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Consensus Report of the 20th European Workshop on Periodontology: Contemporary and Emerging Technologies in Periodontal Diagnosis

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ABSTRACT

Background: This Consensus Workshop dealt with diagnostic methodologies in the context of surveillance, screening, assessment of stage and grade, prognosis, monitoring and prediction of periodontal status. Several elements provided the impetus for the workshop, including the limited quality of available research on diagnostic tests, the rapid development of new technologies, the implementation of the 2018 classification and the declarations of the World Health Organisation on diagnosis and oral health.

Aim: To update and evaluate the evidence on diagnostic methods, considering recent advances in knowledge and the implementation of the 2018 classification.

Methods: The European Workshop Committee of the European Federation of Periodontology guided the development of a consensus report after commissioning eight systematic reviews within three working groups. The reviews were discussed during the in-person consensus meeting involving 70 participants from 21 different countries.

Results: Working Group 1 discussed innovations in traditional diagnostic approaches, justified manual probing as the reference standard and assessed the value of image-based methods. Working Group 2 analysed diagnostic tests based on microbial and host biomarkers and genetic diagnostic tests. Working Group 3 covered emerging technologies to be used within dental and non-dental clinical settings, focusing principally on the impact of questionnaire-based assessments and artificial intelligence systems (AIS) in interpreting different data modalities.

For affiliations refer to page 29.

Conclusion: Although manual periodontal probing is firmly established as the reference standard, additional approaches based on imaging, biomarkers, host genetics, questionnaires and the development of emerging applied data science methods (e.g., AIS) are increasingly integrated in periodontal diagnostics.

1 | Introduction

1.1 | Concepts of Diagnosis and Diagnostics

Diagnosis is the 'process of recognizing an injury, condition, or disease from the signs and symptoms the individual is displaying' (National Cancer Institute 2024). Diagnostics are 'medical devices, techniques and procedures used for in vitro and in vivo determination of physiological status or the presence and characteristics of a disease' (World Health Organization 2023a).

A broader concept of diagnosis embraces a process that involves surveillance, screening, staging, diagnosis, prognosis, monitoring and prediction of diseases and conditions (Bossuyt et al. 2015). For that process, different medical tests can be used, including imaging procedures, laboratory tests, information from medical histories, findings from physical examinations or combinations thereof, or any other method for collecting clinically relevant information.

1.2 | Research on Medical Tests

The evaluation of the accuracy of a medical test can be made by means of 'diagnostic accuracy studies' (DASs), which are designed to evaluate the ability of one or more medical tests to correctly classify study participants as having a target condition or not (Bossuyt et al. 2015). In this context, target conditions may be disease entities, the stage of disease, the response to or benefit from therapy or an event or condition in the future. In a DAS, the 'index test' is the one for which accuracy is being tested, although more than one index test can be assessed at the same time. The results of the index test(s) are compared with those of a reference standard, which represents the best available method for establishing the presence or absence of the target condition. Like index tests, DASs can include more than one reference standard.

When the results from a DAS are categorised as positive or negative, they are presented in 2×2 contingency tables, in which the outcomes generated by the index test are shown against those of the reference standard. From this table, the sensitivity of the index test will be the proportion of participants with the target condition who have a positive index test result, and the specificity is the proportion of participants without the target condition who have a negative index test. Positive and negative predictive values of the index test can also be calculated from the table (Bossuyt et al. 2015).

In some DASs, the outcomes of the index test are expressed through a continuous scale, and the categorisation of test results, as positive or negative, requires a cut-off value. When cut-offs can be defined, a receiver operating characteristic (ROC) curve can be prepared, which graphically represents the plot of sensitivity versus (1 − specificity) for each possible cut-off value. The area under the ROC curve (AUC) informs the overall diagnostic accuracy of the index test in a single numerical value (Bossuyt et al. 2015).

In addition to DASs, studies can also be designed to develop, validate or update prediction models for diagnostic or prognostic purposes (Moons et al. 2015).

1.3 | The Need for an Update in Periodontal Diagnostics

In the previous 19 European Workshops on Periodontology, dating back to 1993, periodontal diagnosis was not addressed as a specific topic, although it has frequently been part of working group topics, discussions and of the content of consensus reports. As an example, in the 7th European Workshop on Periodontology on the biology of periodontal and peri-implant diseases (Sanz, Lang, et al. 2011), two working groups focused on the main elements of the aetiopathogenesis of periodontitis, namely the microbial component (Sanz, van Winkelhoff, et al. 2011) and the host response (Kinane et al. 2011). In 2018, the current classification of periodontal and peri-implant diseases and conditions was proposed (Caton et al. 2018) and included clear case definitions to facilitate diagnosis for the diseases and conditions described. An update on the topic of diagnosis in periodontology and the associated diagnostic processes is thus timely and justified based upon the following considerations.

1.3.1 | Quality of Research on Diagnostic Tests

The currently available literature assessing diagnostic tests in dentistry in general, and periodontology in particular, falls short of equivalent medical standards. Although rarely used, multiple reference documents are available for DASs. These include a checklist for reporting DAS (STARD, STAndards for Reporting Diagnostic accuracy studies) (Bossuyt et al. 2015), tools for assessing quality, including both risk of bias and concerns regarding applicability (QUADAS-2, QUAlity of Diagnostic Accuracy Studies) (Whiting et al. 2011) and its extension for comparative studies (QUADAS-C) (Yang et al. 2021) and a checklist for reporting systematic reviews of DASs, referred to as diagnostic test accuracy studies (PRISMA-DTA, Preferred Reporting Items for a Systematic review and Meta-Analysis of Diagnostic Test Accuracy studies) (McInnes et al. 2018), which are available.

For studies developing, validating or updating a prediction model for diagnostic or prognostic purposes, a checklist for reporting (TRIPOD, Transparent Reporting of a multivariable prediction model for Individual Prognosis Or Diagnosis) (Moons et al. 2015) and a checklist for reporting clinical prediction models that use regression or machine learning methods (TRIPOD+AI) (Collins et al. 2024) are available.

1.3.2 | Development of New Technologies

Another important justification for evaluating the status of periodontal diagnosis is the development of different technologies that are dramatically improving our knowledge and understanding of different disease processes, allowing the development of diagnostic tests with substantial potential. Good examples are 'omics' approaches, which encompass multiple molecular disciplines that involve the characterisation of global sets of biological molecules, such as DNAs, RNAs, proteins or metabolites (Institute of Medicine 2012), and associated technologies and, more recently, multi-omics approaches (Wang et al. 2024). However, the development of technologies and techniques to process huge amounts of data obtained through omics approaches or for the use of artificial intelligence (AI) sy tools is critical to progress in this field.

1.3.3 | Publication and Implementation of the 2018 Classification

A key reason to review periodontal diagnosis is the publication, in 2018, of the current classification of periodontal and peri-implant diseases and conditions (Caton et al. 2018), with clear proposals of case definitions to support the diagnosis of periodontal and peri-implant diseases. Based on these case definitions, the European Federation of Periodontology (EFP) developed and published different clinical practice guidelines (CPGs), for the treatment of stages I–III periodontitis (Sanz et al. 2020), for the treatment of stage IV periodontitis (Herrera et al. 2022) and for the prevention and treatment of peri-implant diseases (Herrera et al. 2023).

1.3.4 | World Health Organisation Declarations

The Declaration 'Strengthening diagnostics capacity' of the World Health Organisation (WHO), after the 76th World Health Assembly in 2023, 'urges' Member States to proceed with the following (World Health Organization 2023b):

- Consider the establishment of national diagnostics strategies, as part of their national health plans, that include regulation, assessment and management of diagnostics and development of integrated networks to tackle all diseases and medical challenges, avoiding current silos often observed.
- Consider health technology assessment systems for the systematic evaluation of the effectiveness and cost effectiveness of diagnostics to support decision making for the selection of diagnostics for interventions for universal health coverage.
- Extend the scope of packages of essential diagnostic services and to make essential diagnostics available, accessible and affordable at the primary healthcare level.

These recommendations are in line with those presented after the 75th World Health Assembly on the 'prevention and control of non-communicable disease' (World Health Organisation 2022), highlighting the importance of oral health, which should be integrated into primary health care by 2030, being an essential component of universal health coverage. The potential benefits of integration include 'increased opportunities for prevention, early detection and control of related conditions and co-morbidities, and more equitable access to comprehensive, high quality health care' and give further importance to diagnostic processes. This message is further emphasised in the context of the development of digital technologies for oral health, including AI systems, which may increase 'early detection, surveillance and referral for oral diseases and conditions within primary care'.

2 | Objectives

The 20th European Workshop on Periodontology on "Periodontal Diagnosis: Contemporary and Emerging Technologies" aimed to update and evaluate the evidence on diagnostic methods, considering new advances in knowledge and the proposals provided by the 2018 classification.

Specifically, the 20th European Workshop on Periodontology aimed at the following:

- To understand the performance of the 2018 classification in periodontal diagnosis;
- To assess the performance of currently used traditional diagnostic methods based on clinical or image-based assessments;
- To assess the performance of currently used diagnostic methods based on the analysis of biomarkers and genetic tests;
- To identify current trends in emerging diagnostic technologies, in both dental-clinic and non-dental-clinic settings;
- To provide further impetus for high-quality research on diagnostic tests in periodontal practice.

3 | Methods

The project commenced in February 2024 (Table 1) and was led by an Organising Committee composed of members of the European Workshop Committee of the EFP. The complete list of workshop participants included the organising committee (7 persons), the responsible reviewers (16), 3 stakeholders representing the EFP, 3 stakeholders representing the American Academy of Periodontology (AAP), 2 observers representing the sponsor and 39 invited experts, totalling 70 participants from 21 different countries (see Figure 1).

The in-person meeting took place in La Granja de San Ildefonso, Segovia, Spain, from 10 to 13 November 2024. Three working groups (WGs) addressed specific aspects of the workshop, each including three reviews, except WG3, which included two reviews. These reviews provided the basis for the subsequent discussions and consensus (Table 2).

3.1 | Working Group 1 (WG1): Contemporary and Emerging Methods for Clinical Examination and Imaging in Periodontal Diagnosis

WG1, chaired by Iain Chapple and Mariano Sanz (Table 3 and Figure 2), reviewed the performance and implementation of the 2018 classification as well as emerging methods for

TABLE 1 | Outline of the 20th European Workshop on Periodontology on periodontal diagnosis.

February 2024	• Decision on and invitation of: (i) topics and (ii) reviewers. • Invitations to be sent to reviewers. • Discussion with reviewers to align reviews within each working group.
April 2024	• Deadline for submission of the protocol for initial validation, including objectives, co-authors and methodology, to be assessed by the working group chairs.
May 2024	• Decision on and invitation of (iii) participants. • Invitations to be sent to participants.
August 2024	• Deadline for draft paper submission to working group chairs, for assessment of consistency among reviews.
October 2024	• Deadline for paper submission to the *Journal of Clinical Periodontology* for conventional peer-review process. • Electronic circulation of reviews drafts. • Submission of conflict-of-interest forms filled.
October–December 2024	• Peer review process for reviews in the *Journal of Clinical Periodontology*.
November 2024	• The 20th European Workshop of Periodontology at the Parador de la Granja (Segovia—Spain), 10–13 November 2024.
December 2023—March 2024	Preparation of consensus report, submission to *Journal of Clinical Periodontology*. Peer review process for consensus report in the *Journal of Clinical Periodontology*.
March–April 2024	Final publication, as special issue, in the *Journal of Clinical Periodontology*. The special issue to include the following: • Consensus report. • Three reviews from Working Group 1. • Three reviews from Working Group 2. • Two reviews from Working Group 3.

FIGURE 1 | Workshop participants during the in-person meeting in La Granja de San Ildefonso, Segovia, Spain.

TABLE 2 | Working Groups (WGs) with the respective WG chairs and review papers, with their responsible authors.

Working group	WG chairs	Topics	Reviews	Responsible authors
WG1—Traditional	Iain Chapple, Mariano Sanz	Periodontal diagnosis and examination methodologies	Evaluating the performance and implementation of the 2018 Classification of Periodontal Diseases. A systematic review	Filippo Graziani, Nicola West
			Methods for clinical assessment in periodontal diagnostics. A systematic review.	Giovanni Salvi, Anders Verket
			Accuracy of ionising and non-ionising radiation-based imaging assessments for the diagnosis of periodontitis: Systematic review and metanalysis.	Maria Clotilde Carra, Nicola Discepoli
WG2—Biomarkers	Moritz Kebschull, Panos Papapanou, Anton Sculean	Biomarkers in diagnosis and risk assessment	Microbial markers for diagnosis and risk assessment for periodontal diseases: a systematic review	Nagihan Bostanci, Wim Teughels
			Host markers of periodontal diseases: meta-analysis with meta-regression of diagnostic accuracy studies	Philip Preshaw, Mia Rakic
			Genetic and epigenetic biomarkers for diagnosis, prevention and management of periodontitis: a systematic review	Henrik Dommisch, Luigi Nibali
WG3—Emerging	David Herrera, Maurizio Tonetti	Emerging approaches and technologies	Emerging applications of digital technologies for periodontal screening, diagnosis, and prognosis in the dental setting	Roberto Farina, Christoph Ramseier
			Emerging technologies and algorithms for periodontal screening and risk of disease progression in non-dental settings: a scoping review	Thomas Dietrich, Eduardo Montero

TABLE 3 | Roles and countries of participants in Working Group 1.

WG1—Traditional		
Role	**Full name**	**Country**
Chair 1	Mariano Sanz	Spain
Chair 2	Iain Chapple	UK
Reviewer 1	Filippo Graziani	Italy
Reviewer 2	Nicola West	UK
Reviewer 3	Giovanni Salvi	Switzerland
Reviewer 4	Anders Verket	Norway
Reviewer 5	Maria Clotilde Carra	France
Reviewer 6	Nicola Discepoli	Italy
AAP representative	Brian Mealey	USA
EFP representative	Spyros Vassilopoulos	Greece
UCM expert	Paula Matesanz	Spain
Kenvue representative	Susana de la Torre S.	Spain
Participant 1	Mario Aimetti	Italy
Participant 2	Juan Blanco	Spain
Participant 3	Nikos Donos	UK
Participant 4	Peter Eickholz	Germany
Participant 5	Ricardo Faria Almeida	Portugal
Participant 6	Elena Figuero	Spain
Participant 7	Karin Jepsen	Germany
Participant 8	Niklaus P. Lang	Switzerland
Participant 9	Bruno Loos	The Netherlands
Participant 10	Andreas Stavropoulos	Sweden
Participant 11	Peter Windisch	Hungary

Abbreviations: AAP, American Academy of Periodontology; EFP, European Federation of Periodontology; UCM, University Complutense of Madrid.

clinical examination and imaging in periodontal diagnosis. The review of the 2018 classification was led by Nicola West and Filippo Graziani (West et al. 2025); the review covering clinical assessments was led by Giovanni Salvi and Anders Verket (Stødle et al. 2025), and the third review, on the accuracy of imaging-based assessments, was led by Maria Clotilde Carra and Nicola Discepoli (Discepoli et al. 2025).

3.2 | Working Group 2 (WG2): Biomarkers in Periodontal Diagnosis and Risk Assessment

WG2, chaired by Moritz Kebschull, Panos Papapanou and Anton Sculean (Table 4 and Figure 3), covered the use of biomarkers in the diagnosis and risk assessment of periodontal diseases. The review on microbial biomarkers was led by Nagihan Bostanci and Wim Teughels (Bostanci et al. 2025); the review on host-derived markers was led by Philip Preshaw and Mia Rakic (Rakic et al. 2025); and the review on genetic and epigenetic biomarkers was led by Henrik Dommisch and Luigi Nibali (Dommisch et al. 2025).

3.3 | Working Group 3 (WG3): Emerging Approaches and Technologies for Periodontal Diagnosis

WG3, chaired by David Herrera and Maurizio Tonetti (Table 5 and Figure 4), focused on emerging technologies, including the use of algorithms developed from different data sources, and on various emerging methods in applied data science. Roberto Farina and Christoph Ramseier led the review of approaches designed for use in clinical dental settings (Farina et al. 2025), and Thomas Dietrich and Eduardo Montero led those applicable in non-dental settings (Montero et al. 2025).

4 | Periodontal Diagnosis: General Considerations

4.1 | What Reference Standard Should Be Used in Periodontal Diagnostic and Prognostic Trials?

The reference standard of periodontal diagnostic trials should align with the current case definitions agreed upon in the 2018 Classification of Periodontal and Peri-implant Diseases and

FIGURE 2 | Workshop participants in Working Group 1.

Conditions (Caton et al. 2018). These definitions consist of periodontal health (Lang and Bartold 2018), dental biofilm-induced gingivitis (Chapple et al. 2018) and periodontitis (Papapanou et al. 2018; Tonetti et al. 2018), and are based on detecting clinical attachment loss (CAL) and specific thresholds of inflammation:

- A case of periodontal health is characterised by limited gingival inflammation, that is, less than 10% of sites with bleeding on probing (BOP) and without CAL attributable to periodontitis.
- A case of gingivitis is defined by gingival inflammation (≥10% of sites with BOP) without CAL attributable to periodontitis.
- A case of periodontitis is defined by detectable CAL at two or more non-adjacent teeth that is not attributable to other local factors.

In treated periodontitis patients, the patient remains a periodontitis patient and, thus, at risk of disease recurrence or progression, but may have a healthy but reduced periodontium or may have gingival inflammation on a reduced periodontium. The risk of recurrence or progression is higher in treated subjects with persistent pockets and inflammation (Chapple et al. 2018; Sanz et al. 2020).

The reference standard for prognostic trials should be based on the hard outcome of tooth loss or detecting disease progression, as evidenced by additional loss of periodontal clinical attachment (e.g., 2 mm) over a particular time period. Validated tools may be used as reference standards in prognostic trials predicting quality of life.

4.2 | How Are Reference Standards Measured?

Consistent with the 2018 classification, clinical attachment levels are assessed in a full-mouth examination involving six sites per tooth at all teeth present by a calibrated examiner using a standard periodontal probe. Similarly, gingival inflammation is estimated as the frequency of bleeding upon gentle probing (0.2–0.25 N).

The 2018 case definition allows the use of a reference standard for periodontitis based upon radiographically confirmed bone loss but highlights the fact that such a definition may create difficulties in capturing early stage periodontitis. Radiographs should be employed judiciously as a reference standard.

4.3 | How Do We Assess Whether a Novel Diagnostic Test Is Ready for Adoption?

Evaluating a new diagnostic test requires a multistep process, including the assessment of analytical performance, clinical performance, clinical effectiveness, cost effectiveness and broader impacts (Horvath et al. 2014).

Novel diagnostics undergo discovery and development phases focusing on their analytical validity. Analytical performance relates to the quality of the test itself, such as the coefficient of variation for a laboratory biomarker test or the internal consistency of a questionnaire. This process provides evidence of potential applicability but rarely offers adequate information on clinical utility. A key consideration is defining the target population and the purpose of the new test by considering how it would be integrated into a new or existing care pathway. As stated by Horvath et al. (2014), 'There is little point in investing a lot of effort into medical test development and evaluation unless the clinical pathway from testing to treatment decisions and health or other outcomes is clearly mapped and well understood, and there is an indication that the new biomarker will offer incremental benefits over existing clinical pathways'. Notably, the expected use and impact of the diagnostic test will inform all stages of test evaluation.

In general, sufficient clinical performance data established from robust, well-designed diagnostic trials should be a prerequisite for

TABLE 4 | Roles and countries of participants in Working Group 2.

WG2—Biomarkers		
Role	**Full name**	**Country**
Chair 1	Panos Papapanou	USA
Chair 2	Moritz Kebschull	UK
Chair 3	Anton Sculean	Switzerland
Reviewer 1	Nagihan Bostanci	Sweden
Reviewer 2	Wim Teughels	Belgium
Reviewer 3	Mia Rakic	Serbia
Reviewer 4	Philip Preshaw	UK
Reviewer 5	Luigi Nibali	UK
Reviewer 6	Henrik Dommisch	Germany
AAP representative	Purnima Kumar	USA
EFP representative	Monique Danser	The Netherlands
UCM expert	Ana Molina	Spain
Kenvue representative	Soha Dattani	UK
Participant 1	Loreto Abusleme	Chile
Participant 2	Georgios Belibasakis	Sweden
Participant 3	Nurcan Buduneli	Turkiye
Participant 4	Coral Deng	China
Participant 5	Kimon Divaris	USA
Participant 6	Nicolás Dutzan	Chile
Participant 7	Ulvi K. Gursoy	Finland
Participant 8	Daniel Hagenfeld	Germany
Participant 9	Soren Jepsen	Germany
Participant 10	Marja L. Laine	The Netherlands
Participant 11	Phoebus Madianos	Greece
Participant 12	Lior Shapira	Israel

Abbreviations: AAP, American Academy of Periodontology; EFP, European Federation of Periodontology; UCM, University Complutense of Madrid.

applying a new test. These trials evaluate the benefits and harms in terms of health outcomes. They may also involve randomised controlled trials comparing downstream health outcomes between patients in whom the test was used and patients following the standard-of-care pathway. However, such trials are rarely performed, are often not feasible and may not be necessary.

As evidence accumulates from multiple trials, specific frameworks have been identified to evaluate the validity of a test to answer a particular diagnostic question at a given point in the care pathway. The *Cochrane Handbook for Systematic Reviews of Diagnostic Test Accuracy* (Deeks et al. 2023) is the accepted model for an evidence-based test evaluation. The process starts with systematically identifying the relevant evidence and its risk of bias using the QUADAS-2 criteria (Whiting et al. 2011). Meta-analyses in systematic reviews are best performed using Bayesian methods, which provide estimates of the diagnostic performance of the test and their credible intervals/regions. These are used to produce evidence tables using the GRADE framework (Schunemann et al. 2019). Critical parameters for interpretation are the strength and certainty of the evidence, the risk-of-bias assessment of individual studies, indirectness, inconsistency, imprecision and publication bias, all of which are used to estimate the certainty of the evidence. The credible range of diagnostic performance and the certainty of the evidence are primary factors in assessing the potential for adopting a novel test. In addition, the value of the test result for the individual or the population plays an important role. Careful consideration needs to be given to the effectiveness of the test when applied within its intended purpose as well as potential harms. Potential harms include adverse effects of the test itself and the consequences of false positive and false negative results.

Cost effectiveness is another crucial aspect to consider and may inform the implementation of the new test. For example,

FIGURE 3 | Workshop participants in Working Group 2.

TABLE 5 | Roles and countries of participants in Working Group 3.

WG3—Emerging		
Role	**Full name**	**Country**
Chair 1	Maurizio Tonetti	China
Chair 2	David Herrera	Spain
Reviewer 1	Roberto Farina	Italy
Reviewer 2	Christoph Ramseier	Switzerland
Reviewer 3	Thomas Dietrich	UK
Reviewer 4	Eduardo Montero	Spain
AAP representative	William Giannobile	USA
EFP representative	Tali Chackartchi	Israel
UCM expert	Nerea Sánchez	Spain
Participant 1	Philippe Bouchard	France
Participant 2	Elena Calciolari	UK
Participant 3	Bettina Dannewitz	Germany
Participant 4	Jan Derks	Sweden
Participant 5	Bahar Eren Kuru	Turkiye
Participant 6	Balazs Feher	USA
Participant 7	Marjolaine Gosset	France
Participant 8	France Lambert	Belgium
Participant 9	Ignacio Sanz-Sánchez	Spain
Participant 10	Faleh Tamimi	Qatar
Participant 11	Cristiano Tomasi	Sweden
Participant 12	Leonardo Trombelli	Italy
Participant 13	Yuan Li	China

Abbreviations: AAP, American Academy of Periodontology; EFP, European Federation of Periodontology; UCM, University Complutense of Madrid.

cost-effectiveness considerations may support the implementation of a test in a specific (e.g., high-risk) population only. Finally, the broader impact and consequences of test implementation in the 'real world' should be assessed. This may include patient and provider acceptability and uptake/use of the test in clinical practice, and it may inform further test development and modifications to the care pathway.

Judging 'readiness' for large-scale testing or clinical use requires a complex process. There are no generally applicable rules or thresholds of diagnostic performance that translate into applicability. A robust evidence base and an expert consensus are prerequisites for clinical introduction.

5 | Working Group 1: Periodontal Diagnosis and Examination Methodologies

5.1 | Introduction—Manual Periodontal Probing as the Standard of Care

The commissioned systematic reviews did not evaluate the standard of care in periodontal diagnosis: manual periodontal probing. Thus, the working group prepared this introductory section, identifying the most appropriate studies as a reference base.

The manual periodontal probe is considered the standard-of-care instrument for periodontal clinical diagnosis and evaluates the two main measurements of probing depth (PD) and clinical attachment level. PD is the distance from the gingival margin to the probeable base of the crevice/pocket, while clinical attachment level is defined as the distance from the cemento-enamel junction (CEJ) to the base of the probeable crevice/pocket, thus providing a clinical approximation of the histological attachment level. This is highly relevant in clinical diagnosis because the 2018 classification clearly states, 'the need to establish clinical attachment loss as the primary

FIGURE 4 | Workshop participants in Working Group 3.

definition of periodontitis', which requires that the CEJ is visible, or that the tip of the periodontal probe identifies the root surface below the CEJ.

BOP is a score that reflects the presence of bleeding from the base of the clinical pocket or sulcus in response to periodontal probing, when bleeding occurs within 10–30 s after probing (Joss et al. 1994). An individual patient's BOP score is calculated from the percentage of bleeding sites (Ainamo and Bay 1975; Lang et al. 1996). BOP is the main clinical diagnostic tool used to monitor inflammation of the periodontal tissues (Lang et al. 1996). Bleeding following probing with a force of 0.25 N provides an accurate representation of inflammation in periodontal tissues, as assessed in histological studies (Greenstein et al. 1981). However, the probability of a site being BOP positive is also related to site-specific anatomical factors (i.e., gingival tissue vascularisation and keratinisation), patient-related factors (i.e., sex hormone status, smoking status) and probing force (Farina et al. 2013). BOP is recommended as a measure of periodontal inflammation.

PD and CAL measurements have been validated with respect to accuracy (the degree of agreement between the measurement and the true [histological] value) and precision or reproducibility (the degree of agreement between repeated measurements, either intra- or inter-examiner). Accuracy in periodontal probing assesses how the probing measurements relate to the apical extent of the pocket epithelium/coronal level of connective tissue attachment, assessed histologically, and has been evaluated using two basic research methodologies:

1. comparing pre-extraction measurements of PD or CAL with post-extraction estimates of probe penetration relative to the histologically assessed pocket depth/connective-tissue attachment level; and
2. evaluating histologically the extent of probe penetration with pre-determined standardised pressures.

During periodontal probing, the tip of the probe may either pass the apical termination of the junctional epithelium or it may remain coronal to it, depending largely upon the status of the gingival tissues. Thus, when gentle probing forces (approximately 0.2–0.5 N) are used, the penetration of the probe tip is determined by the degree of inflammation of the periodontal tissues. At sites with moderate to severe inflammation, the periodontal probe typically penetrates the most apical level of the junctional epithelium by up to 0.5 mm, although mean values may range from −0.34 to +0.50 mm. At uninflamed sites, such as those that have been successfully treated, probes tend to stop coronal to the apical termination of the junctional epithelium (range −0.09 to −2.94 mm) (Aguero et al. 1995; Armitage 1996; Armitage et al. 1977; Fowler et al. 1982; Hancock and Wirthlin 1981; Jansen et al. 1981; Listgarten et al. 1976; Magnusson and Listgarten 1980; Polson et al. 1980; Robinson and Vitek 1979; Sivertson and Burgett 1976; Spray et al. 1978; van der Velden 1979, 1982; van der Velden and Jansen 1980). Indeed, there is evidence for a strong correlation (R-value ~0.7; $p < 0.01$) between the degree of inflammation and probe penetration beyond the junctional epithelium (Anderson et al. 1991). In summary, PD as a clinical measurement does not necessarily accurately reflect the amount of attachment loss or damage to periodontal tissues, as probe position depends on the inflammatory status and readings may fluctuate because of the variable position of the gingival margin (e.g., overgrowth, recession).

Intra- and inter-examiner reproducibility have been reported in terms of percentage agreement and intra-class correlation coefficient (ICC). When using standardised manual periodontal probes (0.4 mm tip with a standard force of 0.25–0.3 N), PD measurements and CAL are reproducible when taken at two different time points by trained and calibrated clinicians. In these studies, perfect agreement (0.0 mm) for PD measurements ranged from 33% to 70%, and the corresponding values for CAL measurements were 32%–71.7%. When the agreement

threshold was set at 1.0 mm, the percentage of agreement between the first and second examinations improved, with ranges being, for PD 81.2%–99.6% and for CAL 84.0%–98.8% (Armitage 1996; Badersten et al. 1984; Glavind and Loe 1967; Isidor et al. 1984; Janssen et al. 1987; Kingman et al. 1991; Mullally and Linden 1994; Smith et al. 1970; Wang et al. 1995). More recent studies achieved >95% agreement (Andrade et al. 2012; Fitzgerald et al. 2022; Lafzi et al. 2007). In terms of ICC, intra-examiner reproducibility has been found to range from 0.759 to 0.863, while values for inter-examiner reproducibility were lower and more variable (0.197–0.791) (Ramanauskaite et al. 2023).

When critically evaluating the reproducibility of periodontal probing, the following factors have been shown to affect the readings of CAL and PD: (i) diameter of the probe at the tip; (ii) graduation scale and tine; (iii) probe angulation, positioning and pressure applied; and (iv) degree of inflammation of the periodontal tissues.

By recording probe penetration as a function of force, PDs depend on the forces applied, with low probing forces having a greater impact on reproducibility than high probing forces. Measurement errors arising from variations in probing pressure applied by clinicians have identified variations in probing pressure (force) ranging from 0.03 to 1.3 N. Furthermore, depth–force characteristics vary before and after therapy, because the shrinkage resulting from therapy may require higher forces, as lower probing forces may overestimate the treatment effect. To minimise errors through variation in probing pressures, so-called pressure-sensitive probes have been developed with forces preset at a probing pressure of 0.3 N.

The probe tip diameter as well as the force has a significant effect on the resulting pressure. The combination of diameter and force (e.g., 0.6 mm diameter with 0.2 N force or 0.4 mm with 0.20–0.25 N force) provides ideal parameters to position the probe tip within the junctional epithelium (Garnick and Silverstein 2000; Keagle et al. 1989). There are numerous reports using various tip diameters (0.4, 0.5, 0.6, 0.8 and 1.0 mm).

Measurement errors also depend upon factors such as the diameter, the tine and the graduation scale of the probe tip, as well as the angulation or positioning of the probe. For example, differences in tine shape (taper) have demonstrated differences in probe accuracy measured histologically when applying the same probing forces (Barendregt et al. 1996; Bulthuis et al. 1998). Furthermore, the accuracy of millimetre distance marks and the diameter of the tip of periodontal probes from different manufacturers varies significantly (Kovalik et al. 2024). Hence, there is a need for standardised probes and careful examination techniques. Typically, probes with a tip diameter ranging from 0.4 to 1 mm have been utilised (Garnick and Silverstein 2000).

Reproducibility of BOP is affected by probing forces, probing angulation and the interval between probing sessions. Higher probing forces (>0.25 N) may result in false positive readings due to trauma (Lang et al. 1991). Angulated probing may underestimate BOP when compared to parallel probing (Van der Weijden et al. 1994), and consecutive measurements have shown a tendency for increasing BOP in patients with gingivitis (Muller and Barrieshi-Nusair 2005).

5.2 | Performance and Implementation of the 2018 Classification

5.2.1 | What Are the Benefits of the 2018 Classification System for Periodontal Assessment, With a Focus on Periodontitis?

The 2017 World Workshop on the Classification of Periodontal and Peri-implant Diseases and Conditions represented a step change, because the international community joined forces to create a unified classification system. The classification was published in 2018 (Caton et al. 2018) and included the development of case definitions. Periodontal health can occur on both an intact and a reduced periodontium. Gingival diseases were classified in detail to include non-biofilm-induced gingival conditions. Periodontitis was defined and subsequently classified using a biological approach rather than one based on simple clinical descriptors. Complexity criteria beyond severity and extent for staging of periodontitis were included. The need for inter-disciplinary approaches to care was also embedded for the first time through the definition of stage IV periodontitis, which implicitly entails a need for oral rehabilitation. Additionally, peri-implant diseases were classified, and case definitions were developed for patients encountered for the first time as well as for those in follow-up post implant placement.

A patient is initially diagnosed as periodontally healthy when he or she has neither gingivitis nor periodontitis. The periodontitis case is further classified according to stage and grade, which reflect disease severity and complexity (stage), extent (generalised, localised or molar-incisor) and rate of progression (grade). In addition, proven risk factors such as poorly controlled diabetes and smoking status were introduced as grade modifiers, embedding concepts of risk within the classification system for the first time. Finally, given the focus of the classification system on historical bone/attachment loss, clinical findings such as deep probing depths, severe furcation involvement and presence of deep intrabony defects were included in the staging framework to assess perceived complexity in treatment and hence to support the clinician in treatment planning.

5.2.2 | How Does the 2018 Classification System Perform Relative to Previous Classification Systems?

According to the systematic review (West et al. 2025), eight studies assessed the diagnostic accuracy of the 2018 classification case definitions, all using the 2012 American Academy of Periodontology (AAP)/Centers for Disease Control and Prevention (CDC) case definitions (Eke et al. 2012) as the reference standard. Compared to the 2012 AAP/CDC case definitions, the 2018 classification was regarded as having high sensitivity (0.92–1.00) for the detection of periodontitis but exhibited variable specificity (0.25–0.92). However, for use in clinical practice, it is inappropriate to employ the 2012 AAP/CDC case definitions as the reference gold-standard definition, as they were designed

for population-based surveillance of periodontitis. No other comparisons with prior classification systems (1989, 1993, 1999) could be made.

5.2.3 | How Does the Classification System Perform Prognostically in Predicting Tooth Loss due to Periodontitis?

In the systematic review (West et al. 2025), two retrospective cohort studies assessed the prognostic capability of the 2018 classification against the clinical endpoint of tooth loss due to periodontitis. One study compared the 2018 classification to the 1999 AAP classification, reporting similar predictive values for tooth loss (AUC = 59.2% and 58.2%, respectively). It is important to mention that significantly more teeth were lost during supportive periodontal care (SPC) in patients with stage IV or grade C disease compared to other stages or grades. Patients' adherence to SPC seems to have an impact on the predictability of the 2018 classification. A second study compared the 2018 classification with the British Society of Periodontology (BSP)-Implementation (adaptation) of the 2018 classification. The prognostic performance of both systems was very similar (0.922 for the 2018 classification and 0.925 for the BSP adaptation). In that study, the performance of the 2018 classification system in predicting tooth loss due to periodontitis was graded as excellent according to a Harrel's index > 0.92 for staging and grading.

5.2.4 | How Reproducible Is the 2018 Classification System Across Practitioners of Differing Levels of Expertise and Training?

Three studies (West et al. 2025) have assessed elements of intra- and inter-examiner reliability related to the 2018 classification. The overall inter-examiner reliability was found to be moderate (range 0.37–0.51) in two studies, and intra-examiner reliability was moderate to very good (range 0.52–0.85) in one study.

In terms of level of expertise, the percentage of agreement compared to gold-standard examiners varied: for undergraduate dental students (81.6% for stage, 74.4% for grade), post-graduate students (68.2% for stage, 82.3% for grade), general dentists (64.4% for stage, 67.6% for grade), periodontal specialists (65.6%–82.0% for stage, 72.4%–86.1% for grade) and university faculty (71.4% for stage, 80.8% for grade). It should be noted that gold-standard examiners were different in each study and varied in number.

5.2.5 | What Are the Reported Barriers to the Universal Implementation of the 2018 Classification in Relation to Clinical Practice and Epidemiological Studies?

In clinical practice, the barriers reported mainly refer to the complexity of the classification system. The classification has been perceived as complex because of the significant number of clinical and radiological components involved in the assessment of stage and grade. Based on data from 1113 interviewees from 95 countries, and within periodontally aware professionals (specialists and those with a special interest), 22% of the sample found the classification to be 'somewhat to very difficult'. Moreover, subjectivity in the interpretation of criteria was perceived as a factor that would enhance difficulty in the assessment of stage and grade. Borderline cases were more difficult to distinguish from each other, and decision-making trees and algorithms may help mitigate this problem. A lack of historical data and information on the causes of tooth loss was reported as one of the reasons for difficulty in applying the classification. One specific issue highlighted is that some national insurance schemes have not incorporated the 2018 classification, and this may therefore negatively impact its implementation.

For epidemiological studies, some concerns were raised on the use of the 2018 classification, particularly in relation to the need for full-mouth clinical and radiographic examination. Because of the large sample sizes involved in epidemiological studies, detailed clinical and radiological evaluations are not practical or feasible. Moreover, the reasons for tooth loss can rarely be determined, leading to a potential underestimation of severe cases. The periodontitis case definition leads to a very high prevalence of incipient disease (stages I and II), which may potentially create important public health concerns related to resources.

5.2.6 | What Modifications to the Original 2018 Classification Should Be Considered in Light of Reported Experience and Uptake?

Based on the aforementioned reported barriers for the implementation of the 2018 classification, some modifications may be considered, which will benefit its implementation, such as reducing process complexity, time to perform, reducing overlapping diagnostic thresholds for cases (gingivitis vs. periodontitis in stage I and stage III vs. stage IV periodontitis) and reasons for tooth loss.

There is a need to consider adapting the classification for implementation in epidemiological studies.

In the future, implementation of AI-assisted methods or other technological advances may simplify the use of the classification in clinical practice and improve efficiency.

5.3 | Methods for Clinical Assessment in Periodontal Diagnostics

5.3.1 | What Clinical Measures Are Recommended to Determine Periodontal Status in Untreated Periodontitis Patients and Those in Supportive Periodontal Care?

After collecting a thorough patient history, the recording of the following variables is recommended: plaque levels, PD, CAL, BOP, suppuration and gingival recession (REC) at six sites per tooth and furcation lesions and tooth mobility (mobility measures should be considered in relation to the height of the periodontal attachment). In patients undergoing SPC, there is no clear benefit in recording all these variables at each appointment. However, even in the absence of significant concerns, there is a need to monitor the patient's periodontal

status by recording a simplified set of parameters (e.g., BOP and PD above a certain threshold, e.g., > 4 mm) at all appointments. Such a monitoring system, however, cannot capture subtle changes characterising progressive CAL without significant pocketing, and hence there is a need to monitor the patient periodically, either by measuring CAL or using radiographs with PD measures. There is no evidence for an optimal time interval (e.g., every 1 or 2 years).

5.3.2 | Which Methods Represent the Standard of Care?

As justified in Section 5.1, the manual periodontal probe is considered the standard-of-care instrument for periodontal clinical diagnosis, which evaluates the three main measurements of BOP, PD and CAL.

5.3.3 | What Is the Evidence for Alternative Methods to Traditional Probing (PD, CAL, BOP, Furcation Involvement) and How Do They Compare in Terms of Accuracy, Reliability and Patient-Reported Outcomes?

Alternative methods that have been compared with traditional manual probing include electronic and manual constant-pressure, pressure-sensitive, temperature and ultrasonographic probes. There is no currently available evidence of their accuracy because of a lack of histological studies comparing manual probing versus these alternative probing methods. According to the systematic review conducted for this workshop (Stødle et al. 2025), and based on the 26 included studies comparing manual probes to emerging probing technologies, the latter did not demonstrate superior outcomes in terms of reproducibility when compared to manual probes.

When assessing the relevance of direct data entry and pressure-sensitive probing to reduce the inherent variability of manual probing, one study reported a mean standard deviation (SD) of repeated PD measurements of 0.58 mm for an electronic constant-force probe system compared to 0.82 mm for manual probing (Gibbs et al. 1988). However, another study reported similar levels of reproducibility when probing with a single pass (SD = 0.66 mm for electronic vs. SD = 0.62 mm for manual), which improved from 0.66 to 0.54 mm when using the electronic probe in a double pass (Osborn et al. 1990), or a high degree of agreement when comparing PD with manual versus an automated force-controlled electronic probe (59.1% vs. 41.3%) (Wang et al. 1995). Importantly, with deep PD measurements, electronic probes consistently record lower depths compared to manual probing (Stødle et al. 2025).

Similarly, in evaluating the intra-examiner reproducibility of relative attachment level measurements following a double pass using electronic constant-force probes, compared with a manual probe (single pass), the mean intra-examiner SD was 0.59 and 0.88 mm, respectively (Osborn et al. 1990). This highlights the methodological strength of double-pass measurements in clinical research.

Alternative probing methods (electronic and manual constant-pressure, pressure-sensitive probes) do not appear to alter patient-reported outcomes or experiences (pain on probing, time of examination) when compared to traditional probing. With respect to pain on probing, conflicting data have been published, as comparative studies have reported higher discomfort with the use of electronic constant-force probes (Chapple et al. 1999; Mishra et al. 2016), while others have reported higher discomfort with manual probes, and some, no differences (Laugisch et al. 2021).

5.3.4 | Based on the Currently Available Evidence in the Context of Periodontitis, Which Technologies Are Recommended to Examine Periodontal Status (PD, CAL, BOP) Clinically for Routine Clinical Care, Clinical Research Studies and Epidemiological Studies?

Evidence from the systematic review by Stødle et al. (2025) did not show any superiority for emerging probing technologies when compared with standard manual probing in any of the above three settings. However, double-pass measurements with the electronic constant-force probe have demonstrated lower intra-examiner variability when measuring PD and CAL. Therefore, this methodology may be considered in clinical research settings, but such decisions need to accommodate higher pain reported with electronic probes in some studies and recognise that accuracy and reproducibility are quite different concepts.

Considering the lack of significant improvements when evaluating the evidence for the use of emerging probe technologies, and for reasons of cost effectiveness and availability, manual probing remains the recommended technique for routine clinical care and for epidemiological studies. Future research and development are needed.

5.3.5 | What Are the Critical Components of a Contemporary Standardised Periodontal Probe?

The contemporary manual probe should include the following components: tip diameter 0.5 mm, cylindrical tine structure, constant force limiter of 0.25 N, 15-mm scale with precise individual or banded millimetre markings and a taper of 1.75° (Chapple et al. 2018).

5.3.6 | What Clinical and Radiological Measures Are Recommended to Evaluate Furcation Involvement in Untreated Periodontitis Patients and Those in Supportive Periodontal Care?

The commissioned systematic reviews did not include the evaluation of furcation involvement (FI), and the information provided here was prepared by the working group by identifying the most appropriate references.

The severity of FI is categorised as 0, I, II or III (Eickholz and Walter 2018; Hamp et al. 1975), and it is assessed by probing the respective furcation in a horizontal direction using a rigid curved probe (e.g., Nabers probe). The distance (horizontal CAL in mm [CAL-H]) is measured from the probe tip to a 'virtual' tangent to the root convexities adjacent to the furcation

(Eickholz and Walter 2018). The distinction between class II and III FI may be complex because even curved probes may struggle to negotiate passage through the furcation channel in class III lesions (Ammons and Harrington 2006). However, intra-examiner reproducibility in categorising and measuring CAL-H at buccal, lingual and mesio-lingual furcation entrances has been rated as excellent, while in distolingual furcations it was only moderate (Eickholz and Kim 1998; Eickholz and Staehle 1994). Similarly, studies evaluating the accuracy of probing, compared with the gold standard of intra-surgically measured FI, have shown that a curved rigid furcation probe (Nabers probe) resulted in greater accuracy compared to a straight rigid (UNC-PCP-15) probe and a pressure-controlled flexible plastic (*True Pressure Sensitive Probe*, TPS) probe. Furthermore, the disto-lingual location and presence of a neighbouring tooth were both associated with reduced accuracy (Eickholz 1995; Eickholz and Kim 1998).

The use of two-dimensional (2D) radiographic techniques is based on identifying a radiolucency at the furcation location, thus providing information on loss of bone density. However, the furcation region enhances the problems of projection and superimposition of other anatomical structures associated with 2D radiography, making the diagnosis of FI unreliable (Topoll et al. 1988). Furthermore, 2D radiographs do not provide any information on soft-tissue attachment, which is particularly relevant when evaluating the effect of regenerative therapies, where new connective tissue attachment within the furcation can be attained without new bone formation.

5.4 | Use of Ionising and Non-Ionising Imaging Methods for Diagnosis of Periodontitis in Untreated Individuals and Recurrence During Supportive Periodontal Care

Currently, radiographic examination of the hard-tissue component of the periodontium is undertaken to support and augment findings from the patient history and clinical examination. The diagnosis is primarily based on findings from the clinical examination, but radiological assessment facilitates disease classification and prognosis.

5.4.1 | What Radiological Methods Are Recommended to Determine Periodontal Status in Untreated Periodontitis Patients and Those in Supportive Care, and What Are Their Limitations?

Two-dimensional radiography is the gold-standard imaging method for assessing periodontal health/disease status in untreated individuals and alveolar bone changes during SPC. Indeed, while technically not eligible for the review by Discepoli et al. (2025), the plenary noted that there is evidence of a strong correlation ($r = 0.8$) between radiographic and clinical assessments of interproximal loss of support (Papapanou and Wennstrom 1989). However, when planning radiographic investigations for periodontal diagnosis, due consideration must be given to minimising the exposure of the patient to ionising radiation by employing digital methods with rectangular collimation and complying with national radiation protection guidelines.

Traditional 2D radiological imaging modalities evaluated in the systematic review (Discepoli et al. 2025) were orthopantomography (OPT) and periapical and bitewing radiography.

OPT is used routinely as an extraoral imaging method and provides a valuable screening tool that is less time consuming for the oral healthcare professional. The quality of panoramic images has improved as a result of advances in digitisation (Persson et al. 2003; Tugnait et al. 2000), and a large amount of information can be obtained while exposing the patient to a comparatively low level of ionising radiation (Gonzalez et al. 2001; White 1992). OPT provides diagnostic value on radiographic bone levels, predisposing (biofilm retention) factors, carious lesions, FI, subgingival/interproximal calculus and others (Kim et al. 2008). However, OPT introduces non-uniform magnification and distortion, as well as superimposition of larger anatomical structures that may reduce the objective analysis of fine structures related to the periodontal apparatus such as the periodontal ligament space (especially in the incisor to canine region), which may compromise the reliability of linear measurements (Mol 2004). Moreover, positioning errors (alignment of the patient's dentition within the image layer) and artefacts (e.g., ghost images) can lead to misrepresentations of anatomical structures.

Intra-oral techniques include periapical (using paralleling methods) and bitewing radiography, which are the most frequently employed methods for evaluating teeth, surrounding alveolar bone, the periodontal ligament space and lamina dura. Furthermore, periapical radiographic assessment enables the clinician to identify local predisposing factors to periodontal diseases, such as subgingival calculus deposits, anomalies in root morphology and overhanging dental restorations. Despite its effectiveness, the inherent 2D nature of radiographs restricts periapical radiography to the detection and measurement of interdental periodontal bone loss (Jacobs et al. 2024).

Bitewing radiographs facilitate the accurate depiction of the distance between the CEJ and alveolar bone crest. This precision is achieved by aligning the x-ray beam perpendicularly with the long axes of both teeth and surrounding bone. However, when patients have moderate to deep pockets, isolated deep pockets or substantial CAL, conventional bitewing radiographs may not adequately capture the entire extent of the residual attachment/supporting bone.

Limitations of 2D radiographs include the nature of the technique (e.g., paralleling or bisecting angle), lack of 3D assessment of defect morphology and complexity, superimposition of anatomical structures, type of machine, nature of the sensor (analogue vs. digital), projection geometry, image distortion and measurement reliability of the reporter.

5.4.2 | Which Method Is the Current Standard of Care and What Is Its Accuracy and Reliability?

Based on three studies comprising 983 patients (Atchison et al. 1995; Machado et al. 2020; Merchant et al. 2004), the evaluation of diagnostic accuracy when detecting periodontitis using conventional 2D radiographs (including peri-apical, bitewing and OPT images) at a patient level yields a high level of diagnostic accuracy (0.82) with a pooled sensitivity of 0.77 (95%

confidence interval [CI]: 0.66–0.85) and a pooled specificity of 0.76 (95% CI: 0.64–0.84), supporting the principle that clinical and radiographic diagnosis are complementary.

When comparing radiographic techniques for detecting evidence of periodontitis, periapical radiographs provide higher specificity than bitewings and OPTs (0.8 vs. 0.69 and 0.46, respectively) and a comparable sensitivity (range 0.84–0.86). Moreover, periapical radiographs, compared to OPTs, offer a greater correlation with CAL ($r = 0.50$ vs. 0.36).

The correlation between clinical measures and radiology for furcation evaluation was highly heterogeneous. A general tendency to underestimate FI was observed, and all methods became more reliable with more advanced levels of FI (i.e., furcation class II and III). The accuracy of periapical radiographs varied greatly among studies, with specificity ranging from 0.71 to 0.92 and sensitivity from 0.39 to 0.73 (Alasqah et al. 2022; Deas et al. 2006), reinforcing the point that FI is a clinical diagnosis and not a radiographic diagnosis.

At sites with intrabony defects, there is a high correlation between the distance from the CEJ to the bottom of the defect (BD) and CAL. The relationship is CEJ–BD = CAL + k, where k is 1 mm. Different studies report a range between 0 and 1.5 mm, depending on the depth of total bone loss and inflammation.

Considering the intrinsic limitations and advantages of each radiographic technique, the biological cost and the information necessary to complement the clinical diagnosis and perform staging and grading, periapical radiography is to be considered optimal (Figure 5). In environments where OPT is the standard 2D radiograph, supplemental periapical radiographs are indicated in areas of poor diagnostic quality.

5.4.3 | Which Imaging Techniques Offer Promise for Improved Periodontal Diagnosis as Alternatives to 2D Radiography, and in What Circumstances Should Their Use Be Considered?

Alternative methods to traditional 2D radiology evaluated in the commissioned systematic review (Discepoli et al. 2025) were cone-beam computed tomography (CBCT), magnetic resonance imaging (MRI), intraoral ultrasound, computer-assisted densitometric image analysis (CADIA), digital subtraction radiography (DSR) and fractal analysis of traditional 2D images. Other additional methods did not provide data on diagnostic accuracy in patients with periodontitis.

No studies complied fully with the checklist for reporting of diagnostic studies (Bossuyt et al. 2015) or provided all data necessary to follow the protocol defined in *The Cochrane Handbook for Systematic Reviews of Diagnostic Test Accuracy* (version 2.0) (Deeks et al. 2023). Pooled meta-analysis was only possible for CBCT.

Fractal analysis is a mathematical model that can be applied to periapical or panoramic radiographs to improve diagnostic accuracy by increasing sensitivity. Its value lies in the identification of stage I or stage II periodontitis and, during follow-up, in the detection of disease progression. Ten studies addressed fractal geometric dimensional analysis as a quantitative measure of image complexity, using a consistent protocol (White and Rudolph 1999). While the fractal dimension (FD) value decreased with increasing disease severity and/or stage of disease, there was no consistent FD cut-off value that differentiated periodontal health from periodontitis. Three studies provided an AUC value for diagnostic accuracy at the patient level (periodontitis vs. no periodontitis) of 0.75–0.82 (Discepoli et al. 2025).

For CBCT, 29 studies were available that met the inclusion criteria. There was significant heterogeneity in study design and outcomes, with target conditions including intra-bony defects, FI and crestal bone loss. Ten studies assessed intra-bony defects, using various comparators including intra-surgical assessment, 2D radiographs and clinical probing. The majority concluded that CBCT was a precise, reliable and accurate tool that was superior to traditional intra-oral radiographs for the analysis of individual defect morphology (Discepoli et al. 2025). Only three studies were included in the meta-analysis (Komsic et al. 2019; Qiao et al. 2014; Walter et al. 2010), being sufficiently homogenous in design. These 3 (out of 14) studies analysed FI in maxillary first and second molars ($n = 168$) only, and employed intra-surgical measures as gold standard. Sensitivity and specificity for CBCT were 0.98 (95% CI: 0.96–1.00) and 0.98 (95% CI: 0.95–1.00), respectively, for the identification/detection of furcation lesions (I^2: 0%). The overall diagnostic accuracy was 0.99. Five studies assessed crestal bone loss, two used 2D periapical radiographs as the comparator and three employed intra-surgical measurements. In general, CBCT was recognised as a valuable tool for assessing periodontal bone loss (sensitivity 0.21–1.00; specificity 0.69–1.00).

Figure 5 provides a decision tree for the integration of clinical and radiographic examinations for periodontal diagnosis, based upon the evidence base for 2D and 3D imaging.

Three studies investigated MRI, one at a patient level for periodontitis (vs. health), one study addressed furcation involvement and one analysed bone loss (Discepoli et al. 2025). Patient-level analysis was compared with clinical examination and panoramic radiography and concluded that MRI identified changes in bone level associated with early disease detection and monitoring. The FI study used clinical examination and CBCT as comparators and reported high levels of reliability for MRI relative to those comparators, with agreement between MRI and CBCT of 80%–100%. Sensitivity and specificity of MRI relative to CBCT were 0.98 and 1.00, respectively, for horizontal bone loss. The corresponding value for the vertical bone loss component was 0.99 for both sensitivity and specificity. When compared with clinical diagnosis, sensitivity and specificity of MRI were not reported by the authors but were calculated as 0.63 and 0.85, respectively. There was >95% agreement between MRI and periapical radiographs for measurement of bone loss.

One study assessed intra-oral ultrasound in comparison with clinical examination, periapical and CBCT radiographs, but was limited to buccal FI at mandibular molars. CBCT was used as the gold standard, and the sensitivity of ultrasound was 0.98 and specificity 1.00.

CADIA and DSR studies were pertinent for research studies rather than clinical diagnosis, as they are designed to assess

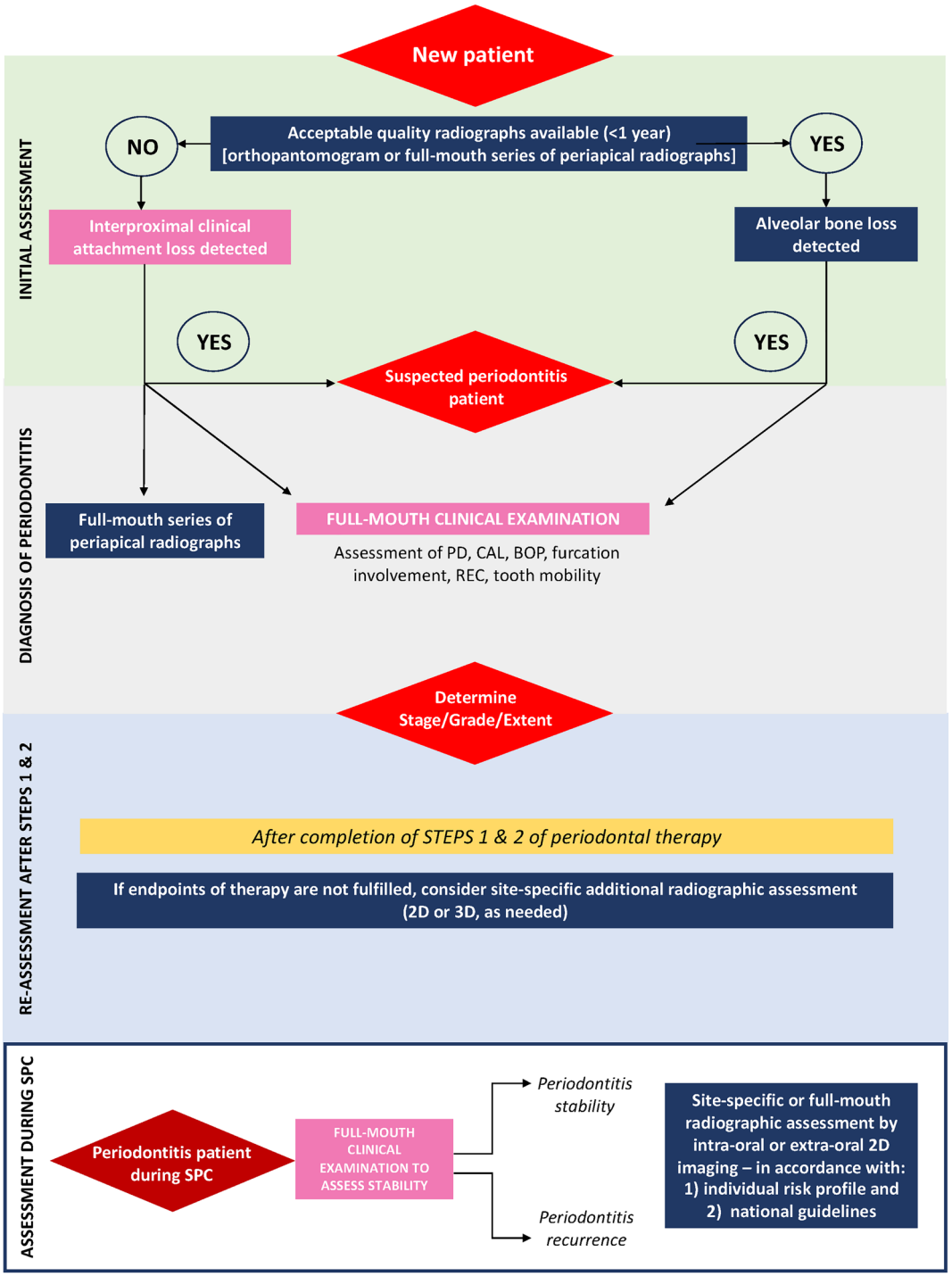

FIGURE 5 | Decision tree for clinical and radiographic examination during initial periodontal diagnosis and post-treatment assessment. 2D, two-dimensional; BOP, bleeding on probing; CAL, clinical attachment loss; PD, probing depth; REC, gingival recession; SPC, supportive periodontal care.

changes in bone density or levels over time and require high levels of standardisation of projection.

5.4.4 | Is There Evidence Currently to Support the Routine Use of CBCT in Periodontal Diagnosis?

Because of exposure to ionising radiation and from cost–benefit considerations, routine use of CBCT for periodontal diagnosis is not advised. This statement is consistent with previous conclusions from the Euratom guideline (European Commission—Directorate-General for Energy 2012), the AAP (Mandelaris et al. 2017) and the German level 2C guideline of the Association of the Scientific Medical Societies in Germany (AWMF) (Schulz 2022). However, in specific circumstances, CBCT imaging may provide additional detail to 2D radiographic imaging, which may benefit diagnosis, decision making and treatment planning, particularly for intra-bony and furcation defects (Figure 5).

5.4.5 | Is There Evidence for Non-Ionising Imaging Methods to Support the Diagnosis of Periodontitis?

There is limited evidence for the use of MRI and ultrasound imaging in periodontal diagnosis; however, both offer promise for improving periodontal diagnosis as the technologies develop further.

Current limitations for MRI are high cost and required time, limited availability, operator training in execution and interpretation and patient acceptance. With respect to ultrasound, limitations include operator dependence, probe size and design, narrow field of view, accessibility to the area of interest and operator training for execution and interpretation.

Other non-ionising techniques, such as optical coherence tomography and fluorescence spectroscopy, have not been evaluated in periodontal diagnosis.

5.4.6 | What Are the Characteristics of the Ideal Diagnostic Imaging Tool for Periodontal Diagnosis, and Which Currently Available Ionising and Non-Ionising Imaging Technologies Best Fulfil These Requirements?

The characteristics of the ideal radiological diagnostic tool should include provision of optimal image quality while minimising radiation exposure dose, low cost, high accuracy, high discrimination, high reproducibility, 3D visualisation, speed, low complexity (shallow learning curve for performance and interpretation), high patient acceptability and universal accessibility.

There are no technologies that currently fulfil all the above criteria. While traditional 2D periapical radiographs obtained by the paralleling technique meet the majority of requirements, they are deficient with respect to 3D capability, high 3D accuracy, discrimination, reproducibility and speed for a full-mouth examination. CBCT as a technology fulfils the criteria of 3D imaging, accuracy, discrimination, reproducibility, speed and patient acceptability.

6 | Working Group 2: Biomarkers in Diagnosis and Risk Assessment

Working Group 2 dealt with microbial, host-derived and genetic/epigenetic biomarkers for periodontal diagnosis (a glossary of terms is available in the Supporting Information).

Focused questions, using the PICOTS (Patient population, Intervention, Comparator, Outcome, Time Setting) scheme, were formulated (Table 6) and three individual systematic reviews provided answers to the questions set by the workshop committee (Bostanci et al. 2025; Dommisch et al. 2025; Rakic et al. 2025). The data in most of the reports included in the three systematic reviews were derived from exploratory studies rather than from diagnostic validation trials.

Studies included in the first review (Bostanci et al. 2025) focused on bacterial biomarkers and typically employed either the presence/absence of single bacterial species (a rather outdated concept according to the current views on the aetiopathogenesis of periodontitis) or bacterial burden estimates that, however, had not been defined a priori. The level of disease severity, the number of remaining teeth and the number and depth of pathological pockets in each participant—important determinants of bacterial load in the saliva and in

TABLE 6 | Overall structure of focused questions, using the Patient population, Intervention, Comparator, Outcome, Time Setting (PICOTS) scheme, for the three commissioned systematic reviews for Working Group 2 (Bostanci et al. 2025; Dommisch et al. 2025; Rakic et al. 2025).

	PICOTS #1	PICOTS #2	PICOTS #3
	Distinction between case categories	**Identification of periodontitis progression over time**	**Prediction of disease resolution/treatment success**
Patients	Dentate individuals with or without periodontal disease	Dentate individuals with or without periodontal disease and therapy	Dentate patients with history of periodontal therapy
Intervention	Diagnostic test for the discrimination between a. Periodontal health and gingivitis b. Periodontal health and periodontitis c. Gingivitis and periodontitis d. Different stages of periodontitis e. Different grades of periodontitis	Diagnostic test for the discrimination between disease progression (e.g., ongoing CAL or ABL) and stability	Diagnostic test for the prediction of disease resolution (e.g., pocket closure)
Comparison	Standard clinical or radiographic measures		
Outcome	Diagnostic accuracy (sensitivity, specificity, positive/negative predictive value, AUC)		
Time	Cross-sectional	Longitudinal (no time limit)	Longitudinal (no time limit)

Abbreviations: ABL, alveolar bone loss; AUC, area under the (receiver operating characteristic) curve; CAL, clinical attachment loss.

subgingival samples—had not typically been accounted for in these studies, which further complicated the definition of bacterial load thresholds. Additionally, the continuous evolution of assay methodologies precluded the ability to establish robust and consistent threshold levels for total bacterial load or for relative abundances of specific bacterial taxa. Importantly, several recent studies using contemporary metrics of community-level dysbiosis and microbial ecology were not included in the systematic review (Bostanci et al. 2025) because of small sample sizes that did not meet the stipulated inclusion criteria.

Likewise, the available studies on host-derived biomarkers included in the second review (Rakic et al. 2025) were a mixture of primarily discovery studies with relatively few replication or validation studies. Furthermore, studies tended to have small sample sizes, exhibited variable risk of bias, frequently used a case–control design and did not follow the recommended diagnostic test guidelines (Deeks et al. 2023) with respect to patient recruitment or blinding in relation to the index test.

The third review (Dommisch et al. 2025) focused on the utility of genetic/epigenetic biomarkers. Periodontal diseases have a substantial heritable component, which is encoded by the human genome. While genomics is crucial in quantifying disease susceptibility, it is not suited for diagnostic applications for the common forms of periodontal diseases. This is because genomics can only aid in the diagnosis of a very small proportion of cases, including rare, heritable monogenic forms of periodontal diseases, and those that constitute periodontitis as a manifestation of syndromes. Conversely, the common forms of periodontal diseases are polygenic in nature, wherein genetic susceptibility is conferred by several gene loci that interact with each other and with the environment, behaviour and lifestyle factors to promote disease development. In this context, genomic testing has the potential to add to susceptibility assessments for common forms of periodontal diseases and, in conjunction with other established risk factors, inform precision approaches to periodontal care.

6.1 | Distinction Between Case Categories (PICOTS #1)

6.1.1 | Can Biomarkers Reliably Differentiate Between Health and Gingivitis?

With respect to the distinction between periodontal health and gingivitis, no microbial or host-derived biomarkers were identified to have acceptable diagnostic performance and utility. Furthermore, genomic testing does not have a place in the diagnosis of gingivitis.

6.1.2 | Can Genomic Testing Identify Susceptibility to Gingivitis?

Use of genomic information from a small number of genetic markers does not appear to lead to improvements in susceptibility assessment of gingivitis (Dommisch et al. 2025).

There is no evidence for specific genetic variants that predispose to the development of experimental gingivitis, based on two studies which evaluated the role of single nucleotide polymorphisms (SNPs) and composite genotype variations for a series of cytokine-coding genes (tumour necrosis factor [TNF]-α, lymphotoxin alpha [LT-A], interleukin [IL]-1 and IL-6 variants). None of the variants analysed, either as single polymorphisms or as a combined genotype, was associated with differences in clinical parameters during the development of gingivitis.

6.1.3 | Can Biomarkers Reliably Differentiate Between Health and Periodontitis?

Most microbiological studies have investigated associations of microbial markers and periodontal health status rather than exploring their utility as diagnostic markers. Therefore, only 22 reports could be included in a qualitative evidence synthesis; additionally, the data did not qualify for meta-analysis. The heterogeneity in assay methods, changes in case definitions over time and variable sample sizes have precluded the a priori estimation of microbial abundance thresholds that can discriminate between different periodontal conditions. While certain species, for example, *Porphyromonas gingivalis*, *Aggregatibacter actinomycetemcomitans*, *Fusobacterium nucleatum*, *Campylobacter rectus* and *Prevotella intermedia*, as well as community-level metrics of dysbiosis and ecological indices, could discriminate between periodontal health and periodontitis, the available studies did not fulfil the criteria for diagnostic markers or tests.

Several commercial tests have been developed over the past four decades based on undisclosed threshold values for selected combinations of selected species, concentrations of bacterial toxins, and proteins. There is little evidence to support their diagnostic value.

A small number of studies based on host-derived biomarkers were amenable to meta-analysis and may provide an assessment of which biomarkers may be better suited for adoption or for larger-scale testing. According to the findings of the meta-analysis and the synthesis of data from the narrative portion of the review, there is insufficient evidence to support the use of host-derived marker tests for the diagnosis of periodontal diseases in different contexts (see below). Most of the reported host-derived markers exhibited diagnostic accuracy, sensitivity and specificity in the range of 0.7 and 0.9, with notable discrepancies between sensitivity and specificity. These results do not reach the levels recommended for the clinical applicability of reported markers as diagnostic tests (Deeks et al. 2023).

Matrix metalloproteinase (MMP)-8 and active MMP-8, demonstrating comparable AUC (0.70–0.90), sensitivity (0.49–0.84) and specificity (0.62–0.79), either derived from saliva or oral rinse, were the most frequently reported biomarkers. These findings are in line with those reported in a recent meta-analysis (Wei et al. 2024), which were based on dichotomous comparisons of periodontitis versus a heterogeneous group including gingival health/gingivitis/mild periodontitis. This

is in contrast with the comparison of clearly defined clinical conditions (periodontal health/gingivitis/periodontitis) recommended by formal validation standards (FDA-NIH Biomarker Working Group 2016) that were adopted in the commissioned systematic review (Rakic et al. 2025). While these values are below the recommended rates for false positivity and false negativity (in the range 2.5%–10.0%) for validation of diagnostic tests (Fleming and DeMets 1996), it is recognised that these recommended performance metrics have been hard to fulfil in several other fields in medicine as well. Therefore, efforts to improve the accuracy of diagnostic tests in periodontology that may still fall short of these ideal metrics are strongly encouraged.

Among the currently commercially available diagnostic tests for periodontitis, the most studied is the one based on the detection of active MMP-8 in oral rinses. The current review (Rakic et al. 2025) as well as recent reports based on the comparisons mentioned above (Li et al. 2025; Wei et al. 2024) indicate evidence of moderate certainty that this test detects periodontitis with low sensitivity, moderate to high specificity and moderate accuracy. Accordingly, the low sensitivity currently precludes recommending the use of this test for purposes of periodontitis detection.

MicroRNAs (MiRs) in the gingival crevicular fluid (GCF) were a single meta-analysed group of biomarkers demonstrating AUC = 0.79. However, the small number of available studies and the partial reporting of the performance metrics of a test based on this biomarker do not allow for a full evaluation of its utility in clinical practice at the present time. Furthermore, it is recognised that diagnostic tests that rely on GCF sampling are impractical given the clinical and technical requirements of GCF sampling protocols. Therefore, GCF-based tests do not appear to be suitable for screening for periodontal diseases, especially in under-served or difficult-to-reach populations.

6.1.4 | Can Genomic Testing Be Useful in Periodontitis Diagnosis?

Genomic testing can aid in the diagnosis of monogenic forms of periodontitis but not in the diagnosis of its common forms. Genomic testing, including trait analyses of rare variants in families with known risk for (e.g., history of) early onset, grade C periodontitis, may be useful as a diagnostic adjunct in the assessment of periodontitis susceptibility.

6.1.5 | Can Genomic Testing Identify Susceptibility to Common Forms of Periodontitis?

Currently, while no validated genomic test exists to quantify periodontitis susceptibility, there is potential, and reasonable expectation, that the emerging genomics evidence base will support the development of such assessments in the future. Small numbers of genetic markers, including those in commercially available tests, do not appear to lead to improved susceptibility assessment beyond what can be achieved by known risk factors (Dommisch et al. 2025). However, the addition of genomic information in multifactorial models has been shown to improve diagnostic performance (Morelli et al. 2020). Thus, as per consensus, validated gene variants can serve as the basis of polygenic risk scores and, combined with other established patient-related factors, may offer valid periodontitis diagnostic/prognostic tools in the future.

6.1.6 | Can Biomarkers Reliably Differentiate Between Gingivitis and Periodontitis?

No microbial, host-derived or genetic markers were identified to have acceptable diagnostic performance and utility in distinguishing between gingivitis and periodontitis.

6.1.7 | Can Biomarkers Reliably Differentiate Between the Different Stages of Periodontitis?

No microbial, host-derived or genetic markers were identified to have acceptable diagnostic performance and utility in distinguishing between different periodontitis stages.

6.1.8 | Can Biomarkers Reliably Differentiate Between the Different Grades of Periodontitis?

No microbial, host-derived or genetic markers were identified to have acceptable diagnostic performance and utility in distinguishing between different periodontitis grades.

6.2 | Identification of Periodontitis Progression Over Time (PICOTS #2)

6.2.1 | Can Biomarkers Predict the Progression of Periodontitis in the Absence of Periodontal Therapy?

The heterogeneity in assay methods, changes in case definitions over time and variable sample sizes precluded a priori estimates of bacterial abundance thresholds that can discriminate between health and periodontitis. While certain species, for example, *P. gingivalis* and *A. actinomycetemcomitans*, emerged as predictors of disease progression, particularly in children and adolescents, the available reports did not fulfil the criteria required for diagnostic studies.

No host-derived or genomic markers were identified to have acceptable diagnostic performance and utility in the prediction of periodontitis progression.

6.2.2 | Can Biomarkers Predict the Progression of Periodontitis Following Periodontal Therapy?

No microbial, host-derived or genetic markers were identified to have acceptable diagnostic performance and utility in predicting periodontitis progression in patients who had received periodontal therapy.

6.3 | Prediction of Disease Resolution/Treatment Success (PICOTS #3)

6.3.1 | Can Biomarkers Predict Disease Resolution or Treatment Success After Periodontal Therapy?

While certain species such as *P. gingivalis* and *F. nucleatum*, or ecological indices, emerged as predictors of disease resolution, the analysed reports did not fulfil the stipulated criteria for diagnostic studies.

No host-derived or genomic markers were identified to have acceptable diagnostic performance or utility in predicting disease resolution after periodontal therapy or treatment success.

6.4 | What Are the Future Requirements for the Development of Diagnostic Tests Utilising Biomarkers?

Diagnostic tests involving biomarkers in oral health care may be grouped under three major categories: direct-to-consumer (D2C) or at-home tests; point-of-care (POC) tests to be used in dental or non-dental settings; and dental-team-performed (DTP) tests.

D2C and POC tests can potentially offer easy-to-use, non-invasive approaches for the detection of periodontal diseases, identification of subjects at risk and monitoring of oral health status and therapeutic outcomes in a non-dental setting (e.g., at home, in care-home facilities, medical or pharmacy settings where an oral healthcare provider is not present, or at settings where access to health care is unavailable [e.g., remote settings, under-served populations]). DTP tests are meant to enhance the diagnostic abilities of dental healthcare professionals in a clinical setting.

The criteria for testing and validation of diagnostic markers involved in the above tests differ across these three categories.

Specifically, for D2C tests, ease of administration and interpretation, availability (storage conditions and shelf-life) and low cost are highly desired properties. By necessity, these tests would be based on the collection of saliva, oral rinse or oral swabs, and would provide data at the subject level only.

For POC tests, additional desired properties include a higher degree of sensitivity and specificity, which may be achieved by concomitant use of complementary tests that work in tandem. If these tests require harvesting of site-specific samples such as GCF or subgingival plaque, it is important to account for variability due to sampling techniques.

For DTP tests that are used to distinguish between disease categories, sensitivity and granularity of the obtained information must surpass those achieved by traditional diagnostic tools. DTP tests that are focused on assessing outcomes over time may require repeated testing and must show low inter- and intra-operator variability.

Overall, selection and standardisation of sampling methodologies, specimen processing and biomarker analyses are a core priority for future research in diagnostic methodologies in periodontology.

6.5 | Is There Scope for the Development of New Composite Sets of Biomarkers, Including Across Different '-Omes' That Could Improve Diagnostic Accuracy?

Humans are holobionts and host a diverse resident microbiota that has been evolutionarily programmed to establish a homeostatic relationship with the immune system. This equilibrium can be disrupted by many factors that may act individually or in concert, and the resulting imbalance underlies the aetiopathogenesis of periodontal diseases. Investigations using integrated multi-omics approaches, combined with AI systems and incorporating elements of medical and social history (France and Miller 2025), offer great potential to study the interactions between the exposome, genome, metagenome, proteome, metaproteome and the metabolome, and to derive composite biomarkers that document these shifts in real time.

Studies that focus on the development of multi-omics diagnostic markers are currently at the discovery stage and are typically being carried out on population samples that have been purposefully selected based on genotypic homogeneity (i.e., similar sex/gender, race/ethnicity and age). Subsequent validation steps are obviously required. AI is expected to play a pivotal role in the future identification of biomarkers, as well as in the development of enhanced integrated diagnostic models. Ultimately, these will yield high generalisability but will also advance the field of diagnostics towards precision periodontal care.

7 | Working Group 3: Emerging Approaches and Technologies

7.1 | Introduction

Working Group 3 (WG3) aimed to identify emerging technologies for screening, diagnosis and risk assessment of disease progression in dental and non-dental settings. Non-clinical settings include medical practices, pharmacies, computer websites or cell-phone-based communication.

The first review was commissioned (Farina et al. 2025) to assess tools for dental clinics, presenting two analyses: one on the screening and diagnosis of periodontal diseases using a scoping review, which retrieved 40 papers across various data types (two-dimensional radiographs, $n=14$; three-dimensional radiographs, $n=7$; photographs, $n=7$; clinical data, $n=6$; oral fluid samples, $n=5$; health records, $n=1$), with emerging tools being artificial intelligence ($n=34$) and advanced imaging ($n=6$). Using a systematic review, the second analysis retrieved eight papers applying AI to structured data to estimate periodontal prognosis.

A second review was commissioned to assess tools for non-dental settings (Montero et al. 2025). Using a scoping review methodology, 104 articles were identified and divided into eight clusters based on information substrates and analytical tools: self-reported questionnaire algorithms ($n=59$), biomarker algorithms ($n=12$),

combined self-reported and biomarker algorithms ($n=4$), self-assessed bleeding algorithms ($n=5$), AI algorithms based on OPG and CBCT images ($n=16$), AI algorithms based on clinical images ($n=5$), combined predictive models (e.g., socio-demographic factors, self-reported questionnaires, biomarkers; $n=4$) and spectroscopic tools from saliva and gingiva ($n=2$).

7.1.1 | Concepts

Artificial intelligence (AI) is a broad term. The Organisation for Economic Co-operation and Development (OECD) has not defined AI but describes an AI system as a machine-based system that infers from inputs how to generate outputs such as predictions, content, recommendations or decisions influencing environments. AI systems differ in levels of autonomy and adaptiveness after deployment (OECD 2023). It also defines machine learning (ML) as techniques that enable machines to improve performance and generate models automatically through exposure to training data, identifying patterns instead of relying on human instructions. This process is known as training (OECD 2023).

The use of AI systems has developed a specific and complex language, whose definitions can be found in the glossary of terms in Supporting Information. For ease of reading, in this section, data modalities refer to the various types or formats in which data are presented. Importantly, the presence and distribution of different data modalities vary across medical disciplines. In dental medicine, data modalities can be divided into three major overarching categories: image data, structured numerical data and unstructured textual data (Feher et al. 2024). Conversely, emerging applied data science methods refer to advanced techniques for handling complex data analysis. These include, but are not limited to, AI-based methods.

7.1.2 | Artificial Intelligence and Machine Learning—Regulatory Issues

Medical devices using AI must follow the requirements of appropriate regulatory bodies. There are two types of regulatory bodies: national and supranational, with nations in supranational unions traditionally possessing their own regulatory power (Feher et al. 2024).

Among national and supranational bodies, those with data available within dentistry include the European Medicines Agency (EMA) of the European Union (EU) (Aboy et al. 2024; Ducret et al. 2024); the Food and Drug Administration (FDA) of the United States, which transparently publishes the list of artificial intelligence and machine learning (AI/ML)-enabled medical devices (U.S. Food and Drug Administration 2024); the National Medical Products Administration (NMPA) of China (Liu et al. 2024); and the Medical Device Committee of the Association of Southeast Asian Nations (ASEAN).

As of 2024, only a handful of these devices have been cleared by the EMA (i.e., Diagnocat AI) and the FDA (i.e., Denti.AI Detect, DTX Studio Clinic 3.0, Videa Perio Assist, Overjet Dental Assist), all within the last 4 years. Products approved by the EMA were usually classified as Class I medical devices, while FDA-approved devices are often classified as Class II medical devices; additionally, under the AI Act of the EU, AI-enabled medical devices are considered high risk (Aboy et al. 2024; European Commission 2024, 43). In China, the NMPA has identified no periodontal-related AI-enabled medical devices.

It is essential to highlight that none of the approved technologies claims to be a diagnostic tool, as the licensed clinician performs the diagnosis. A diagnostic tool is considered a high-risk device that may immediately be classified as a class III medical device. In the United States, all the approved technologies were cleared through the 510(k) pathway, with manufacturers arguing substantial equivalence of their technologies to previously cleared products (i.e., predicates).

All these technologies claim to be medical image management and processing systems intended to aid in measuring alveolar bone levels in the permanent dentition derived from bitewing, periapical or panoramic radiographs. The validation of these technologies usually involves both stand-alone bench testing and validation of performance by clinicians aided by the device. Stand-alone bench testing consists of using hundreds to thousands of images, for which a consensus of a small panel of dental clinicians establishes the reference standard. Routine outcome measures (e.g., precision, recall) are based on true and false positives and negatives for classification tasks and Dice scores, intersection over union metrics, and so on, for detection/segmentation tasks, with core outcome sets now proposed for the latter (Buttner et al. 2024).

Clinical validation is typically undertaken in fully crossed, randomised, multiple-reader multiple-case (MRMC)-controlled studies. This methodology implies a series of clinicians recruited to perform an examination in which they are asked to assess radiographic bone loss twice: once with the aid of AI and a second time without the assistance of AI. In the case of the FDA, these studies have involved between 2 and 30 dentists or licensed periodontists, assessing 154 to 216 images collected from across U.S. sites. The studies should ideally report improved dental clinician performance when using AI. These methods used in FDA filings may be helpful to guide researchers on how to design future validation studies. The validation site determines where the AI is approved for deployment; thus, to apply these technologies more globally, validation in a wide range of sites would be crucial.

7.1.3 | Artificial Intelligence and Machine Learning—Benefits and Challenges

The expected benefits of using AI are multiple: timesaving, better diagnostic performance in identifying disease and enhanced time for clinician interaction with patients.

However, one important aspect not evaluated in the literature to date, or by regulatory agencies, is the impact of these technologies on outcomes. This includes benefits to society or health economic outcomes, as well as the burden it could impose in terms of CO_2 emissions and environmental sustainability related to the development of such technologies.

In addition, while the dental industry is leading in terms of AI innovations in dental medicine, much of the data are not publicly

available for validation and for transparency due to the limited publication of studies by the private sector. This scenario raises concerns about the transparency of how algorithms work and how they can be compared. Understanding the methods used in regulatory filings could be useful to guide researchers in designing future clinical validation studies.

7.2 | Screening and Diagnosis of Periodontal Diseases in Dental Clinical Settings

7.2.1 | In the Context of Emerging Applied Data Science Methods for Periodontal Screening and Diagnosis in Dental Clinical Settings, What Are the Most Frequently Reported Data Modalities?

The most common data modalities were radiographs, either 2D ($n = 14$) or 3D, such as micro-CT or CBCT ($n = 7$), followed by photographs (primarily intra-oral but also including those taken by a mobile phone; $n = 7$), clinical data ($n = 6$), oral fluid samples (particularly saliva and GCF, $n = 5$) and electronic health records ($n = 1$).

7.2.2 | In the Context of Emerging Applied Data Science Methods for Periodontal Screening and Diagnosis in Dental Clinical Settings, What Are the Most Frequently Reported Analytical Methods?

The most common AI-based analytical methods identified were ML and deep learning (DL) algorithms. DL algorithms comprised convolutional neural networks (CNNs) and artificial neural networks (ANNs).

7.2.3 | What Is the Current Diagnostic Performance of Using Emerging Applied Data Science Methods for Periodontal Screening and Diagnosis in Clinical Dental Settings?

Emerging applied data science methods are improving the accuracy and efficiency of periodontal screening and diagnosis. ML and DL achieve accuracy similar to that of oral healthcare professionals and perform well in distinguishing between different periodontal statuses. Together, these methods show promising accuracy and reliability, highlighting their potential to assist clinicians in periodontal screening and diagnosis in dental settings.

Across 14 studies employing 2D radiographs, CNNs and other DL models showed high accuracy in detecting and classifying alveolar bone loss, achieving high sensitivity and specificity. Models that integrate radiographs with additional clinical data, such as periodontal probing depths, further improve staging accuracy. The accuracy of photographic analysis (seven studies) was difficult to assess because of the lack of valid reference standards. Oral fluid analysis, supported by five studies, showed high diagnostic accuracy in classifying periodontal status, with high true positive rates across patient groups. One single study applying ML to medical records reported a moderate diagnostic performance, with age and tooth mobility suggested as predictors of periodontal status. In six studies, internally validated clinical data models reported high classification accuracy for specific periodontal conditions, demonstrating strong predictive values for targeted assessment in dental settings.

7.2.4 | What Are the Current Limitations of Using Emerging Applied Data Science Methods for Periodontal Screening and Diagnosis in Clinical Dental Settings?

Limitations of emerging data science methods for periodontal screening and diagnosis in dental clinics include (i) low interpretability (unclear parameters influencing model decisions) and (ii) poor generalisability (uncertainty about model performance in different populations), leading to potential trust issues. Models mainly rely on a single data modality, which limits screening and diagnosis capabilities. Furthermore, there needs to be greater clinical translation, with only a few models being clinically available.

7.2.5 | What Are the Future Research Directions and Clinical Perspectives on Using Emerging Applied Data Science Methods for Periodontal Screening and Diagnosis in Dental Clinics?

Future research in applied data science for periodontal screening should focus on developing AI tools with high diagnostic accuracy. These tools must be trained on diverse datasets to enhance generalisability across different patient populations and to ensure clinical relevance. Building models with continuous learning will allow adaptation to new data. Emphasising algorithm transparency will make AI recommendations interpretable, increasing clinician trust. In the long term, ongoing clinical validation with updates against established methods will be critical to confirm and refine AI tool performance.

Future AI-based diagnostic tools must offer interpretable and transparent decision making to help clinicians understand and explain outcomes. Compliance with regulatory standards and data security will safeguard patient privacy and ensure ethical practices. Cost controls and availability are crucial for equitable use in dental settings. Additionally, integrating patient communication features will enhance clinicians' ability to convey AI-driven information, boosting patient understanding and engagement in their own care.

7.3 | Assessment of Periodontal Prognosis in Clinical Dental Settings

7.3.1 | What Are the Most Frequently Reported Emerging Applied Data Science Methods for Assessing Periodontal Prognosis in Clinical Dental Settings?

In this context, periodontal prognosis was defined as estimating the probability of an individual or tooth developing a specific event, ranging from the onset of periodontitis to tooth loss, over a pre-defined prediction period. To date, the only emerging applied data science method reported for assessing prognosis in the dental setting is supervised machine learning (SML). Different

SML models were tested to estimate patient (five studies) and tooth-related (three studies) prognosis.

7.3.2 | What Are the Most Frequently Reported Data Modalities to Train SML Models for Assessing Periodontal Prognosis in Clinical Dental Settings?

To date, SML models for periodontal prognosis have mostly been tested in periodontitis patients following active treatment. The training of SML models was conducted using only structured data (e.g., demographics, medical and dental history, periodontal charts and radiographic assessments).

7.3.3 | What Is the Current Evidence on the Prognostic Performance of Emerging Applied Data Science Methods When Used in Clinical Dental Settings?

Evidence on the performance of emerging applied data science methods to support clinical applications for predicting periodontal prognosis in dental settings is related to SML only and is limited both quantitatively and qualitatively (eight studies). Available data indicate that the prognostic performance of the SML models tested is equal or superior to validated traditional risk assessment methods. When different SML models were compared, similar performance in predicting tooth loss was generally observed.

7.3.4 | Are Patients Expected to Benefit From the Application of Emerging Applied Data Science Methods in the Assessment of Periodontal Prognosis?

Current evidence is scarce, but applied data science methods in clinical practice show promise for predicting both patient and tooth prognosis. These methods can integrate information from different data sources, providing unbiased estimates to assist oral healthcare professionals in treatment and monitoring. Implementing methods that minimise the role of operator training may reduce variability in clinical judgement and improve therapeutic outcomes. Improvement in performance metrics of these methods is expected, enhancing efficiency in personalised patient care. However, the added value, including cost–benefit and cost–effectiveness ratios, still needs assessment.

7.3.5 | What Are the Current Limitations of Emerging Applied Data Science Methods in the Assessment of Periodontal Prognosis Within Clinical Dental Settings?

The following are the current limitations inherent to the emerging applied data science methods that have been tested:

- Structured data were the only data modality used for the training of prognostic models.
- Variables generating structured data were decided a priori. When incorporated into traditional risk assessment tools, these variables have been shown to exhibit limitations in explaining the variability in disease progression among individuals.
- The majority of studies applied data science methods to patients actively treated for periodontitis and eventually enrolled in an SPC programme.
- Interpretability was low in the models tested.
- Prognostic performance appeared to be related to the population (country) and setting used for model testing, thus affecting model generalisability for clinical application.

7.3.6 | What Are the Future Focus Areas for Using Emerging Applied Data Science Methods for Periodontal Prognosis in Dental Clinics?

To improve the clinical applicability of emerging applied data science methods for the assessment of periodontal prognosis, the following focus areas should be considered in the future:

- Development of models using multiple data modalities.
- Testing the models in prospective trials involving both healthy volunteers and patients with varying levels of disease severity at different treatment phases.

7.4 | Screening of Periodontal Diseases in Non-Dental Settings

7.4.1 | What Are the Most Frequently Reported Assessments for Screening for Periodontal Diseases in Non-Dental Settings?

The most common assessment for periodontal status (periodontal health, gingivitis or periodontitis) in non-dental settings is self-reported questionnaires ($n = 57$). The primary tool used to screen for periodontitis is the CDC/AAP group questionnaire (Eke and Dye 2009).

Eighteen papers reported biomarker-based algorithms that discriminate between periodontal health, gingivitis and periodontitis. These algorithms utilised saliva or blood samples alone ($n = 10$) or in combination with self-reported questionnaires ($n = 4$) and/or risk determinants/indicators ($n = 4$).

AI algorithms applied to OPGs and/or CBCT images ($n = 16$) were used to detect bone loss for the screening of periodontitis, while AI algorithms trained on clinical images ($n = 5$) were mainly used to detect gingival inflammation.

Five papers correlated self-assessed bleeding alone with periodontal status.

7.4.2 | What Are the Most Frequently Reported Analytical Methods for Periodontal Screening in Non-Dental Settings?

In studies evaluating self-reported questionnaires, traditional statistical analyses were primarily utilised. Various AI algorithms were applied to biomarkers or image-derived data (i.e., radiographic images or clinical photographs).

7.4.3 | What Is the Performance of Screening for Periodontal Diseases in Non-Dental Settings?

Meta-analyses could not be performed because of pronounced heterogeneity and inconsistent reporting of the evaluated parameters.

Screening for gingivitis in the non-dental setting is characterised mainly by low sensitivity values (≈40%), irrespective of the screening tool (i.e., self-reported questionnaires, biomarkers, self-assessed bleeding and AI algorithms trained with clinical photographs). The exception is one study ($n = 408$) evaluating the haemoglobin concentration in toothpaste slurry after brushing (83.9% sensitivity) (Deng et al. 2021).

For severe (stage III-IV) periodontitis, screening in the non-dental setting using self-reported questionnaires and algorithms trained on biomarkers or image-derived data showed sensitivity and specificity values of over 70% and AUCs above 0.8, while performance was weaker for milder forms of periodontitis. All algorithms increased their screening performance when certain risk determinants (e.g., age, gender) and risk indicators (e.g., smoking) were added to the models. Similarly, when certain biomarkers were added to questionnaire data (e.g., aMMP-8), performance in terms of AUC and sensitivity/specificity improved to 0.9 and approximately 90%, respectively.

AI algorithms applied to OPGs were reported as highly accurate (AUC ≥ 0.8 and/or sensitivity ≥ 80%) in detecting marginal bone loss and classifying stages of periodontitis ($n = 8$ studies; 15,890 OPGs). Furthermore, two studies reported that the time required to evaluate OPGs was significantly less for AI algorithms (less than 1 s for each). One study ($n = 1121$ OPGs) used an AI algorithm to identify marginal bone loss (AUC = 0.951), but also angular bone defects (AUC = 0.733) and furcation defects (AUC = 0.868) (Kurt-Bayrakdar et al. 2024).

Current evidence shows that all algorithms performed poorly for gingivitis and mild periodontitis, regardless of the data source (e.g., questionnaires, saliva biomarkers, clinical or radiographic images). Thus, they are primarily suitable for screening severe (stages III and IV) periodontitis.

7.4.4 | What Are the Current Limitations of Screening in Non-Dental Settings?

Limitations of the current evidence base on screening of periodontal diseases in non-dental settings include (i) absence of appropriate reference standards (particularly for AI algorithms trained with clinical photographs); (ii) absence of external validation; (iii) applicability related to different populations (due to transcultural diversity)or settings; (iv) use of self-reported questionnaires that were initially designed for surveillance purposes, including questions on prior diagnoses; (v) heterogeneous combinations of different data sources and incomplete data reporting (e.g., true positives, true negatives, false positives, false negatives); (vi) non-evaluation yet of patient benefit and cost-effectiveness of the different algorithms.

7.4.5 | What Are the Future Focus Areas Regarding Screening for Periodontal Diseases in Non-Dental Settings?

Future studies on screening for periodontal diseases should take the following into consideration:

- Use of an appropriate reference standard (i.e., clinical and/or radiographic evaluation following current case definitions according to the 2018 classification system).
- Use of questionnaires aimed specifically at the screening of periodontal diseases.
- Use of AI to aid in developing cognitive and semantic evaluations of self-report questions for different populations, considering transcultural elements and settings.
- Combined use of different data modalities to optimise the performance of the algorithms.
- Provision of complete data information regarding AUC, sensitivity, specificity and positive/negative predictive values.
- Evaluation of clinical applicability, patient acceptability and cost effectiveness of the algorithm.

7.5 | Emerging Approaches and Technologies—Summary and Conclusions

7.5.1 | Which Emerging Applied Data Science Methods Show Promise in Improving the Performance of Non-Clinical or Clinical Tests?

The study of applied data science methods in periodontology is in its infancy. The field has experienced rapid expansion and, in diagnostics, has explored multiple data modalities and the application of several general-purpose networks. No method has demonstrated superiority over radiographic image analysis, photographic analysis or multimodal integration. AI-assisted diagnostic interpretation, however, performs at least as well as that of experts, and it may outperform them. As more powerful data science methods are tested, specific algorithms may emerge that are superior to others.

7.5.2 | How Has Artificial Intelligence Been Applied? Does It Show Potential Benefits or Limitations?

AI is considered a disruptive technology in medical care, and the potential benefits are unprecedented. Clinically available methods cleared by regulatory agencies consist of Class I/II devices, which are not approved diagnostics but aid in clinical diagnosis performed by licensed practitioners. These commercially available devices are not fully supported by published, independent, peer-reviewed studies, which may detract from the trust required to build clinician confidence for adoption.

Currently available methods may only partially capture the full benefits that AI can bring to the field. These benefits may require systematic validation of more advanced systems and satisfy a higher bar of regulatory requirements, such as Class III devices.

Most reported applications are from small-scale proof-of-principle studies. Many scientific studies still need to address critical questions about the interpretability of AI-based predictions. Future research must focus on this aspect. To our knowledge, no method has been scientifically validated for diagnostic purposes.

7.5.3 | Research Agenda for AI Models in Periodontology

Focus on Clinically Relevant Outcomes. AI models in periodontology must focus on clinically meaningful outcomes aligned with diagnostic and treatment protocols. Future systems should predict periodontal disease presence, progression, severity, complexity, intervention strategies and treatment outcomes for each patient.

Prioritise High-Quality, Multi-Centre Datasets. A key challenge in dental AI research is the lack of standardised, annotated datasets reflecting diverse demographics and clinical heterogeneity. Collaborative efforts among dental institutions, practices and insurance companies to create multi-centre datasets would improve model generalisability across populations. This involves balancing datasets with various forms of periodontal health and disease and collecting comprehensive longitudinal data for prognostic studies.

Integrate AI With Imaging Modalities Beyond Radiographs. While panoramic radiographs are widely used for initial screening, AI models should leverage 3D imaging data (such as CBCT or intra-oral scanners) where feasible. Multiple imaging modalities can enhance diagnostic precision, particularly in identifying early periodontal changes and complex anatomical variations. Developing multimodal models that integrate patient radiographs, clinical data and omics information can enable a more holistic assessment.

Ensure Interpretability for Trust in Clinical Settings. While ML and DL models may be better equipped to capture intricate associations in data than classical statistical methods, their complexity makes their reasoning harder to explain. As this limits trust in such systems, interpretability should be prioritised. Clinically meaningful and interpretable outcomes that should be routinely reported include relative feature importance (how important a parameter was for the model), partial dependency (in which direction a parameter influenced the model) and class activation mapping (which regions of visual data were important for a model).

Facilitate Seamless Integration Into Clinical Workflows. AI solutions for periodontitis management must be designed to integrate seamlessly into existing clinical workflows to increase rates and levels of adoption. This may include developing plug-in applications compatible with electronic health records (EHRs) or integrating digital imaging systems commonly used in dental clinics. Systems should prioritise ease of use, low-latency image processing and minimal disruption to existing workflows.

Address Regulatory Compliance and Economic Feasibility. AI applications in periodontology need to navigate rigorous regulatory standards, particularly for diagnostic applications. Developers should work closely with regulatory bodies and clinicians to ensure that AI solutions meet safety and efficacy standards. Additionally, demonstrating economic feasibility for clinics and practitioners is crucial. This could involve cost–benefit analyses to show the value of AI in reducing rates of mis-diagnosis and optimising patient management.

Establish Standardised Evaluation Metrics. The dental and medical communities should establish standardised performance metrics and validation frameworks to facilitate benchmarking and comparison across AI systems in periodontology. These frameworks should include criteria such as sensitivity, specificity, AUC and misclassification rates. Collaboration with international periodontal associations may help develop these standards, improving the consistency and transparency of AI evaluation in periodontal research. An example of early efforts in computer vision with radiographic images has been recently published (Buttner et al. 2024).

Expand Real-World Testing and Continuous Learning. Most AI models are tested in controlled settings, which may not reflect the complexities of real-world clinical practice. A robust AI model for periodontology should undergo extensive real-world testing in diverse clinical environments. Furthermore, models can be designed for continuous learning, allowing them to adapt to new data and improve over time, which is essential for maintaining relevance in changing clinical landscapes.

7.6 | Concepts for Clinical Translation in Periodontology

The evidence reviewed herein points to the exciting potential of applied data science methods to enable prediction beyond current diagnostic tools. AI applications open the possibility of entering a new era of precision periodontology. The ability to integrate omics technologies, imaging and EHR information will aid in predicting disease onset and progression, as well as individual responses to treatment. Subsequently, patient stratification will enable clinicians to better guide patients in clinical decision making.

Achieving these goals requires assembling interdisciplinary teams of data scientists, biological and clinical domain experts and practising clinicians. For generalisability, data must be sourced heterogeneously from diverse global patient populations and clinical settings. Institutions and regulatory bodies must establish governance structures and policies to enable collaborative research.

Considering the global burden of periodontal diseases, these emerging technologies must be developed and validated in an approach that strives to enable deployment across the entire socioeconomic spectrum, thereby achieving better health equity. Sustainable and accessible AI-enabled tools should be promoted to facilitate their implementation in lower resource settings (Buttner et al. 2024).

Author Contributions

David Herrera, Maurizio S. Tonetti, Iain Chapple, Moritz Kebschull, Panos N. Papapanou, Anton Sculean and Mariano Sanz, substantially contributed to the conception and design of the project, interpretation of data, and drafting and critically reviewing the manuscript. The EFP workshop participants (listed in alphabetical order) significantly contributed by critically reviewing the consensus report and by participating in the workshop discussions. All authors approved the final version of the manuscript.

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Conflicts of Interest

Individual potential conflicts of interest forms were completed by all participants and are available on file at the European Federation of Periodontology.

Data Availability Statement

The authors have nothing to report.

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Supporting Information

Additional supporting information can be found online in the Supporting Information section.