

Risk factor assessment tools for the prevention of periodontitis progression a systematic review

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Abstract

Objectives: (i) To identify characteristics of currently published patient-based tools used to assess levels of risk for periodontitis progression and (ii) systematically review the evidence documenting the use of patient-based risk assessment tools for predicting periodontitis progression.

Material and methods: A systematic review was prepared on the basis of an electronic search of the literature supplemented with manually searching the relevant journals of the latest 5 years. Prospective and retrospective cohort studies were included as no randomized controlled clinical trials were available.

Results: The search identified 336 titles, and 19 articles were included in this systematic review. The search identified five different risk assessment tools. Results of nine of 10 cohort studies reporting outcomes of 2110 patients indicate that risk assessment tools are able to identify subjects with different probability of periodontitis progression and/or tooth loss. Subjects with higher risk scores showed more progression of periodontitis and tooth loss.

Conclusions: In treated populations, results of patient-based risk assessments, for example periodontal risk calculator (PRC) and periodontal risk assessment (PRA), predicted periodontitis progression and tooth loss in various populations. Additional research on the utility of risk assessment and results in improving patient management are needed.

Key words: attachment levels; periodontal disease progression; risk factor assessment; tooth loss; validity

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The host response to aetiological agents and routine periodontal treatment outcomes vary amongst periodontitis patients; it is therefore clinically important to determine the relative risk for disease progression

in a once-treated patient. For the last several decades, efforts have been made to evaluate the utility of various predictors for periodontal disease progression. Unaided risk assessment and prognostication,

however, have shown significant variability because chronic periodontitis is a multifactorial disease.

In that respect, single parameters have been assessed for their positive or negative predictive values to indicate

Conflict of interest and source of funding

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periodontal disease progression or stability. Initially, these efforts were hampered by the lack of consensus on a clear definition of disease progression. Generally, the loss of periodontal attachment of ≥ 2 mm was used as an indication of progressive disease (Lang et al. 1986, Claffey et al. 1990, Tonetti & Claffey 2005). Occasionally, ≥ 3 mm was chosen as a threshold (Socransky et al. 1984). It is evident that with such thresholds, minimal true loss of attachment of < 2 mm was not detected as such. Consequently, an evaluation of parameters usually underestimated predictive values in a given time.

As it was recognized that the extent and severity of previous disease is helpful in identifying individuals at risk of further disease progression (Haffajee et al. 1991), efforts focused on tooth- and site-based predictions. While originally single parameters such as bleeding on probing (BOP) (Lang et al. 1986), suppuration and probing pocket depth (PPD) (Claffey et al. 1990) were evaluated for their ability to predict disease progression, it was soon realized that the positive predictive values of these parameters were at best approximately 30%. Hence, the search for additional parameters and combinations of parameters was necessary.

Lang & Tonetti (1996) suggested the need for a continuous multilevel risk assessment at the patient, tooth and tooth site level to improve predictive values. While tooth- and site-based risk assessment using the severity of the lesion (pocket depth, attachment loss, remaining bone support, furcation involvement) and inflammation (BOP) had been clinically utilized, the challenge was the incorporation of subject-based factors.

The systematic assessment of known risk factors discussed at the World Workshop on Periodontics (Papapanou 1996, Tonetti 1998) highlighted that known risk factors for periodontitis could be clustered in seven groups: aetiology, genetic predisposition, medical conditions, lifestyle, psychological profile, access to care and background factors. Each of these groups of factors may confer increased susceptibility to disease onset and progression. In his paper, in the first attempt to account for the multidimensional nature of

patient-based risk, Tonetti (1998) proposed the use of a target diagram to communicate and manage the multidimensional risk of periodontitis progression.

Clinical implication of the principles, however, required the development and validation of tools to measure and communicate risk in its multiple dimensions. The significance of single subject attributes or exposure to outcomes of periodontal supportive care has been recently systematically reviewed (Chambrone et al. 2010). In that systematic review, different patient-related factors (i.e. age and smoking) and tooth-related factors (tooth type and location, and the initial tooth prognosis) were associated with tooth loss during supportive periodontal care. No systematic review is available to understand the predictive value of multiple factors for periodontitis progression and tooth loss in treated populations.

The specific aims of this review were as follows: (i) to identify the characteristics of currently published patient-based tools or systems used to assess levels of risk for periodontitis progression and (ii) systematically review the evidence documenting the use of patient-based risk assessment tools for predicting periodontitis progression. For the second aim, the focused question was as follows: *“Are results from current patient-based risk assessment tools predictive of periodontitis progression in adults treated for this disease?”*

Material and Methods

Scope

The focus of this review was to provide a comprehensive summary of the evidence of existing tools or methods proposed to assess patient-level risk for the progression of periodontitis. Hence, inclusion criteria were set to be broad and inclusive. Study designs eligible for inclusion were randomized controlled clinical trials and cohort studies for answering the focused question of prediction. Cross-sectional studies were included in the summary of currently reported risk assessment tools. Risk assessment tools for peri-implant disease initiation or progression were not within the scope of this review.

Any published risk assessment tool was considered. For this review, a risk assessment tool was defined to include any composite measure of patient-level risk directed towards determining the probability for further disease progression in adults with periodontitis. Periodontitis was defined to include both chronic and aggressive forms in adult populations. Periodontitis progression outcomes included changes in attachment levels and/or deepening of periodontal pockets in millimetres in study populations undergoing supportive periodontal therapy (SPT) (Tonetti & Claffey 2005).

Search and screening

The electronic search strategy included the search of electronic databases to July 2014 using terms and strategy set a priori according to each database (Cochrane Library, Ovid MEDLINE, EMBASE and LILACS). No language or year restrictions were applied. Hand searching comprised of checking bibliographic references of included articles and related review articles. In addition, on-line hand searching of recent issues of key periodontal journals from the previous 5 years was performed (Journal of Clinical Periodontology, Journal of Dental Research, Journal of Periodontal Research, Journal of Periodontology, Oral Health and Preventive Dentistry).

The electronic search strategy framework was developed based on risk assessment tools and periodontitis search terms and then tested to confirm its suitability to the focus of the review. It was customized as appropriate before application to each database. Table S1 provides an example of the basic search strategy.

Titles and abstracts (when available) of all reports identified through the search were scanned by two reviewers independently (JES and NPL). Full reports were obtained and reviewed independently for studies appearing to meet the inclusion criteria or for which there was insufficient information in the title and abstract to allow a clear decision (JES and NPL).

Bias protection assessment

Bias protection assessment of included studies was undertaken

independently and in duplicate by two reviewers. Studies were assessed using the validated Newcastle-Ottawa quality assessment scale as recommended by the Cochrane Collaboration guidelines for the assessment of non-randomized studies (Wells et al. 2009). These tools award stars (*) in three categories for each study based on incorporation of design elements associated with minimizing bias. Due to a lack of validated tools to assess the risk of bias of cross-sectional studies, cross-sectional studies were not evaluated.

Data abstraction

Data were abstracted from full-text articles directly into electronically generated evidence table templates. Data abstraction was performed on all included studies independently and in collaboration (JES and NPL). Completed evidence tables were re-checked to validate accuracy of the data abstraction (JES, NPL, MT).

Data synthesis

Descriptive methods

Descriptive summary was performed by summarizing the studies in evidence tables to determine the quantity of data, checking further for study variations in study characteristics (populations, outcomes, design, quality and results). Bias protection assessment was also summarized in table format. Evidence tables provided the framework to assess data suitability for further quantitative analyses such as meta-analysis.

Quantitative methods

Due to the heterogeneity of the studies, data were not adequate to warrant performing a meta-analysis.

Results

Search results

The electronic search provided 388 citations, including 61 duplicate publications. Hand searching provided nine additional citations. 336 titles and abstracts were screened in duplicate (Kappa score for screening agreement 0.95, 95% CI 0.90–0.99).

Figure 1 illustrates the PRISMA flow diagram. 303 irrelevant citations were excluded, confirming the broad nature of the search. The majority of these contained information pertaining to associations of specific risk factors to periodontitis. Moreover, articles about risk factors for caries and periapical lesions as well as narrative reviews were amongst the excluded titles and abstracts.

All 33 potentially relevant full-text articles were screened independently in duplicate according to the eligibility criteria. Reviewers were in full agreement on inclusion of articles. This last screening excluded 14 citations that did not provide evidence for risk assessment tools or were duplicate publications of already included articles, or were narrative summaries or comments (Page et al. 2002, 2005, Persson et al. 2003a,c, Renvert et al. 2004, Sandberg 2004, Chapple 2007, Sandberg & Fors 2007, Matuliene et al. 2008, Martin et al. 2009, 2011, Busby et al. 2013, Giannobile et al. 2013, Thyvalikakath et al. 2013). Detailed reasons for exclusion are reported in Table S2.

Characteristics of included studies

All evidence was published within the last 13 years, and 10 articles were published since 2010. Three included articles reported a risk assessment tool without providing supporting data (Fors & Sandberg 2001, Lang & Tonetti 2003, Teich 2013). Evidence comprised 10 cohort studies: in seven of these, risk was calculated retrospectively at the end of the follow-up period using available baseline data (Page et al. 2003, Eickholz et al. 2008, Jansson & Norderyd 2008, Leininger et al. 2010, Martin et al. 2010, Matuliene et al. 2010, Lü et al. 2013); in 1, risk was calculated retrospectively using data assessed at the end of the study (Meyer-Bäumer et al. 2012), while 2 studies were conducted fully with a prospective design (Lindskog et al. 2010, Costa et al. 2012). 6 cross-sectional studies were also identified (Persson et al. 2003b, Renvert & Persson 2004, Chandra 2007, Trombelli et al. 2009, Eshwar et al. 2010, Busby et al. 2014).

Aim 1. Summary of identified patient-based periodontal risk assessment tools

The 19 included studies reported on different patient-based periodontal risk assessment tools. A total of five risk assessment tools were identified in the current review. Five publications dealt with the DenPlan Excel/Previsor® Patient Assessment (DEPPA) and its modifications (Page et al. 2002, Persson et al. 2003b, Trombelli et al. 2009, Martin et al. 2010, Busby et al. 2014). One article described the HIDEP model, a computerized tool that used predetermined risk groups for selecting and managing individual treatment and prevention schemes (Fors & Sandberg 2001). One article presented the risk assessment-based individualized treatment (RABIT) (Teich 2013). One study (Lindskog et al. 2010) described the dentition risk system (DRS) at both the patient and tooth level. Twelve publications reported on the Periodontal Risk Assessment (PRA) and its modifications (Lang & Tonetti 2003, Persson et al. 2003c, Renvert & Persson 2004, Chandra 2007, Eickholz et al. 2008, Jansson & Norderyd 2008, Eshwar et al. 2010, Leininger et al. 2010, Matuliene et al. 2010, Costa et al. 2012, Meyer-Bäumer et al. 2012, Lü et al. 2013).

Table 1 displays the characteristics and the parameters utilized by these tools. A qualitative analysis indicates that the parameters that are taken into account are to a large degree the same even though differences are evident with regard to the actual assessment of the parameters. Furthermore, the majority of the tools are variations of few basic approaches and in particular of the periodontal risk calculator, PRC (Page et al. 2002) and of the periodontal risk assessment, PRA (Lang & Tonetti 2003). Variations frequently addressed different ways of assessing the parameters included either in PRC or in PRA.

A total of six studies reporting on 1078 patients had a cross-sectional design and reported comparisons of different risk assessment tools and/or measures of adjusted and unadjusted associations between periodontal outcomes and the subject risk stratification provided by the assessment tools (Table S3).

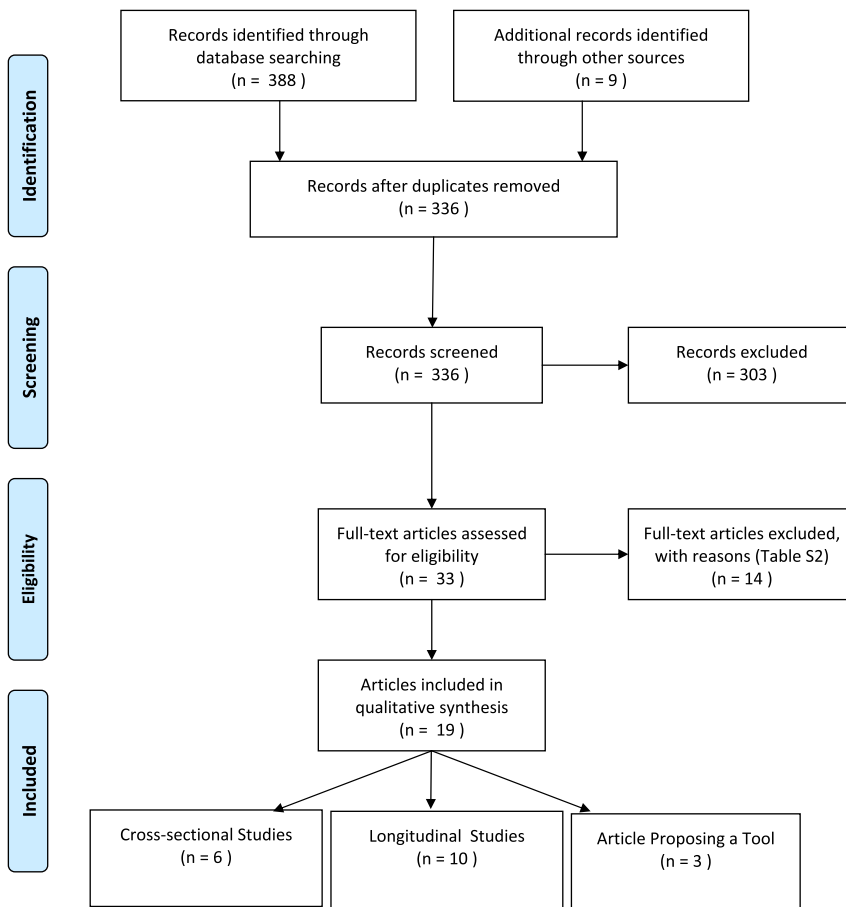


Fig. 1. Prisma flow diagram.

Aim 2. Prediction of periodontitis progression

Ten included studies (Table 2) had a cohort design and reported on a total of 2130 patients. The observation period spanned from 3 years to 12 years. The time at risk (follow-up time) was different for the different subjects enrolled in each study in five of 10 studies. In general, these studies report that the risk assessment tool was able to effectively separate subjects with different probability of disease progression and tooth loss. The observed effect was dose dependent (the higher the estimation of risk the higher the level of observed disease progression and/or tooth loss).

One study (Page et al. 2002) assessed the predictive value of risk estimation with the periodontal risk calculator (PRC), also known as PreViser® in a largely untreated population. This study enrolled 523 men of the VA Dental Longitudinal Study with data gathered over 15 years. The risk scores applied

were strong predictors for the periodontal status as measured by alveolar bone loss of periodontally affected teeth. Increasing risk scores after 15 years also revealed increasing numbers of teeth lost. A risk score of 2 corresponded to a loss of 0.5 teeth, a risk score of 3 to a loss of 1.6 teeth, a risk score of 4 to a tooth loss of 2.4 teeth and a risk score of 5 to a tooth loss of 5.8 teeth. The authors recommended the PRC as a predictive tool for risk assessment in clinical decision-making. It should be noted that determining risk subjectively by expert clinicians tended to underestimate the periodontitis risk compared to the PRC. Another study utilizing the PRC system reported on 776 SPC patients from 9 periodontal practices (Martin et al. 2010).

Another prospective cohort study (Lindskog et al. 2010) provided evidence for the dentition risk system (DRS), a proposed combination of factors in assessing disease progres-

sion at both the patient (dentition) and the tooth level in a population comprising 183 subjects.

Seven studies reporting on 648 subjects assessed the predictive value of risk estimation with the PRA or its modifications as a predictive tool for periodontal disease progression (Eickholz et al. 2008, Jansson & Norderyd 2008, Leininger et al. 2010, Matuliene et al. 2010, Costa et al. 2012, Meyer-Bäumer et al. 2012, Lü et al. 2013). With the exception of one retrospective cohort study with 20 subjects and a mean follow-up of 5 years (Jansson & Norderyd 2008), 6 of the seven cohort studies reported on a total of 628 subjects followed for 3 to 12 years (Eickholz et al. 2008, Leininger et al. 2010, Matuliene et al. 2010, Costa et al. 2012, Meyer-Bäumer et al. 2012, Lü et al. 2013). All provided a longitudinal external validation of the PRA as a predictive tool for periodontitis progression and tooth loss. The study that failed to report an association between PRA score and periodontitis progression (Jansson & Norderyd 2008) assessed risk before treatment and after 5 years, while all other studies assessed PRA at the end of active therapy. Matuliene et al. (2010) reported that subjects with a low-risk profile experienced an average tooth loss of 1.8 teeth (SD 1.9 teeth), subjects with a middle-risk profile 1.02 teeth (SD: 1.8 teeth) and subjects with a high-risk profile 2.59 teeth (SD 3.9 teeth) (Matuliene et al. 2010). In a Chinese study with 88 patients (Lü et al. 2013), a modified PRA was used to evaluate treatment outcomes in severe generalized aggressive periodontitis. High-risk patients showed more tooth loss and less bone fill than low-risk or moderate-risk patients. Another cohort study, reporting on PRA in generalized aggressive periodontitis patients, reported more tooth loss and shorter time to the first tooth loss event in PRA-defined high-risk individuals compared to low- and moderate-risk individuals (Meyer-Bäumer et al. 2012). This latter study, however, retrieved risk profile data at follow-up rather than after active periodontal therapy.

Based on the Newcastle-Ottawa quality assessment scale for the prospective and retrospective cohort

Table 1. Summary of identified risk assessment tools

Author (country) study type	Risk assessment tool description	Parameters utilized in tool	Objective
Fors & Sandberg (2001) (Sweden)	Health Improvement in Dental Practice Model (HIDEP) Computerized tool that uses predefined risk groups for selecting and managing individual treatment and prevention schemes. The model does not use new risk estimation techniques, but combines already available examination methods, risk estimation systems and treatment suggestions into a new entity. Tool designed to assess the risk of other aspects of oral health in addition to periodontal status	Total number of teeth, total number of intact teeth (teeth without restorations, caries, or crowns, number of caries lesions (initial lesions included), caries experience, fluoride exposure, saliva diagnostics (including secretion, buffering capacity, lactobacilli criteria, and <i>streptococcus mutans</i>), sugar intake frequency, oral hygiene screening, professional risk estimation for caries and periodontitis, gingival bleeding, probing of periodontal pockets, radiographic examination, registration of tartar and/or overhang	To create and evaluate a computerized tool capable of creating overviews of the oral health situation as well as identifying risk factors and at-risk patients. Consists of 5 risk and 4 disease categories for both caries and periodontal diseases. Scores assigned according to 14 parameters. Final result places patients on a health-disease scale and low or high risk for disease scale for both caries and periodontal disease
Page et al. (2003) (USA)	Periodontal Risk Calculator (PRC) Computer-based tool that is periodontal risk assessment focused. Based upon information obtained from clinical periodontal examination (later incorporated with additional oral health risk assessment tools to form PreViser). Generated risk score is the results of mathematically derived algorithms that assign relative weights to the various factors that enhance patients' susceptibility to develop periodontitis	Calculation of risk involves mathematical algorithms using nine parameters: age, smoking history, diabetes, history of periodontal surgery, pocket depth, furcation involvements, restorations or calculus below the gingival margin, radiographic bone height and vertical bone lesions	To provide a risk score of a patients' susceptibility for periodontal progression on a scale of 1 (lowest risk) to 5 (highest risk).
Lang & Tonetti (2003) (Switzerland)	Periodontal Risk Assessment Model (PRA) A functional diagram (spider web shape) formulated based upon the combination of various parameters that have been proposed in scientific literature as impacting the patient risk for further disease progression.	Estimation of patient-level risk involves using six parameters: bone loss/age, number of pockets ≥ 5 mm, number of missing teeth, percentage of sites with BOP, cigarette smoking and systemic factors (such as diabetes and II-1 gene polymorphism)	To classify patients as low, medium or high risk for periodontal disease progression.
Chandra (2007) (India)	Modified Periodontal Risk Assessment Model (Modified PRA) A new periodontal risk assessment model based on the periodontal risk assessment (PRA) model by Lang and Tonetti that was targeted to be: 1/easier to generate and use, 2/would assess diabetes on an individual radius and 3/would incorporate dental factors include "others factors" such as stress and socio-economic factors	Based upon the design of the PRA, 4 factors of the PRA are retained: BOP, no of sites with $PD \geq 5$ mm, tooth loss and smoking. Additional factors are re-defined or included: diabetic status, AL/age, dental status-systemic factors interplay and other background characteristics. Differences from PRA are that 1/environmental factors, systemic and genetic factors are specifically defined as diabetes status and interplay of dental-systemic factors that accounts for dental factors. 2/bone loss/age is replaced with attachment level/age 3/other background factors are included to include estimated socio-economic or stress factors. 4/the scores on each trajectory ranged between 1 and 5/based on a coding system rather than using actual factor thresholds such as bleeding on probing per cent, or numbers of pockets ≥ 5 mm	To classify individuals as low, medium or high risk for periodontal disease progression

Table 1. (continued)

Author (country) study type	Risk assessment tool description	Parameters utilized in tool	Objective
Trombelli et al. (2009) (Italy)	University of Ferrara(UniFe) A proposed simplified method for periodontal risk assessment based upon five parameters derived from patient medical history and clinical recordings. Each parameter assessed is allocated a parameter score according to defined criteria. The algebraic sum of the parameter scores is calculated and relates to a risk score between 1 and 5.	Smoking status, diabetic status, number of sites with probing depth ≥ 5 mm, bleeding on probing score (BoP) bone loss/age	To provide a risk score of a patients' susceptibility for periodontal progression on a scale of 1 (lowest risk) to 5 (highest risk).
Lindskog et al. (2010) (Sweden)	DRS a patient risk score (DRS dentition) or tooth risk score (DRS tooth). A Web-based analytic tool that calculates chronic periodontitis risk for the dentition (Level I) and, if an elevated risk is found, prognosticates disease progression tooth by tooth (Level II).	Systemic predictors: age, family history of periodontitis, systemic disease, skin test result (assesses patient's inflammatory reactivity), patient compliance and disease awareness, socioeconomic status, smoking habits and therapist's experience with periodontal care Local predictors: plaque, endodontic pathology, furcation involvement, angular bony destruction, radiographic marginal bone loss, pocket depth, bleeding on probing, marginal dental restorations and tooth mobility	To provide a dentition (patient level) risk score based upon systemic and local predictors. It allows for further risk assessment at the tooth level if patient-level risk is found to be elevated.
Teich (2013) (USA)	Risk Assessment-Based Individualized Treatment (RABIT) Advocates a modified approach that supports individualized risk-based recall schedules not only after active therapy is completed but also during the course of treatment. Approach assesses risk of other aspects of oral health in addition to periodontal status	Computer system assigns a risk level based upon caries risk assessment and periodontal risk assessment. The specific parameters used to generate the level of risk are not reported in the paper (reported as developed according to existing evidence)	To classify patients as low, medium or high risk for periodontal disease progression or caries risk with accompanying recommendation for maintenance visit interval
Lü et al. (2013) (China)	PRA (as proposed by Lang & Tonetti 2003): Bone loss/age, number of pockets ≥ 5 mm, number of missing teeth, percentage of sites with BOP, cigarette smoking, diabetes and IL-1 gene polymorphism Modified MPRA is an alternate modification of the PRA that replaces BOP with bleeding index ≥ 2 and counting sites with PPD ≥ 6 mm, calculating full-mouth average bone loss over age	MPRA Model 1: BL > 2 , PD ≥ 6 mm (four sites per tooth), tooth loss, bone loss (worst site/age), smoking and systemic disease MPRA Model 2: BL > 2 , PD ≥ 6 mm (four sites per tooth), tooth L, bone loss (mean/age), smoking and systemic disease MPRA Model 3: BL > 2 , PD ≥ 6 mm (six sites per tooth), tooth loss, bone loss (mean/age), smoking and systemic disease	To classify patients as low, medium or high risk for periodontal disease progression.
Busby et al. (2014) (UK)	Oral Health Status (OHS) as part of DenPlan Excel/Previsor Patient Assessment (DEPPA) On-line assessment tool that incorporates PreViser™ risk scores for periodontal disease, caries, non-carious tooth surface loss, oral cancer, revised versions of DenPlan Excel's Oral Health Score, and capitation-fee guidance	Pocketing and bleeding based upon BPE result in patient score for healthy periodontium, gingivitis only, mild periodontal disease, moderate periodontal disease and severe periodontal disease	To provide patient-level risk scores for periodontal disease, caries and oral cancer.

Table 2. Longitudinal studies reporting periodontitis progression or tooth loss based on risk stratification with multidimensional tools

Author (country) study type	Population/sample/condition	Follow-up (Time at risk in years)	Risk assessment tool description (included parameters)	Results	Risk of bias (Newcastle-Ottawa scale)	Study conclusions
Page et al. (2003) (USA) Retrospective Cohort Study	$N = 523$ General population: Men enrolled in the Veterans Administration Dental Longitudinal Study Age range 25–74 years Smokers $n = 101$ Diabetics $n = 9$	Follow-up after 3, 9 and 12 years	PRC Computer-based tool periodontal risk assessment focused. Provides a risk score on a scale of 1 (lowest risk) to 5 (highest risk). Calculation of risk based upon mathematical algorithms using nine risk factors: age, smoking history, diabetes, history of periodontal surgery, pocket depth, furcation involvements, restorations or calculus below the gingival margin, radiographic bone height and vertical bone lesions	Risk scores were strong predictors of periodontal status, as measured by alveolar bone loss and loss of periodontally affected teeth. Risk scores consistently ranked risk score groups from least to most bone loss and tooth loss. Compared with a risk score of 2, the relative risk of tooth loss was 3.2 for a risk score of 3, 4.5 for a risk score of 4 and 10.6 for a risk score of 5. Mean number of teeth lost at 15 years (risk group based upon baseline risk score): Risk score 2: 0.5 teeth Risk score 3: 1.8 teeth Risk score 4: 2.4 teeth Risk score 5: 5.8 teeth	Low	Risk assessed by PRC significantly predicted outcomes in terms of periodontitis progression and tooth loss.
Jansson & Norderyd (2008) (Sweden) Retrospective Cohort Study	$N = 20$ Periodontitis patients treated and in supportive periodontal care Mean age = 48.4 years Age range 33–67 years Tobacco users $n = 12$ Diabetics $n = 1$	5 year follow-up	PRA Periodontal risk hexagon diagram proposed by Lang & Tonetti (2003). Included parameters were: percentage BOP, number of residuals pockets with probing depths ≥ 5 mm, number of teeth lost, bone loss/age ratio, systemic or genetic factors (diabetes or IL-1 gene polymorphism) and environmental factors (smoking status).	Thirteen patients categorized as high risk 7 patients categorized as moderate risk - Individuals with BOP \leq 20% had a mean loss of 3.5 teeth - Individuals with BOP $>$ 20% had mean loss of 1 tooth - mean reduction of sites with PD $>$ 5 mm was in similar magnitude in both groups; BOP \leq 20% and BOP $>$ 20% (22% and 19%, respectively)	Low	Risk assessed by PRA did not significantly predict outcomes in terms of tooth loss.
Eickholz et al. (2008) (Germany) Retrospective Cohort Study	$N = 100$ Periodontitis patients in supportive periodontal therapy for 10 years. 53 were SPT compliers, and 47 were erratic compliers	10 year follow-up	PRA Modification of periodontal risk hexagon diagram proposed by Lang & Tonetti (2003). BOP percentage, mean PI, IL-1 polymorphism and smoking history complying with the SPT schedule were assessed 10 years following active periodontal therapy	Significant risk factors identified by Poisson regressions as contributing factors for tooth loss were mean plaque index during SPT, irregular attendance of SPT, age, initial diagnosis, IL-1 polymorphism, smoking and gender	Medium	Risk assessed by PRA significantly predicted outcomes in terms of tooth loss.

Table 2. (continued)

Author (country) study type	Population/sample/condition	Follow-up (Time at risk in years)	Risk assessment tool description (included parameters)	Results	Risk of bias (Newcastle-Ottawa scale)	Study conclusions
Leiminger et al. (2010) (France) Retrospective Cohort Study	N = 30 Untreated periodontitis patients assessed before and following treatment Low-to-moderate risk n = 17 High risk n = 13 Mean age = 51.0 years Age range 22–67 years Males = 50% Smokers = 40% Diabetic n = 1	Follow-up between 6 and 12 years	PRA Periodontal risk hexagon diagram proposed by Lang & Tonetti (2003): included parameters were percentage BOP, number of residuals pockets with probing depths ≥5 mm, number of teeth lost, bone loss/age ratio, systemic or genetic factors (diabetes or IL-1 gene polymorphism) and environmental factors (smoking status).	Tooth loss = 0.11 for the low-to-moderate-risk group, 0.26 for the high-risk group (p = 0.05). PPD reduction=2.57 and 2.17, respectively, and bleeding on probing reduction was 6.7% and 23.3%, respectively. No. PPD sites reduction was 3.39 in the compliant group and 1.40 in the non-compliant group (p = 0.05).	Medium	Risk assessed by PRA significantly predicted outcomes in terms of periodontitis progression and tooth loss.
Lindskog et al. (2010) (Sweden) Prospective Cohort Study	N = 183 Approx. 35 patients per practice in five clinics (clinicians included three periodontal specialists and four general dentists). Consecutive patients attending clinics (with and without periodontitis) then treated accordingly Mean age = 47.9 years Males = 47%	Follow-up time point about 4 years	DRS a patient risk score (DRS denition) or tooth risk score (DR Stooth). Systemic predictors: - age, family history of periodontics, systemic disease, skin test result (assesses patient's inflammatory reactivity), patient compliance and disease awareness, socio-economic status, smoking habits and therapist's experience with periodontal care Local predictors: - plaque, endodontic pathology, furcation involvement, angular bony destruction, radiographic marginal bone loss, pocket depth, bleeding on probing, marginal dental restorations and tooth mobility	Total number teeth lost amongst sample during the observation period were 66 or 2.25%. -21.3% of patients lost teeth 31.8% of 107 patients with DRS denition >0.5 lost teeth compared to 5 of 76 patients (6.6%) with DRS denition score <0.5.	Low	Risk assessed by DRS significantly predicted outcomes in terms of tooth loss.

Table 2. (continued)

Author (country) study type	Population/sample/condition	Follow-up (Time at risk in years)	Risk assessment tool description (included parameters)	Results	Risk of bias (Newcastle-Ottawa scale)	Study conclusions
Martin et al. (2010) (USA) Retrospective Cohort Study	$N = 776$ Periodontitis patients treated and in supportive periodontal care patients recruited by nine periodontists with target of 100 per specialist risk and disease severity scored at baseline and after follow-up. Low risk = 0.6% Moderate risk = 7.9% High risk = 36.6% Very high risk level = 54.9% Age range = 46.0 ± 10.5 years	Follow-up Mean – 13.2 ± 7 years	PRC Computer-based tool periodontal risk assessment focused. Provides a risk score on a scale of 1 (lowest risk) to 5 (highest risk). Calculation of risk based upon mathematical algorithms using nine risk factors: age, smoking history, diabetes, history of periodontal surgery, pocket depth, furcation involvements, restorations or calculus below the gingival margin, radiographic bone height and vertical bone lesions Disease score categorized as 1–100	Mean Tooth loss/patient 1.26 ± 2.53 Entire study population's mean tooth loss rate (MTLR) = 0.11 ± 0.26	Low	Risk assessed by PRC and disease severity score significantly predicted outcomes in terms of tooth loss.
Matuliene et al. (2010) (Switzerland) Retrospective Cohort Study	$N = 160$ Periodontitis patients treated and in supportive periodontal care Low risk $n = 11$ Moderate risk $n = 90$ High risk $n = 59$ Mean age = 46.7 years Age range 15–71 years Males = 45%	Follow-up = approx. 10 years	PRA Periodontal risk hexagon diagram proposed by Lang & Tonetti (2003) Included parameters were percentage BOP, number of residuals pockets with probing depths ≥ 5 mm, number of teeth lost, bone loss/age ratio, systemic or genetic factors (diabetes or IL-1 gene polymorphism) and environmental factors (smoking status).	% of patients experiencing periodontitis recurrence with: Low-risk profile – 18.2% Moderate-risk profile – 42.2% High-risk profile – 49.2% Tooth loss by risk profile: Low-risk profile – 1.18 ± 1.9 Moderate-risk profile – 1.02 ± 1.8 High-risk profile – 2.59 ± 3.9	Low	Risk assessed by PRA significantly predicted outcomes in terms of periodontitis progression and tooth loss.
Meyer-Bäumer et al. (2012) (Germany) Retrospective Cohort Study	$N = 86$ Aggressive periodontitis (AgP) treated and in supportive periodontal therapy (SPT) Moderate-risk profile $n = 26$ High-risk profile $n = 70$ Age = ≤ 36 years at baseline Males = 18.6%	More than 5 years	PRA Periodontal risk hexagon diagram proposed by Lang & Tonetti (2003). Included parameters were percentage BOP, number of residuals pockets with probing depths ≥ 5 mm, number of teeth lost, bone loss/age ratio, systemic or genetic factors (diabetes or IL-1 gene polymorphism) and environmental factors (smoking status).	-During SPT, 98 teeth/2202 teeth were lost (mean tooth loss of 1.14 per patient (SD 1.78) over mean of 9.7 SPT years. -53.5% of patients had no tooth loss -High-risk profile resulted in 1.23 teeth loss/patient (SD 1.86) -Most teeth lost in non-compliant patients with high-risk profile (mean loss of 1.36 teeth per patient) -Differences were significant for tooth loss when IL-1 gene polymorphism was removed as factor.	Medium	Risk assessed by PRA significantly predicted outcomes in terms of tooth loss.

Table 2. (continued)

Author (country) study type	Population/sample/condition	Follow-up (Time at risk in years)	Risk assessment tool description (included parameters)	Results	Risk of bias (Newcastle-Ottawa scale)	Study conclusions
Costa et al. (2012) (Brazil) Prospective Cohort Study	<i>N</i> = 164 Periodontitis patients treated and in supportive periodontal therapy Regular compliers = 75 Erratic compliers = 89 Age range 18–62 years Males = 37% Smokers = 29% Diabetes = 8%	3 years follow-up assessment	PRA Applied the periodontal risk assessment diagram proposed by Lang & Tonetti (2003) Included parameters were percentage BOP, number of residuals pockets with probing depths ≥ 5 mm, number of teeth lost, bone loss/age ratio, systemic or genetic factors (diabetes or IL-1 gene polymorphism) and environmental factors (smoking status).	Rate of periodontitis recurrence for regular compliers and erratic compliers: - moderate risk group 2.7% and 3.4% respectively - high-risk group 6.7% and 11.2%, respectively Tooth loss in regular and erratic compliers: - Risk for tooth loss (OR 95% CI) by PRA parameter: BOP 2.23 (1.02, 5.68) $p = 0.021$ Sites with PD ≥ 5 mm 1.81 (0.96, 1.94) $p = 0.361$ Number of missing teeth 2.21 (1.13, 5.31) $p = 0.022$ Bone loss/age ratio 2.73 (1.04, 4.92) $p < 0.001$ Diabetes (yes vs. no) 1.92 (1.01, 7.28) $p = 0.026$ Smoking (yes vs. no) 3.41 (1.26, 11.41) $p < 0.001$	Low	Risk assessed by PRA significantly predicted outcomes in terms of periodontitis progression and tooth loss.
Lü et al. (2013) (China) Retrospective Cohort Study	<i>N</i> = 88 Aggressive periodontitis (AgP) treated and in supportive periodontal care Mean age = 27 years Males $n = 30$ Smokers $n = 3$ Systemic diseases = none	Approx. 3–7 years follow-up	PRA/MPRA PRA (as proposed by Lang & Tonetti 2003) Included parameters were percentage BOP, number of residuals pockets with probing depths ≥ 5 mm, number of teeth lost, bone loss/age ratio, systemic or genetic factors (diabetes or IL-1 gene polymorphism) and environmental factors (smoking status). MPRA is an alternate modification of the PRA that replaces BOP with bleeding index > 2 , counting sites with PPD ≥ 6 mm, calculating full-mouth average BL over age	Based on original PRA, 87 patients (98.8%) had a high-risk profile. According to three MPRA models, annual TL per patient values were greater in high-risk groups than in low-to-moderate risk groups (MPRA-1, 0.20–0.33 versus 0.04–0.14; MPRA-2, 0.18–0.32 versus 0.05–0.14; MPRA-3, 0.17–0.32 versus 0.05–0.15; $p < 0.05$). By MPRA-1, irregular compliers with low-to-moderate risk profile had greater Δ BL (0.027–0.031, indicating bone increment) than those with high risk (–0.012–0.064, tendency for BL). For regular compliers, no significant differences of annual TL or Δ BL were found between risk groups.	Medium	Risk assessed by PRA significantly predicted outcomes in terms of periodontitis progression and tooth loss.

study design (Wells et al. 2009), 6 studies met the criteria to be categorized as being at low risk of bias, while 4 studies were at medium risk of bias.

No retrieved study evaluated in a comparative way the effect of knowledge of the risk assessment profile on the management of the patient.

Discussion

This systematic review identified five periodontal risk assessment tools in the literature. These employed assessment of a small set of well-documented risk factors and indicators. Differences consisted mainly of the methods of estimation of the different parameters, their number and the inclusion of tooth- or site-specific factors. Amongst these, three tools – and their variations – have been assessed in longitudinal studies. One tool termed the periodontal risk calculator or PRC was studied in two studies from the USA (Page et al. 2002, Martin et al. 2010). Another tool, the periodontal risk assessment or PRA (Lang & Tonetti 2003) was tested in a total of seven studies including 648 subjects. One of the seven studies with a very limited number of subjects ($n = 20$) was unable to attribute a predictive function for periodontitis progression or tooth loss to the periodontal risk assessment (PRA), but the other six studies confirmed such predictive value. Authors commented that this result may have been influenced by a more aggressive treatment approach including more extractions at initial therapy as baseline was defined as before initial therapy. The last tool, the dentition risk system, was evaluated in 183 individuals recruited by seven dental practitioners from five clinics in Sweden (Lindskog et al. 2010).

Taken together, these data support the possibility to predict periodontitis progression and tooth loss in a treated population based on risk segmentation using these tools. No data, however, are available on the impact that such risk assessment may have on patient management. In this respect, the use of risk assessment to determine the frequency of supportive periodontal care appointments has been proposed along with the idea that it may help in treatment

planning. While rationale, these suggestions remain unsubstantiated. In this situation of incomplete knowledge, however, clinicians may wish to consider application of risk assessment tools to improve their ability to identify, communicate and manage the multifactorial nature of periodontitis. Both PRC and PRA seem well suited to satisfy the goals proposed with patient-based risk assessment (Tonetti 1998). It appears, however, particularly important to emphasize that risk segmentation of recall populations with PRA or its modifications have been validated in multiple populations and settings around the world (Brazil, China, France, Germany, India, Sweden and Switzerland), increasing the generalizability and external validity of the tool and therefore the potential applicability to clinical practice.

References

- Busby, M., Chapple, E., Matthews, R. & Chapple, I. L. (2013) Practitioner evaluation of a novel online integrated oral health and risk assessment tool: a practice pilot. [Erratum appears in *Br Dent J* 2013 Sep;215(5):212]. *British Dental Journal* **215**, 115–120.
- Busby, M., Chapple, L., Matthews, R., Burke, F. J. & Chapple, I. (2014) Continuing development of an oral health score for clinical audit. *British Dental Journal* **216**, E20.
- Chambrone, L., Chambrone, D., Lima, L. A. & Chambrone, L. A. (2010) Predictors of tooth loss during long-term periodontal maintenance: a systematic review of observational studies. *Journal of Clinical Periodontology* **37**, 675–684. available from: PM:20528960
- Chandra, R. V. (2007) Evaluation of a novel periodontal risk assessment model in patients presenting for dental care. *Oral Health & Preventive Dentistry* **5**, 39–48.
- Chapple, I. L. (2007) Management of periodontal diseases within the NHS three years on: are things any better? *British Dental Journal* **202**, 569–570.
- Claffey, N., Nylund, K., Kiger, R., Garrett, S. & Egelberg, J. (1990) Diagnostic predictability of scores of plaque, bleeding, suppuration and probing depth for probing attachment loss. 3 ½ years of observation following initial periodontal therapy. *Journal of Clinical Periodontology* **17**, 108–114. available from: PM:2406292
- Costa, F. O., Cota, L. O., Lages, E. J., Lima Oliveira, A. P., Cortelli, S. C., Cortelli, J. R., Lorentz, T. C. & Costa, J. E. (2012) Periodontal risk assessment model in a sample of regular and irregular compliers under maintenance therapy: a 3-year prospective study. *Journal of Periodontology* **83**, 292–300.
- Eickholz, P., Kaltschmitt, J., Berbig, J., Reitmeir, P. & Pretzl, B. (2008) Tooth loss after active periodontal therapy. I: patient-related factors for risk, prognosis, and quality of outcome. *Journal of Clinical Periodontology* **35**, 165–174.
- Eshwar, S., Ankola, A. V., Kumar, A. & Hebhal, M. (2010) Evaluation of periodontal risk assessment model among adults aged 30–60 years attending KLE Dental College, Belgaum: a hospital-based study. *Journal of Indian Society of Periodontology* **14**, 173–177.
- Fors, U. G. & Sandberg, H. C. (2001) Computer-aided risk management—a software tool for the Hidep model. *Quintessence International* **32**, 309–320.
- Giannobile, W. V., Braun, T. M., Caplis, A. K., Doucette-Stamm, L., Duff, G. W. & Kornman, K. S. (2013) Patient stratification for preventive care in dentistry. *Journal of Dental Research* **92**, 694–701. available from: PM:23752171
- Haffajee, A. D., Socransky, S. S., Lindhe, J., Kent, R. L., Okamoto, H. & Yoneyama, T. (1991) Clinical risk indicators for periodontal attachment loss. *Journal of Clinical Periodontology* **18**, 117–125.
- Jansson, H. & Norderyd, O. (2008) Evaluation of a periodontal risk assessment model in subjects with severe periodontitis. A 5-year retrospective study. *Swedish Dental Journal* **32**, 1–7.
- Lang, N. P., Joss, A., Orsanic, T., Gusberti, F. A. & Siegrist, B. E. (1986) Bleeding on probing. A predictor for the progression of periodontal disease? *Journal of Clinical Periodontology* **13**, 590–596. available from: PM:3489010
- Lang, N. P. & Tonetti, M. S. (1996) Periodontal diagnosis in treated periodontitis. Why, when and how to use clinical parameters. [Review] [102 refs]. *Journal of Clinical Periodontology* **23**, 240–250.
- Lang, N. P. & Tonetti, M. S. (2003) Periodontal risk assessment (PRA) for patients in supportive periodontal therapy (SPT). *Oral Health & Preventive Dentistry* **1**, 7–16.
- Leininger, M., Tenenbaum, H. & Davideau, J. L. (2010) Modified periodontal risk assessment score: long-term predictive value of treatment outcomes. A retrospective study. *Journal of Clinical Periodontology* **37**, 427–435.
- Lindskog, S., Blomlof, J., Persson, I., Niklason, A., Hedin, A., Ericsson, L., Ericsson, M., Jarncrantz, B., Palo, U., Tellefsen, G., Zetterstrom, O. & Blomlof, L. (2010) Validation of an algorithm for chronic periodontitis risk assessment and prognostication: risk predictors, explanatory values, measures of quality, and clinical use. *Journal of Periodontology* **81**, 584–593.
- Lü, D., Meng, H., Xu, L., Lu, R., Zhang, L., Chen, Z., Feng, X., Shi, D., Tian, Y. & Wang, X. (2013) New attempts to modify periodontal risk assessment for generalized aggressive periodontitis: a retrospective study. *Journal of Periodontology* **84**, 1536–1545.
- Martin, J., Page, R., Kaye, E., Hamed, M. T. & Loeb, C. (2009) Periodontitis severity plus risk as a tooth loss predictor. *Journal of Periodontology* **80**, 202–209.
- Martin, J., Page, R., Loeb, C. & Kaye, E. (2011) Reduction of tooth loss associated with periodontal treatment. *International Journal of Periodontics and Restorative Dentistry* **31**, 471–479.
- Martin, J., Page, R., Loeb, C. & Levi, P. Jr. (2010) Tooth loss in 776 treated periodontal patients. *Journal of Periodontology* **81**, 244–250.
- Matuliene, G., Pjetursson, B. E., Salvi, G. E., Schmidlin, K., Bragger, U., Zwahlen, M. & Lang, N. P. (2008) Influence of residual pockets on progression of periodontitis and tooth loss: results after 11 years of maintenance. *Journal of Clinical Periodontology* **35**, 685–695. available from: PM:18549447

- Matuliene, G., Studer, R., Lang, N. P., Schmidlin, K., Pjetursson, B. E., Salvi, G. E., Bragger, U. & Zwahlen, M. (2010) Significance of periodontal risk assessment in the recurrence of periodontitis and tooth loss. *Journal of Clinical Periodontology* **37**, 191–199.
- Meyer-Bäumer, A., Pritsch, M., Cosgarea, R., El, S. N., Kim, T. S., Eickholz, P. & Pretzl, B. (2012) Prognostic value of the periodontal risk assessment in patients with aggressive periodontitis. *Journal of Clinical Periodontology* **39**, 651–658.
- Page, R. C., Krall, E. A., Martin, J., Mancl, L. & Garcia, R. I. (2002) Validity and accuracy of a risk calculator in predicting periodontal disease. *Journal of the American Dental Association* **133**, 569–576.
- Page, R. C., Martin, J. A. & Loeb, C. F. (2005) The Oral Health Information Suite (OHIS): its use in the management of periodontal disease. *Journal of Dental Education* **69**, 509–520.
- Page, R. C., Martin, J., Krall, E. A., Mancl, L. & Garcia, R. (2003) Longitudinal validation of a risk calculator for periodontal disease. *Journal of Clinical Periodontology* **30**, 819–827. available from: PM:12956658
- Papapanou, P. N. (1996) Periodontal diseases: epidemiology. *Annals of Periodontology* **1**, 1–36. available from: PM:9118256
- Persson, G. R., Attström, R., Lang, N. P. & Page, R. C. (2003a) Perceived risk of deteriorating periodontal conditions. *Journal of Clinical Periodontology* **30**, 982–989.
- Persson, G. R., Mancl, L. A., Martin, J. & Page, R. C. (2003b) Assessing periodontal disease risk: a comparison of clinicians' assessment versus a computerized tool. *Journal of the American Dental Association* **134**, 575–582.
- Persson, G. R., Matuliene, G., Ramseier, C. A., Persson, R. E., Tonetti, M. S. & Lang, N. P. (2003c) Influence of interleukin-1 gene polymorphism on the outcome of supportive periodontal therapy explored by a multi-factorial periodontal risk assessment model (PRA). *Oral Health & Preventive Dentistry* **1**, 17–27.
- Renvert, S., Ohlsson, O., Persson, S., Lang, N. P. & Persson, G. R. (2004) Analysis of periodontal risk profiles in adults with or without a history of myocardial infarction. *Journal of Clinical Periodontology* **31**, 19–24. available from: PM:15058370
- Renvert, S. & Persson, G. R. (2004) Patient-based assessments of clinical periodontal conditions in relation to alveolar bone loss. *Journal of Clinical Periodontology* **31**, 208–213.
- Sandberg, H. (2004) Practice management based on risk assessment. *Oral Health & Preventive Dentistry* **2** (Supplementum 1): 293–299.
- Sandberg, H. C. & Fors, U. G. (2007) The HI-DEP model—a straightforward dental health care model for prevention-based practice management. *Swedish Dental Journal* **31**, 171–179.
- Socransky, S. S., Haffajee, A. D., Goodson, J. M. & Lindhe, J. (1984) New concepts of destructive periodontal disease. *Journal of Clinical Periodontology* **11**, 21–32. available from: PM:6582072
- Teich, S. T. (2013) Risk Assessment-Based Individualized Treatment (RABIT): a comprehensive approach to dental patient recall. *Journal of Dental Education* **77**, 448–457.
- Thyvalikakath, T. P., Padman, R. & Gupta, S. (2013) An integrated risk assessment tool for team-based periodontal disease management. *Studies in Health Technology & Informatics* **192**, 1150.
- Tonetti, M. S. (1998) Cigarette smoking and periodontal diseases: etiology and management of disease. *Annals of Periodontology* **3**, 88–101. available from: PM:9722693
- 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. *Journal of Clinical Periodontology* **32** (Suppl 6), 210–213. available from: PM:16128839
- Trombelli, L., Farina, R., Ferrari, S., Pasetti, P. & Calura, G. (2009) Comparison between two methods for periodontal risk assessment. *Minerva Stomatologica* **58**, 277–287.
- Wells, G. A., Shea, B., O'Connell, D., Peterson, J., Welch, V., Losos, M. & Tugwell, P. (2009) The Newcastle-Ottawa Scale (NOS) for assessing the quality of nonrandomised studies in meta-analyses. Department of Epidemiology and Community Medicine, University of Ottawa, Canada. <http://www.lri.ca/programs/ceu/oxford.htm>.

Supporting Information

Additional Supporting Information may be found in the online version of this article:

Table S1. Basic search strategy.

Table S2. Excluded articles with reasons.

Table S3. Cross-sectional studies reporting multidimensional risk assessment tools.

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Clinical Relevance

Scientific rationale for the study: It would be clinically beneficial to stratify subjects into risk categories using tools accounting for the multifactorial nature of the disease as this may help in improving case prognosis and management after

completion of active periodontal therapy.

Principal findings: Results from this systematic review indicate that risk assessment tools such as the Periodontal Risk Calculator or the Periodontal Risk Assessment are predictors of periodontitis progres-

sion and tooth loss in treated populations.

Clinical implications: Even in the absence of direct evidence of the clinical utility of risk assessment in patient management, clinicians may consider application of these principles to clinical practice.