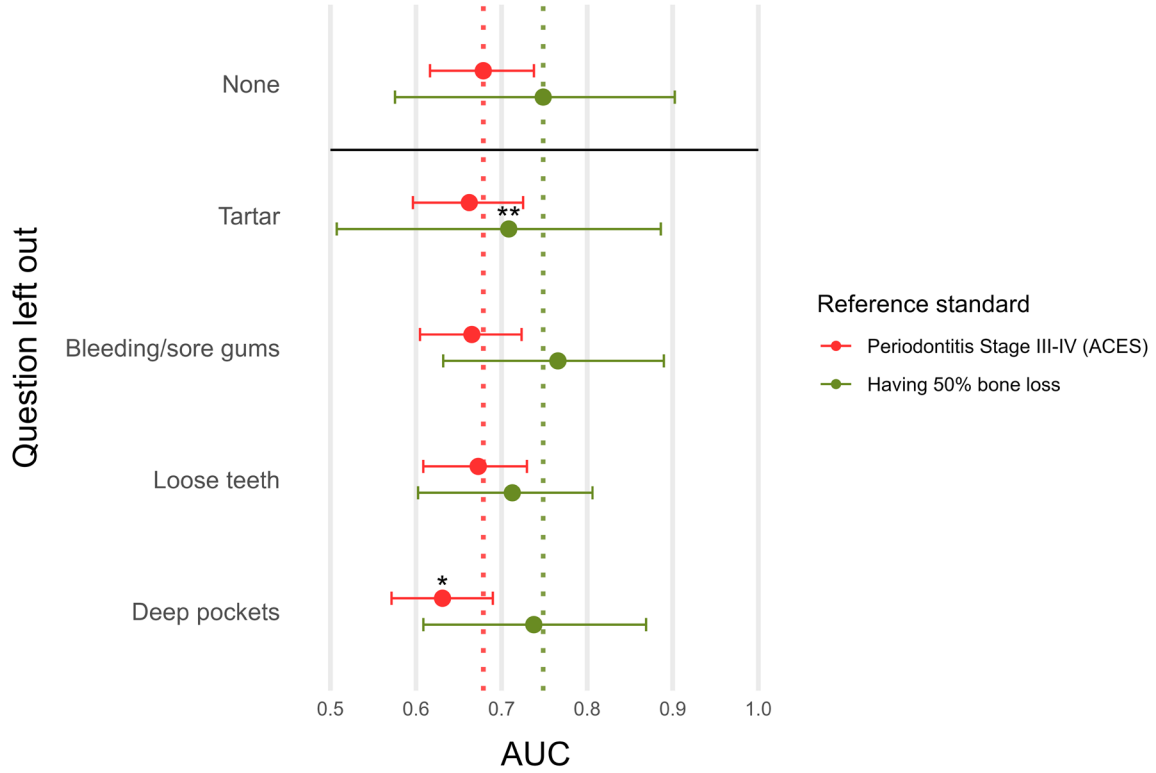


**FIGURE 5** | Questionnaire diagnosing periodontitis, and leave-one-out analysis showing the high impact of the question 'Has anyone told you that you have deep periodontal pockets?' relative to Stage III–IV periodontitis. The question 'Do you usually have tartar on your teeth?' was significant in relation to having 50% bone loss, but should be interpreted with caution due to the wide confidence interval (CI). The receiver operator characteristic (ROC) curves were compared using DeLong's test for two correlated ROC curves. ***$p < 0.001$, *$p < 0.05$. The figure depicts area under the curve (AUC) and 95% CI. ACES, Application of the 2018 periodontal status Classification to Epidemiological Survey data.

data and holds minor importance when investigating slowly progressing diseases, like cardiovascular disease. However, the time shift becomes more significant when register data are compared with biomarkers, especially in smaller cohorts. Additionally, it might be expected that the study itself would have an impact on the participants seeking dental care. However, the mean number of PTPs during the 3 years before MODS recruitment was similar to that within 3 years after MODS recruitment, indicating no effect on care-seeking behaviour.

The 2018 classification is based on CAL *or* bone loss on radiographs. Our ACES-based reference standard was based on bone loss rather than CAL, and supplemented with modifying factors, such as PPD, furcation involvement and vertical bone loss. The ACES paper includes a detailed discussion of the advantages and disadvantages of CAL and radiographic bone loss in epidemiological studies (Holtfreter et al. 2024). Because MODS has no data on the reason for tooth loss, ≥ 5 tooth gaps were used instead of ≥ 5 teeth lost due to periodontitis to identify Stage IV. This approach increases the likelihood that extractions were due to periodontitis by excluding cases related to orthodontic treatment. Finally, SKaPa is based on PPD, although attachment loss is the primary measure of periodontitis. However, active periodontitis is frequently associated with deep PPD, which is a strong predictor of tooth loss (Matuliene et al. 2008).

### 4.2 | Conclusions

The present results indicate that register-based data can be used as a proxy for clinical assessments of severe periodontitis, enabling comprehensive and reliable population-level periodontal research.

Future studies could combine the PTP-based data in DHR with the clinical data in SKaPa to reveal subjects that did versus did not achieve improved periodontal status (SKaPa) from periodontitis treatment (DHR), thereby assessing the extent to which periodontitis treatment affects a given outcome. The groups with effective versus ineffective treatment could then be handled as an intervention and control group, respectively. This would enable assessment of the beneficial effects of periodontitis treatment on periodontal and systemic disease outcomes in a population-wide setting.

#### Author Contributions

Conceptualization: D.J., A.M. and A.N.-A. Methodology: D.J., S.T., N.G., E.L.J., M.B., N.V., K.D.S. and A.N.-A. Designing and conducting Malmö Offspring Study and Malmö Offspring Dental Study: P.N., M.O.-M., O.M., D.J. and K.B. Designing the questionnaire: D.J. and K.B. Analysis: P.P., M.B., S.T., N.G., E.L.J., K.D.S., N.V., D.J. and A.N.-A. Writing the original manuscript: D.J. and P.P. Contributing to the manuscript: All authors.

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## Conflicts of Interest

The authors declare no conflicts of interest.

## Data Availability Statement

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

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## Supporting Information

Additional supporting information can be found online in the Supporting Information section. **Data S1:** jcpe70015-sup-0001-supinfo.docx.