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REVIEW ARTICLE

Diagnostic measures for monitoring and follow-up in periodontology and implant dentistry

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Abstract

This review discusses the role of diagnostic measures in the lifelong management of periodontal disease and peri-implant complications. After active treatment, these conditions require regular monitoring of the supporting structures of teeth and dental implants to assess bone and soft tissue health over time. Several clinical measures have been developed for the routine assessment of periodontal and peri-implant tissues, including periodontal and peri-implant probing, bleeding on probing, intraoral radiography, biomarker analysis, and microbiological testing. This review highlights the evolution of diagnostic practices, integrating traditional methods with emerging technologies such as resonance frequency analysis and ultrasound imaging to provide a holistic view of peri-implant health assessment. In addition to objective measurements, patient risk factors are considered. The goals of periodontal and peri-implant maintenance are to control disease activity and stabilize tissues through supportive care, which includes diagnostic measures at follow-up visits. This enables clinicians to monitor treatment outcomes, assess health status, and detect recurrence or progression early through routine evaluation, allowing additional interventions, including adjustment of supportive therapy intervals, to further improve and maintain periodontal and peri-implant stability over time.

KEYWORDS
dental radiography, diagnostic measures, peri-implant probing, peri-implantitis, periodontal probing, periodontitis, supportive periodontal care, supportive periodontal therapy

1 | INTRODUCTION

Periodontal and peri-implant diseases are chronic conditions that require lifelong management and monitoring. The supporting structures of teeth and dental implants — the gingiva, alveolar bone, and surrounding tissues — are susceptible to inflammation and breakdown over time if not properly maintained. Available diagnostic measures and careful monitoring play a key role in the prevention, early detection, and treatment planning of these conditions. Through regular evaluation, clinicians can assess the health of the periodontium and peri-implant sites, monitor for deteriorating bone levels or infectious processes, and determine if intervention is needed.[1–6]

Several different diagnostic measures have been developed to evaluate periodontal and peri-implant tissues. Traditional periodontal probing uses a periodontal probe to measure the depth of pockets around each tooth and identifies pockets greater than 3–5 mm, indicating disease. Full-mouth periodontal probing also provides valuable information about the extent and location of periodontal

disease. Probing around implants, known as peri-implant probing, works in a similar way to monitor the health of the tissues supporting dental implants. Bleeding on probing (BOP) is also assessed, as bleeding indicates an increased risk of further tissue and bone loss.[7–9]

Dental radiographs are a complementary diagnostic tool, allowing assessment of alveolar bone levels that cannot be visualized clinically. Serial intraoral radiographs taken over time can detect subtle changes in marginal bone height around teeth and implants.[10,11] More advanced 3D imaging modalities, such as cone beam computed tomography, provide a highly accurate assessment of three-dimensional bone defects.[12] In addition, microbiological testing involves the collection of supra- and subgingival biofilm samples and analysis of bacterial composition, which has both diagnostic and prognostic value.[13,14]

In addition to objective clinical measurements, patient history and risk factor assessment play a role. Factors such as poor oral hygiene, smoking status, pre-existing medical conditions, and history of periodontitis may influence prognosis and treatment planning. Monitoring biofilm control with disclosing agents and calculus detection prior to scaling also provides information about an individual's health and response to treatment over time.[13,14]

The goal of periodontal and peri-implant supportive care is to control disease activity and stabilize hard and soft tissues over time. Diagnostic testing during routine follow-up visits allows the clinician to track treatment results, evaluate the patient's periodontal and peri-implant health status, and detect any recurrence or progression of disease at an early stage. With timely diagnosis and appropriate intervention, further attachment and bone loss can often be prevented. The purpose of this review is to discuss the role and utility of various diagnostic measures used in periodontology and implant dentistry for long-term patient care.

2 | THE IMPORTANCE OF DIAGNOSTIC MEASURES FOR MONITORING

Diagnostic measures in periodontology and implant dentistry are crucial for several reasons. First, they aid in the early detection of periodontal disease and potential implant failure, which is critical for timely intervention. Secondly, they help to assess the ongoing response to treatment, allowing adjustments to be made to management strategies. Finally, they are essential for long-term monitoring to ensure maintenance of oral health after treatment.

In their landmark publication, Axelsson and Lindhe[15] highlighted the importance of regular maintenance care in the management of periodontal disease. The study, which involved 90 patients after advanced periodontitis treatment, found that adherence to a regular recall programme consisting of professional teeth cleaning and oral hygiene education every 2–3 months resulted in superior periodontal health maintenance. In contrast, patients who neglected this programme experienced recurrent periodontitis, characterized by increased probing pocket depths (PPDs). Their research demonstrated that sustained and structured follow-up care is as important as initial treatment for the maintenance of long-term periodontal health. Building on this understanding, Matuliene et al.[16] investigated the impact of such residual pockets on periodontitis progression and tooth loss over 11 years, emphasizing the importance of achieving low PPDs during active periodontal therapy to reduce the long-term risk of disease progression and tooth loss. Similarly, Costa et al.[17] examined tooth loss in patients with chronic periodontitis undergoing supportive periodontal therapy (SPT) over 5 years. Their study of 212 patients compared tooth loss between those who regularly adhered to SPT and those who did not. The results revealed that regular compliers experienced significantly less tooth loss. Other key risk factors for tooth loss identified in this study included male gender, smoking, and elevated PPDs, with these factors being more pronounced in irregular compliers. A more recent literature study, including studies by McCracken et al.[18] and Echeverria et al.,[19] has addressed the multifaceted reasons for failure to achieve the goals of periodontal recall programmes, such as patient non-compliance, inadequate education, and inappropriate diagnostic measures. These studies highlight that a lack of patient understanding and socio-economic barriers, among other factors, can lead to poor adherence to recall visits, thus undermining periodontal health stability.[20] They emphasize the need for personalized patient education and regular monitoring to enhance adherence and improve treatment outcomes.

In summary, the success of periodontal and implant treatments hinges on patient compliance, accurate diagnosis, and ongoing monitoring. Addressing these through personalized education, tailored treatment plans, and regular monitoring can markedly improve outcomes. As both periodontology and implant dentistry continue to advance, incorporating these insights into clinical practice is fundamental for the long-term success of periodontal and dental implant therapies.

The range of diagnostic measures in periodontology and implant dentistry extends beyond initial assessments and includes a variety of tools and techniques to support comprehensive supportive periodontal care (SPC). Oral hygiene assessments, such as biofilm indices, play a fundamental role in monitoring and instructing patients on effective oral hygiene practices. Additionally, periodontal and peri-implant PPD measurements, alongside BOP around teeth and dental implants, offer valuable insights into the health status of the periodontal and peri-implant tissues. The use of indices such as a gingival index around teeth and a sulcus bleeding index around dental implants further refines the diagnostic process. Furthermore, intraoral radiographs provide an essential visual assessment of bone levels and tooth supporting structures. Salivary diagnostics and the analysis of crevicular fluids from around teeth and dental implants have emerged as non-invasive methods for monitoring biochemical and immunological changes. Lastly, microbiological assessments play a crucial role in better understanding the aetiology of periodontal diseases and tailoring patient-specific treatments. These diverse diagnostic modalities are integral to the management and long-term

success of periodontal and implant therapies, highlighting the need for their thorough understanding and application in clinical practice.

Given the established importance of diagnostic measures in periodontology and implant dentistry, it is indicated to review these specific diagnostic parameters in detail. In both periodontal and peri-implant scenarios, the following discussion of these parameters first addresses their relevance and application in natural teeth, followed by their adaptation in the context of dental implants. This structured approach provides a comprehensive understanding of the diagnostic measures in different clinical situations and highlights their role in the effective management and long-term success of treatments in periodontology and implant dentistry.

3 | MONITORING ORAL HYGIENE

Monitoring oral hygiene around teeth and dental implants is a comprehensive and multifaceted process, integrating clinical assessments, patient education, and individualized care strategies to ensure long-term periodontal and peri-implant health. One of the cornerstones of this process is the education of patients in appropriate oral hygiene practices and the provision of effective oral hygiene aids.[21,22] This approach plays a pivotal role in controlling biofilm and reducing the risk of developing periodontal and peri-implant diseases. Customized oral hygiene protocols, tailored for each patient, including specific instructions during active periodontal therapy as well as pre- and post-implantation surgery care, are essential components of this strategy.

The use of various biofilm indices is a primary method for clinicians to assess the extent of biofilm, a key factor in both periodontal and peri-implant diseases. As outlined in detail by D'Elia et al.,[23] these indices are categorized into non-quantitative and quantitative methods. The former, such as the "Plaque Control Record" introduced into clinical practice by O'Leary in 1972, is subjective and relies on the clinician's judgment to detect the presence of biofilm.[24] In contrast, quantitative methods, such as the "Plaque Index System" introduced into clinical research by Silness and Löe,[25] provide objective measurements of biofilm deposition and allow for more accurate assessment. In addition, the use of disclosing agents significantly enhances the monitoring process. By staining the dental biofilm, these agents increase its visibility on the tooth surfaces, thereby facilitating its detection and removal. This is not only beneficial in a clinical setting, but also serves an educational purpose, helping patients to visualize biofilm accumulation and understand the importance of thorough oral hygiene over time (Figure 1).

Professional cleaning techniques, using tools such as ultrasonic devices, curettes, scalers, air-polishing, and rubber cup polishing, are integral to maintaining periodontal and peri-implant health. These professional measures aim to remove dental biofilm and calculus from both supragingival and subgingival areas. In addition to these professional measures, patient self-care routines involving the use of toothbrushes and interdental cleaning devices such as dental floss and interdental brushes are necessary to maintain daily oral hygiene. In addition, the monitoring process includes the assessment of oral hygiene.[24] A percentage between 20% and 25% is usually considered acceptable for maintaining periodontal and peri-implant health. However, in scenarios such as regenerative periodontal surgery, more stringent biofilm control with a percentage threshold of 15% is required to ensure optimal clinical outcomes.

In summary, monitoring oral hygiene around teeth and dental implants requires a holistic approach that combines clinical assessments, patient education, individualized care plans, and professional cleaning methods. This comprehensive process is critical to the successful prevention of periodontal and peri-implant disease and the maintenance of oral health.

4 | MONITORING PROBING DEPTHS

Periodontal probing is considered the gold standard diagnostic measure for assessing the status of periodontal disease. It involves using a periodontal probe, typically a University of North Carolina (UNC) 15 probe, to measure the PPD of the gingival sulcus or periodontal pocket around each tooth. Measurements are recorded in millimetres and provide key clinical parameters including PPD, clinical attachment level, gingival recession, and furcation involvement. Measurements are taken at four or six sites around each tooth—mesial-buccal, mid-buccal, distal-buccal, mesial-lingual/palatal, distal-lingual/palatal, and in multi-rooted teeth with furcation involvement. Particular attention should be paid to posterior teeth, which are at higher risk of periodontal tissue destruction. Measurements allow the clinician to create a periodontal chart (e.g. periodontalchart-online.com) or calculate periodontal disease indices to objectively stage the severity of periodontitis or peri-implantitis, respectively. Later, during follow-up, probing also helps to evaluate the patient's response to previous therapies by monitoring the reduction or elimination of periodontal pockets by regeneration or surgical correction of infrabony defects.

Various studies have investigated both inter-examiner and intra-examiner reproducibility and validity of periodontal probing. It was found that for clinical attachment level measurements, approximately 90% of the recordings could be reproduced within a ±1.0 mm difference.[26] Further research, such as the studies by Wang et al.[27] and Araujo et al.,[28] has highlighted the critical importance of technique sensitivity in periodontal probing, demonstrating that both manual and automated force-controlled probes can yield reproducible results when applied correctly. The precision of these measurements is significantly influenced by the examiner's expertise and the standardization of probing force, which is ideally around 0.25 N.[29] This standard is critical to avoid over-probing, which can damage epithelial attachment, and under-probing, which may lead to an underestimation of PPD.[30] Such research indicates that PPDs may be overestimated in inflamed periodontal sites, while post-treatment, healthy sites might be underestimated. Additionally, periodontal probing is key to the development of maintenance programs for SPT. Regular serial assessments, suggested every 3–6 months, are

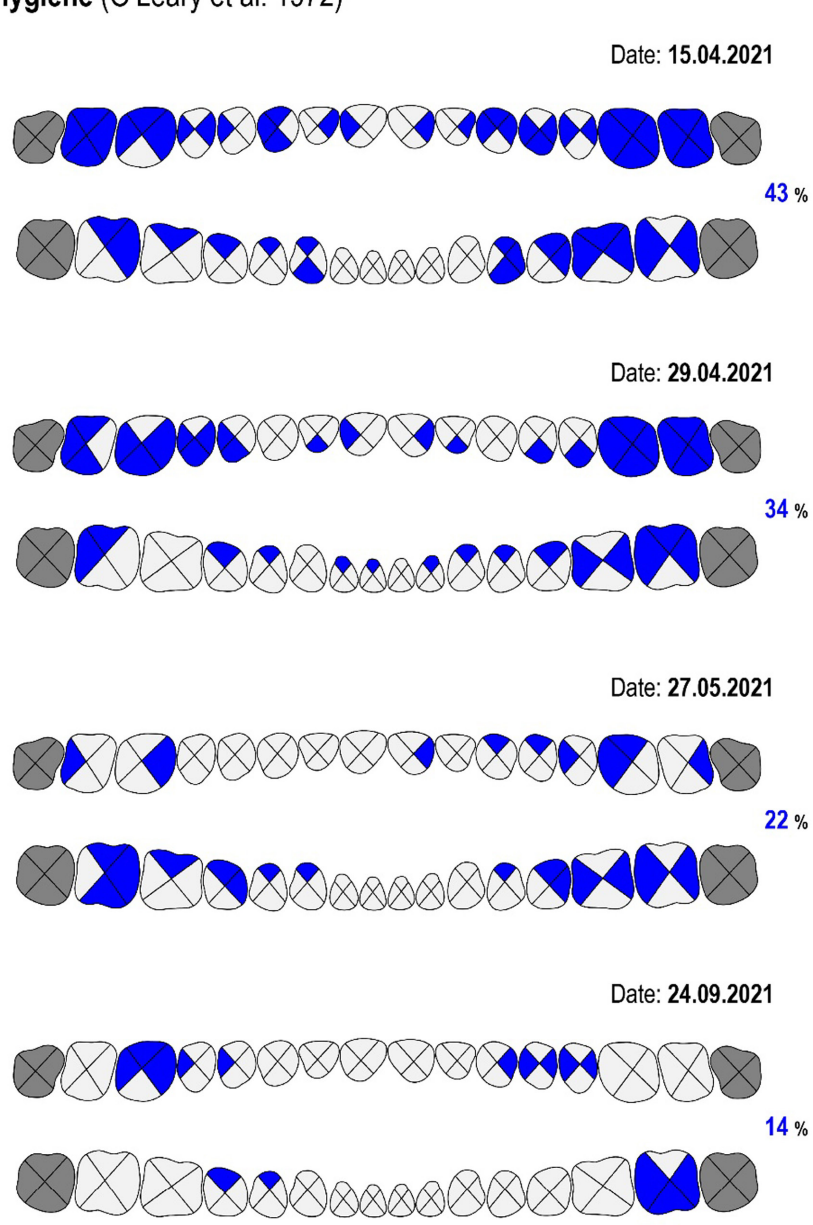


FIGURE 1 38-year-old male patient during initial periodontal therapy and subsequent visits. Oral hygiene monitoring according to O'Leary et al.[24] over four dental visits to monitor improvements in oral hygiene.

essential to monitor changes in disease activity in susceptible individuals and to effectively control periodontal and peri-implant disease to maintain stability over time.

4.1 | Type of periodontal probes and their characteristics

There are a variety of probe types available for periodontal probing, each with unique characteristics to suit specific clinical situations. Probes such as the UNC 15 probe are favoured for their calibrated markings, which allow for accurate measurements. Other probes, such as the Michigan O probe and the World Health Organization (WHO) probe, have distinct features to meet different clinical needs.[31] The material composition of these probes is a critical factor. Metal probes have traditionally been favoured for their durability and precision, but their use, particularly in cases involving implants, has come under scrutiny due to potential damage to dental surfaces.[32] Recent innovations have introduced probes made from alternative materials such as plastic or carbon fibre, which offer a softer contact, reducing the risk of scratching delicate implant surfaces.[33] The flexibility of these probes, especially plastic ones, can provide better access in challenging anatomical situations such as overhanging restorations or complex implant-retained prosthetics, potentially leading to more accurate measurements.[34] In addition, tactile feedback and force application vary between probe types, requiring clinician skill and experience to accurately interpret PPDs.[35] It is essential for clinicians to adeptly choose the appropriate probe, balancing the need for accurate measurement against the potential risk of tissue or surface damage.

4.2 | Safety in probing around dental implants

Probing around dental implants requires a cautious approach due to the delicate nature of the peri-implant tissues and the potential risks to the implant surface. Metal probes, which are standard in traditional periodontal probing, pose a risk of microabrasion to the titanium surface of implants. Such abrasions can increase surface roughness, creating niches for bacterial colonization and potentially leading to peri-implant disease.[32] Studies have shown that the movement of metal probes over implant surfaces can cause discrete changes, the clinical relevance of which is still being evaluated.[36] In contrast, non-metallic probes, particularly those made of carbon or plastic, are less likely to cause such damage due to their softer and less abrasive nature.[37] These probes are recommended to reduce the risk of implant surface modification. The clinical implications of using non-metallic probes are significant, as maintaining the integrity of the implant surface is paramount in preventing peri-implant complications. Probing force is another critical factor; excessive force can traumatize the peri-implant mucosa, leading to inflammation or recession.[38] It is therefore advisable to use a standardized force, ideally around 0.25 N, to obtain accurate and reliable measurements.[39] This approach, coupled with the use of non-metallic probes, forms the cornerstone of safe and effective probing practices around dental implants. Clinicians must be vigilant in their technique to ensure that implant integrity is maintained while accurately assessing peri-implant health.

5 | MONITORING FURCATIONS

The management of multi-rooted teeth, such as molars, poses a significant challenge to dental professionals due to their complex anatomy and difficulty in maintaining proper oral hygiene measures.[40,41] Clinical studies have shown that molars with furcation involvement (FI) are less responsive to non-surgical periodontal treatments and are more likely to experience further attachment loss.[42,43] Various treatment modalities, including both non-surgical and surgical approaches, have been used to address these specific anatomical challenges.[44]

The long-term prognosis of molars with FI remains compromised, as demonstrated by several clinical studies.[45–51] Hirschfeld and Wasserman[45] reported that over a 22-year period, patients receiving SPT lost 7.1% of all teeth to recurrent periodontitis, with this number increasing to 32% for multi-rooted teeth with FI. This finding is supported by similar studies by Ross and Thompson, McFall, and Goldman et al.[52–54] In 2009, Huynh-Ba et al.[55] conducted a systematic review to evaluate the impact of periodontal therapy on the survival and success rates of furcation-involved teeth. This review found good long-term survival rates for multi-rooted teeth with FI following various treatments. Specifically, FI degree 1 could be effectively managed with non-surgical mechanical debridement alone. The review also noted that the development of caries in the furcation area was a common cause of molar loss following tunneling and that complications following resective procedures were typically not related to periodontal progression, but rather to vertical root fractures and endodontic failures.

A subsequent study by Salvi et al. (2014) found further evidence that teeth with FI degrees of 2 or 3, indicating more advanced involvement, had a higher risk of loss compared to teeth with no furcation involvement (FI degree 0). In contrast, FI degree 1 did not significantly increase the risk of tooth loss compared to FI degree 0.[56] The anatomical complexity of multi-rooted teeth, particularly those with furcation involvement, makes them more difficult to treat and maintain. These teeth are less responsive to non-surgical periodontal therapy and more prone to attachment loss. The study also highlighted the importance of compliance with regular SPT and the negative impact of smoking on the prognosis of these teeth. Non-smokers and compliant patients with less severe furcation involvement (FI degree 0 or 1) had significantly lower rates of multi-root tooth loss during SPT compared with non-compliant smokers with more severe furcation involvement (FI degree 2 or 3). In addition, the study suggests that strategic treatment decisions, such as resective procedures, including root amputation and hemisection, may lead to favourable outcomes in the management of molars with furcation involvement.[56] These procedures have been shown to facilitate better plaque control and have comparable success rates to other dental treatments such as implants in periodontally compromised patients. In conclusion, the management of furcation-involved multi-rooted teeth in periodontally compromised patients requires careful assessment of the degree of involvement, patient compliance with SPT, and lifestyle factors such as smoking. These elements are critical in determining the long-term prognosis and treatment strategy for these teeth.

6 | MONITORING PERIODONTAL AND PERI-IMPLANT INFLAMMATION

The effective management of periodontal and peri-implant disease depends on the accurate and early detection of inflammation. Under conditions ranging from gingivitis and periodontitis to peri-implant mucositis and peri-implantitis, monitoring inflammation is critical for diagnosing disease stages, formulating treatment plans, and evaluating therapeutic outcomes. This section reviews a selection of widely used methods and indices for assessing and monitoring inflammation under these conditions.

6.1 | Gingival indices

In periodontology, numerous gingival indices have been developed and used in clinical practice to assess gingival inflammation. Three indices are particularly noteworthy. The sulcus bleeding index (SBI) by Mühlemann and Son[57] and the papillary bleeding index (PBI) by Saxer and Mühlemann[58] are used to determine the percentage of gingival inflammation and to motivate patients in prophylaxis. Both

indices help quantify gingival health, assist clinicians in identifying areas of inflammation, and educate patients about the importance of maintaining oral hygiene.

Another significant gingival index described by Ainamo and Bay[59] involves probing the gingival sulcus with a periodontal probe to a maximum depth of 3 mm. The presence of bleeding from the sulcus during probing is interpreted as an indication of gingival inflammation. This method is essential for periodontal monitoring as it provides both a topographical and quantitative record of the extent of gingivitis.

6.2 | Bleeding on probing (BOP)

In contrast, for patients with periodontitis, the bleeding on probing (BOP) index developed by Lang et al.[60] is used. This index documents BOP *to the bottom of the existing periodontal pocket*, providing a quantitative and topographical representation of periodontal inflammation. The BOP index is particularly valuable in monitoring periodontal stability and response to treatment (Figure 2). Several studies have evaluated its utility as a predictor of disease progression and stability. Lang et al.[60,61] examined the predictive value of BOP at individual sites and found that BOP-positive sites had only a low positive predictive value of 29% for future periodontal attachment loss, whereas the absence of BOP was highly predictive of periodontal stability at 88%. With regard to the force applied during periodontal probing, Lang et al.[62] focused on establishing a relationship between BOP, probing pressure, and gingival health. Their findings indicated that BOP with uncontrolled forces could result in false positive readings. It was observed that applying a probing force greater than 0.25 N could traumatize clinically healthy gingival tissue. A key finding of their study is the demonstration that probing forces should be carefully applied to avoid false positives and potential trauma to healthy tissue. This has significant implications for periodontal monitoring and highlights the need for standardized probing pressures in clinical practice.

Later in 1995, Claffey and Egelberg[63] investigated the use of percentage of bleeding on probing (%-BOP) at the individual level to predict disease activity and found that %-BOP provided more definitive information about overall periodontal prognosis than assessment of BOP at individual sites. Studies of patients undergoing SPT reported that patients with mean %-BOP between 20% and 30% were at higher risk for further periodontal disease progression, whereas patients with %-BOP below 20% demonstrated greater stability.[64–66] Similarly, Joss et al.[67] followed SPT patients for 4.5 years and concluded that a mean %-BOP of ≤20% predicted periodontal stability, supporting the threshold proposed by previous investigators. However, none of these studies considered the potential confounding effects of smoking on the relationship between %-BOP and periodontal stability. As smoking is a major risk factor for periodontitis, it is likely to affect the predictive value of clinical parameters such as %-BOP. Subsequently, Ramseier et al.[68] found that smokers who maintained periodontal stability had a mean %-BOP of 16.2%, even if they were initially diagnosed with advanced periodontitis. It is noteworthy that during SPT, smokers have mean %-BOP values below their percentage of residual PPDs (Figure 3). Consistent with this, Farina et al.[69,70] reported reduced %-BOP in smokers and noted that deeper pockets were more prone to bleeding.

In the context of peri-implant BOP, the study by Gerber et al.[71] investigated the relationship between peri-implant BOP and various probing pressures around dental implants. Conducted in 17 healthy patients with a history of periodontal disease but currently with good oral hygiene and well-maintained peri-implant tissues, the study evaluated the trend of the modified BOP described by Mombelli et al.[72] and the penetration depth of periodontal probes at two standardized probing pressures (0.15 or 0.25 N). The results revealed that increasing the probing pressure from 0.15 N to 0.25 N resulted in a 13.7% increase in BOP percentage around implants and a 6.6% increase around contralateral teeth. A significant difference in mean BOP percentage was observed between implant and dental sites at 0.25 N pressure. The study concluded that a probing pressure of 0.15 N may be the threshold to avoid false-positive BOP measurements around dental implants, suggesting a higher sensitivity of probing around implants compared to teeth. This finding is critical for the diagnosis and monitoring of peri-implant mucositis and peri-implantitis and indicates that lower pressures are required to accurately assess tissue around implants compared to periodontal sites.

Farina et al.[38] expanded the understanding of BOP in peri-implant monitoring. Their study, which focused on peri-implant BOP, found a direct correlation between PPD and the likelihood of BOP, with an increased probability in females and in anterior implant sites. In line with Ramseier et al.,[68] their study confirmed the diagnostic significance of BOP in determining periodontal stability by demonstrating that the probability of BOP around implants was comparable to that around natural teeth when adjusted for PD. These findings highlight the need for clinicians to consider PD, gender, and implant position in peri-implant assessments, allowing for a more nuanced approach to supportive peri-implant care.

7 | OVERLAY TECHNIQUE FOR MONITORING ORAL HYGIENE AND GINGIVAL INFLAMMATION

The use of an overlay technique for monitoring oral hygiene and gingival inflammation indices can provide a more complete visual representation of the relationship between the presence of dental biofilm and gingival health. This method involves superimposing both a plaque index and a gingival index from subsequent examinations to highlight areas of inadequate hygiene and advanced inflammation, respectively. By visually mapping these indices, clinicians can more effectively identify critical areas that require targeted intervention. This approach not only facilitates accurate clinical assessments, but also enhances patient education by clearly demonstrating the impact of poor oral hygiene on gingival health (Figure 4).

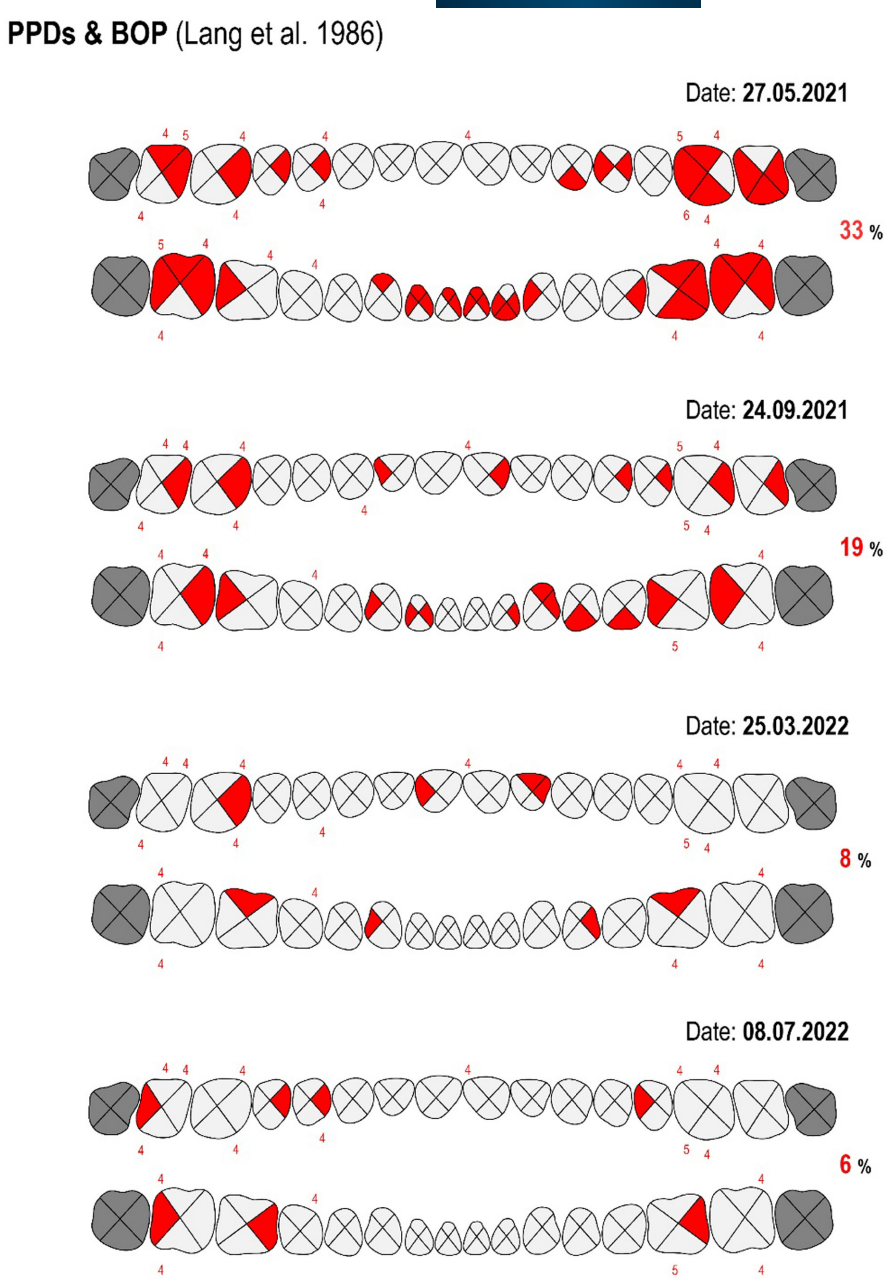


FIGURE 2 38-year-old male patient from Figure 1. Residual PPDs and BOP monitoring in a periodontitis patient (male smoker, age 41–42 years) according to Lang et al.[60] over four dental visits to monitor improvements in periodontal health.

8 | MONITORING WITH INTRAORAL RADIOGRAPHS

Radiographic examination, particularly intraoral radiographs, plays a critical role in periodontology and implant dentistry, providing invaluable insight into alveolar bone levels and other details not visible by clinical examination alone. Intraoral periapical and bitewing radiographs are essential for monitoring marginal bone levels around teeth and dental implants. These radiographs are critical for tracking changes over time.[73,74]

For teeth, clinicians use follow-up radiographs to compare with baseline radiographs taken before or immediately after non-surgical periodontal therapy. This comparison is key to assessing bone fill in infrabony defects or the resolution of vertical bony craters following resective surgery. Subtle changes, such as a 0.5–1 mm change in marginal bone height, are significant indicators of progressive bone loss and require further evaluation. In the context of dental implants, radiographic assessment is critical for evaluating osseointegration after implant placement. It helps to detect peri-implant radiolucencies or any loss of marginal bone integrity over time. Follow-up radiographs may be considered for patients in good health, with more frequent assessments required in the presence of disease.[75]

Advanced 3D imaging modalities, such as cone beam computed tomography (CBCT), provide a more accurate assessment of defect morphology and bone volume, overcoming some of the limitations of two-dimensional imaging techniques. Unlike conventional radiographs, which can suffer from superimposition of anatomical structures and provide only a two-dimensional representation of three-dimensional anatomy, CBCT allows complex cases to be visualized with greater clarity and detail. This is particularly valuable in surgically guided bone

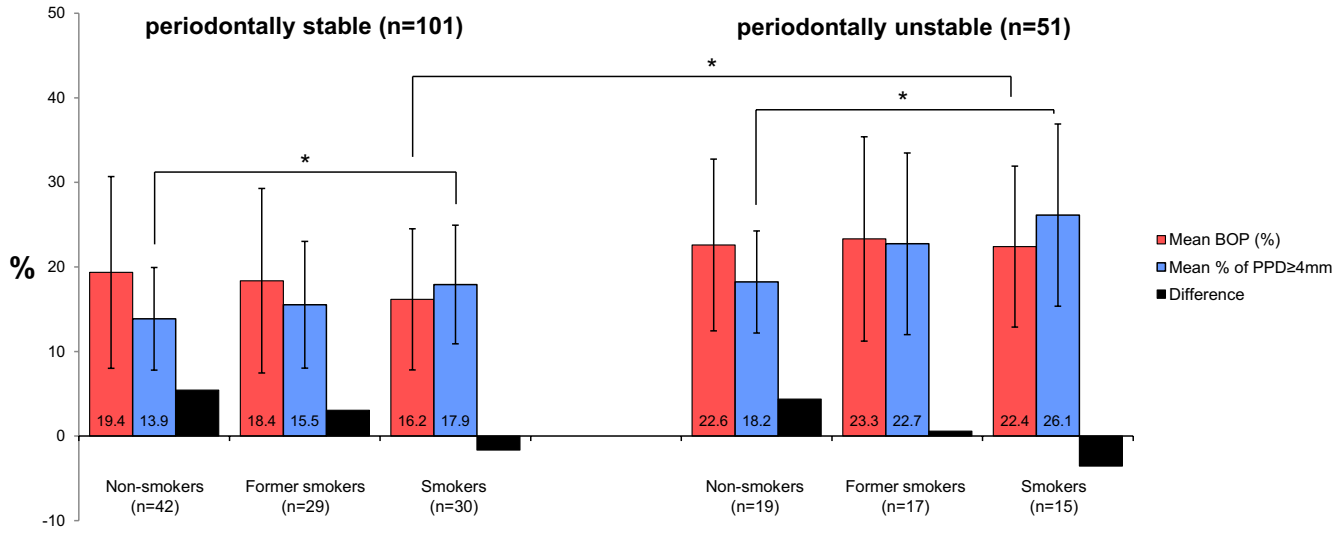


FIGURE 3 Mean BOP, mean %-PPD ≥4 mm and calculated difference per smoking status over 5 years SPT in $n = 101$ periodontally stable and $n = 51$ periodontally unstable patients initially classified with advanced periodontal disease.[68] Error bars indicate standard deviations, calculated negative differences in both periodontally stable and periodontally unstable smokers represent a higher mean %-PPD ≥0.5 of PPD ≥4 mm compared to a lower mean BOP. * Statistically significant difference at $p < 0.05$.[68]

regeneration procedures where a comprehensive understanding of spatial relationships and bone architecture is critical. CBCT allows quantitative and qualitative analysis of bone changes, providing a three-dimensional perspective that greatly aids surgical planning and assessment.[76] However, it is important to recognize that consistent image orientation and angulation remain critical factors in ensuring the accuracy and reliability of serial CBCT images, similar to the considerations required for conventional radiography. This is essential for valid longitudinal monitoring of changes over time.[77]

While digital radiography offers advantages such as immediate viewing, long-term retrieval, and the ability to assess marginal bone levels at multiple sites without repeated radiation exposure, it does not provide the same level of three-dimensional detail as CBCT. However, when combined with clinical parameters and the patient's risk profile, both digital radiography and CBCT are invaluable tools in the long-term monitoring and management of patients in periodontics and implant dentistry.[78]

9 | MONITORING WITH LABORATORY DIAGNOSTIC MEASURES

Laboratory diagnostic measures have been developed to improve the accuracy of periodontal disease monitoring.[79] Among these, the analysis of gingival crevicular fluid (GCF), peri-implant crevicular fluid (PICF), or whole saliva (WS) biomarkers has emerged as a key diagnostic tool. Both GCF and PICF, a serum exudate from the gingival and peri-implant crevice, are rich in biomarkers that reflect the inflammatory status and tissue breakdown associated with periodontal and peri-implant disease. Assessment of various inflammatory mediators and enzymes in GCF, PICF, and WS provides insight into the presence and severity of periodontal and peri-implant pathology. This non-invasive, chair-side diagnostic approach may provide clinicians with a valuable adjunct to traditional clinical examinations, allowing for a more comprehensive evaluation and monitoring of periodontal and peri-implant health.

9.1 | Gingival (GCF) and peri-implant crevicular (PICF) fluid biomarkers

GCF, a serum exudate from the marginal gingiva, provides a minimally invasive means of biochemical analysis of periodontal status and inflammatory levels. Studies have identified elevated levels of inflammatory mediators such as prostaglandin E2, interleukin (IL)-1β and tumour necrosis factor-alpha in GCF from periodontitis sites.[80,81] In addition, commercially available chair-side tests for MMP-8 and -9 levels in GCF correlate well with the severity of periodontitis, providing valuable complementary information to clinical signs.[82]

Around dental implants, PICF biomarkers may substitute the clinical assessment peri-implant health. Analysis of PICF around implants provides information about the inflammatory status and potential risks of peri-implant disease.[83] The presence of specific biomarkers in the PICF may indicate peri-implantitis and aid in the early detection and management of implant-related complications.[84] Various biomarkers have been investigated to monitor the health status of peri-implant tissues. Studies have highlighted the potential of biomarkers such as PGE2, soluble ST2 (sST2), CCL-20/MIP-3α, BAFF/BlyS, IL-23, RANKL and osteoprotegerin and active matrix metalloproteinase-8 (aMMP-8) in assessing peri-implant disease. PGE2 levels in peri-implant sulcular fluid have been shown to correlate with disease severity, while sST2 levels have been associated with inflammatory conditions such as periodontitis. In addition,

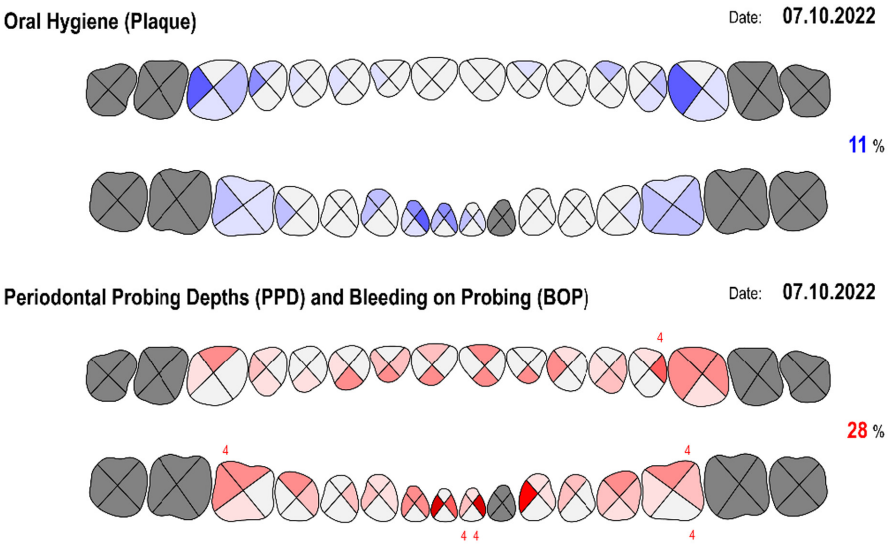


FIGURE 4 Overlay of two oral hygiene (top) and gingival indices (bottom) from two subsequent SPT visits for the monitoring of periodontal stability during supportive periodontal care (pariodontalchart-online.com).[24,60] Darker areas indicate higher prevalence of plaque and inflammation.

biomarkers such as IL-23 and RANKL have been proposed to elucidate the pathogenesis of peri-implant disease, emphasizing the importance of early diagnosis and monitoring.[85]

The use of aMMP-8 as a point-of-care test has shown promise in the early detection and screening of peri-implant disease risk. The PerioSafe® PRO DRS and ImplantSafe® DR tests (dentognostics GmbH, Jena, Germany) are examples of commercially available tests that can detect active MMP-8 levels in PICF and provide both qualitative and quantitative results. These tests are non-invasive, require minimal specialized equipment, and provide rapid results with high sensitivity and specificity.[86] In addition, elevated levels of IL-1β and MMP-8 in peri-implant crevicular fluid have been significantly associated with peri-implantitis, distinguishing it from healthy implant conditions. These biomarkers not only help to diagnose the current state of peri-implant health, but also to predict disease progression and monitor treatment outcomes.[85]

In conclusion, the incorporation of specific validated biomarkers into clinical practice can assist in the monitoring and management of peri-implant tissue health, thereby aiding in the early detection and prevention of peri-implant disease.

9.2 | Salivary biomarkers

Due to its non-invasive nature, salivary diagnostics is increasingly being used to detect periodontal disease. Saliva contains over 1000 proteins, including inflammatory modulators and matrix metalloproteinases, which are altered in both periodontal and peri-implant diseases.[87] Research has demonstrated the efficacy of salivary diagnostics for the detection of periodontitis-associated bacteria such as *P. gingivalis*, using the polymerase chain reaction (PCR) and cytokine profiling using multiplex assays.[88,89]

Saliva has shown potential as a diagnostic tool for periodontitis due to its ease of collection and comprehensive representation of oral and systemic health.[81] Several salivary biomarkers, including macrophage inflammatory protein-1 alpha (MIP-1α), IL-1β, IL-6 and MMP-8, have been extensively studied. These biomarkers have demonstrated high sensitivity and specificity in differentiating between periodontal health and disease. Salivary levels of these biomarkers are significantly elevated in patients with periodontitis and correlate with disease severity, making them valuable for both diagnosis and monitoring of treatment outcomes.[90,91]

In the context of dental implants, salivary diagnostics can provide insight into the local and systemic effects of peri-implant disease. Although there are fewer studies on salivary biomarkers for peri-implantitis compared to periodontitis, some promising candidates have emerged. Elevated levels of MMP-8, IL-1β and other pro-inflammatory cytokines have been found in the saliva of patients with peri-implantitis, reflecting the inflammatory status of peri-implant tissues. The systemic inflammatory burden associated with peri-implantitis, particularly when multiple implant sites are involved, may exacerbate conditions such as cardiovascular disease and diabetes, highlighting the importance of early detection and intervention.[85] Further research is needed to validate these biomarkers and establish standardized protocols for their use in clinical practice.

9.3 | Combining biomarkers with clinical monitoring measures

As clinical research has shown, the integration of biomarker data with clinical parameters, including microbial profiles, should improve the accuracy of periodontal diagnosis. This approach is exemplified by Kinney et al.,[92] who demonstrated how clustering subjects based on pathogen levels and biomarker profiles can predict periodontal disease progression.

10 | MONITORING WITH MICROBIAL SAMPLING

Microbial sampling is an available and adjunctive method for monitoring periodontal and peri-implant conditions. Analysis of these

samples provides critical insight into the microbial ecosystem associated with both healthy and diseased states in periodontology and implant dentistry.

A pilot cross-sectional study by Barbagallo et al. (2021) compared the microbiomes in periodontal, peri-implant, and healthy sites, revealing distinct microbial signatures in these environments. This study highlights the complexity and uniqueness of the microbial landscape in different oral conditions.[93] Similarly, the work of Suzuki et al.[94] identified health indicator bacteria useful for assessing the risk of peri-implantitis, highlighting the importance of specific microbial profiles in the diagnosis and monitoring of peri-implant health. Zhuang et al. (2016) performed a comprehensive analysis of the periodontal and peri-implant microbiota in patients with inflamed and healthy tissues. Their findings significantly contribute to the understanding of microbial dynamics in periodontal and peri-implant diseases.[95] In line with this, de Waal et al.[96] focused on the microbial characteristics of peri-implantitis, providing valuable insights into the specific microbial pathogens associated with this condition. The molecular analysis of the microbiota associated with peri-implant disease, as explored by Al-Radha et al.,[97] provides a deeper understanding of the microbial factors contributing to implant-related complications. In addition, Dabdoub et al.[98] presented a patient-specific analysis of periodontal and peri-implant microbiomes, highlighting the role of individual microbial profiles in disease management. Sahrmann et al. (2020) conducted a systematic review and meta-analysis of the peri-implantitis microbiome. This comprehensive review provides a global perspective on the microbial involvement in peri-implant diseases, further enhancing our understanding of these complex conditions.[99] Luterbacher et al. (2000) reviewed the diagnostic characteristics of clinical and microbiological tests for monitoring periodontal and peri-implant mucosal tissue conditions. This study highlights the clinical relevance of integrating microbial analysis into routine periodontal therapy.[7] Finally, de Leitao et al.[100] analysed the presence of pathogens in peri-implant sites using PCR, a technique that significantly improves the detection and risk assessment of peri-implant disease.

In summary, these studies demonstrate that microbial specimens may be considered in the diagnosis, monitoring, and management of periodontal and peri-implant conditions. In clinical research, they provide a window into the complex microbial world associated with oral health and disease, providing clinicians with valuable data to tailor treatment strategies.

11 | MONITORING DENTAL IMPLANTS WITH RESONANCE FREQUENCY ANALYSIS (RFA)

Resonance frequency analysis (RFA) is an available tool in implant dentistry, particularly for monitoring and assessing osseointegration. RFA primarily measures implant stability, a critical factor in the success of dental implants. Understanding the role of RFA, particularly in the context of peri-implant monitoring, requires a detailed review of its application, advantages, limitations, and future implications.

RFA, particularly with devices such as the Osstell (Osstell AB, Gothenburg, Sweden), is used to assess the stability of dental implants. This stability is indicated by the implant stability quotient (ISQ), a numerical value derived from the resonance frequency of the implant. RFA is valuable both immediately after implant placement and during the follow-up period. It serves as a non-invasive method of monitoring the osseointegration process—the biological process by which the bone forms a bond with the implant. Studies such as Cornelini et al.[101] have demonstrated the utility of RFA in determining the appropriateness of immediate implant placement in specific clinical scenarios such as mandibular molar sites.

The primary advantage of RFA is its ability to provide quantitative data on implant stability, which aids in making evidence-based clinical decisions. This is particularly important when considering early or immediate loading of the implant. It also provides a means of continuously assessing osseointegration over time, which is critical to the long-term success of the implant. Despite its advantages, RFA is not without limitations. It does not provide direct information about bone quality or the biological aspects of the surrounding tissue. In addition, the technique is sensitive to many factors, including the type of transducer used and the operator's technique. Also, as highlighted by Kuchler et al.,[102] although RFA is effective in assessing stability, it does not always show a significant increase in ISQ values over time, indicating the need for a comprehensive approach to implant monitoring.

To gain a holistic understanding of peri-implant health, RFA is often used in conjunction with other diagnostic tools. Radiographic assessments remain a standard for assessing bone levels, while innovations in ultrasound technology provide detailed images of soft tissues. The combined use of these technologies allows a comprehensive assessment of both the mechanical and biological aspects of implant integration. The future of RFA in implant dentistry is likely to see improvements in the technology for more precise and user-friendly applications. The integration of RFA data with digital dentistry tools, such as 3D imaging and computer-aided design/computer-aided manufacturing (CAD/CAM), may further revolutionize implant monitoring and treatment planning. In addition, ongoing research is aimed at refining the interpretation of RFA values in different clinical conditions to improve their predictive value for implant success.

In summary, in clinical research, RFA may be considered for peri-implant monitoring, providing critical insight into implant stability, a key determinant of successful osseointegration. While it is not a stand-alone solution, its integration with other diagnostic measures provides a comprehensive approach to ensuring the longevity and success of dental implants. As the field evolves, RFA will play an increasingly important role, guided by advances in technology and clinical research.

12 | MONITORING DENTAL IMPLANTS WITH ULTRASOUND

Ultrasound has gained interest as a potential diagnostic tool for monitoring the soft and hard tissues surrounding dental implants. Conventional periapical radiographs provide only a two-dimensional assessment of crestal bone levels. Ultrasound overcomes this limitation by providing non-invasive, non-ionizing, real-time cross-sectional imaging of peri-implant tissues. While Tanaka et al. assessed furcation involvement in mandibular first molars, Thöne-Mühling et al. highlighted the application of ultrasound for real-time evaluation of peri-implant tissues, demonstrating its potential in implant dentistry.[103,104]

Studies have used various ultrasound modalities such as periodontal probe-integrated ultrasound, A-scan, B-scan, and C-scan ultrasonography to evaluate soft and hard tissue dimensions around implants. Ghimire et al.[105] have investigated the accuracy and reproducibility of ultrasound measurements of mucosal thickness, PPD, implant diameter and marginal bone levels compared with direct clinical measurements. These studies show a good correlation between ultrasound and direct measurements, suggesting that ultrasound can potentially complement dental radiographs as a diagnostic tool for monitoring. Advantages of ultrasound include the ability to analyse buccal and lingual bone plates in detail, unlike 2D radiographs, and the early detection of biological complications. However, disadvantages include user dependence, limitations in capturing furcation anatomy, and cost compared to conventional radiography. Chan et al.[106] highlighted the potential of ultrasound for non-invasive, real-time assessment of peri-implant tissue dimensions.

Advancements in three-dimensional ultrasound techniques, such as volumetric ultrasound and specific transducer probes optimized for peri-implant tissue assessment, show promise for future developments. The integration of ultrasound with cone beam computed tomography could provide high-resolution cross-sectional images for accurate diagnosis.[107] Research is also focused on establishing normative ultrasound tissue dimensions for healthy peri-implant sites to aid in the diagnosis of disease.[108]

13 | PATIENT COMPLIANCE: A CLOSER LOOK

Patient compliance is a critical factor influencing the long-term success of periodontal therapy.[19,109] Several studies have evaluated patient compliance with SPT visits after active periodontal treatment. Checchi et al.[110] reported that less than 50% of patients were compliant with attending the recommended SPT visits over a 5-year period. Jansson and Hagstrom[111] found that only 26% of patients were fully compliant with the recommended SPT schedule. In addition, non-compliance with SPT may compromise the stability of periodontal outcomes achieved by active therapy. Failure to attend regular maintenance visits results in inadequate control of biofilm and pathogens at vulnerable sites, increasing the risk of further periodontal disease progression.[112] Several studies have also linked increased compliance with SPT to clinically healthier periodontal status compared to irregular or non-compliant patients.[111,113]

There are many factors that influence patient compliance. Socioeconomic variables play a role, with lower education and income associated with poorer compliance.[112,114] Smoking status may also negatively affect compliance, as smokers tend to be more irregular in their compliance.[111] Other factors, such as emotional intelligence, health beliefs, psychological stressors, and personality traits, require further research to better understand their influence on patient compliance behavior.[115,116]

Definitions of compliance vary between studies, making direct comparisons difficult. However, most of them consider patients to be 'compliant' if they return for prescribed SPT intervals within a predefined threshold, such as ≥50%–75% of scheduled visits. Greater standardization of definitions is needed.[110,113] Improving patient education and motivation through tailored motivation and reminder techniques may help to improve compliance outcomes. Later, the study by Ramseier et al.[117] focused on the compliance of cigarette smokers with scheduled visits for SPT. This retrospective study analysed data from patients undergoing dental hygiene treatment at the Medi School of Dental Hygiene in Bern, Switzerland, from 1985 to 2011. A total of 1336 patients were included in the study, of whom 32.1% were smokers, 23.1% former smokers and 44.8% non-smokers. The study aimed to assess both qualitative and quantitative aspects of compliance in these groups.

The study introduced a novel method to quantitatively calculate compliance. The "% compliance" was determined by dividing the number of SPT visits attended by the number of visits expected, as follows:

$$\%\,\text{compliance} = \frac{A \times 100}{E}$$

A = number of attended SPT visits, E = number of expected visits, while E was calculated as follows:

$$E = \sum_{p=1}^{k} \left(\frac{m_p}{i_p} \right)$$

This method provided a nuanced understanding of patient adherence to SPT schedules, highlighting variations between different patient groups.

Qualitative analysis showed that smokers were significantly less likely to return for SPT than non-smokers or former smokers (Figure 5). Quantitatively, the overall mean percentage compliance was 69.8%, with smokers having a lower compliance rate of 67.0% compared to former smokers (69.7%) and non-smokers (71.7%). This difference was statistically significant. However, confounder-adjusted analysis revealed that factors such as older age, female sex, longer SPT intervals and greater severity of periodontal disease had a greater effect on compliance than smoking status.[117]

The results suggest that while smokers are qualitatively less likely to return for SPT, the lower quantitative compliance

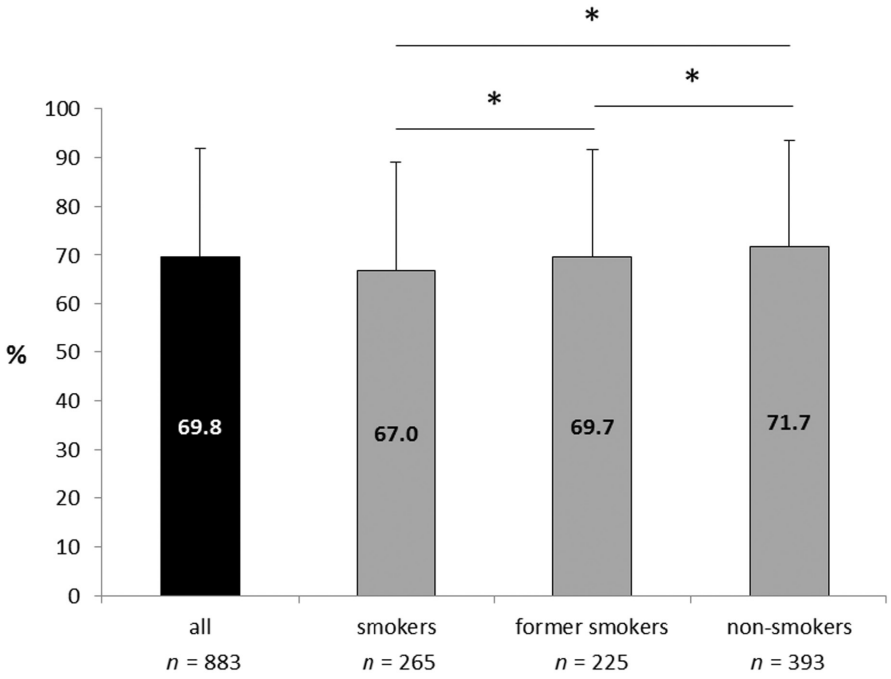


FIGURE 5 %-compliance overall and by smoking status.[117] Error bars indicate standard deviations. * Statistically significant difference at $p < 0.05$.[117]

among smokers attending scheduled SPT visits may be due to confounding factors. This study highlights the complexity of factors influencing patient compliance with periodontal therapy and the importance of considering these factors when planning and scheduling SPT.[117]

This study contributed to the understanding of patient compliance with periodontal therapy, particularly in smokers. It introduced a useful metric for quantifying compliance in clinical practice. As regular compliance with SPT intervals plays an important role in stabilizing periodontal treatment outcomes and preventing disease recurrence, a multifactorial understanding of the determinants of compliance may help to develop strategies and interventions aimed at improving long-term patient engagement in periodontal maintenance programmes.

14 | PERIODONTAL STABILITY: A CLOSER LOOK

Periodontal stability, a central goal in the management of periodontal disease, serves as a measure of treatment success and a reference point for ongoing maintenance. This concept depends on assessing and maintaining the health of the periodontal tissues after treatment to ensure that disease progression does not recur. Understanding periodontal stability requires a thorough knowledge of various clinical parameters and their thresholds, which are critical in assessing treatment outcomes and determining the frequency of SPT. During SPT, stability is assessed using several parameters, such as quality of oral hygiene, absence of BOP, residual PPDs not exceeding 5 mm, no clinical attachment loss greater than 0.5 mm relative to previous assessments, and absence of progressive bone loss on radiographs.

At the 2017 World Workshop on the Classification of Periodontal and Peri-implant Diseases and Conditions, the concepts of disease remission and periodontal health on a reduced periodontium were introduced. Lang and Bartold (2018) proposed four levels of periodontal health: (1) pristine periodontal health, characterized by a structurally sound and uninflamed periodontium; (2) well-maintained clinical periodontal health, with an intact periodontium; (3) periodontal disease stability, with a reduced periodontium; and (4) periodontal disease remission or control, also with a reduced periodontium but not fully stable. These definitions emphasize the importance of individualized treatment outcomes based on the structural and clinical status of the periodontium.[118] Therefore, the following set of criteria may be considered when monitoring periodontal stability over time.

14.1 | Criteria for periodontal stability

14.1.1 | At the patient level

- Good oral hygiene with plaque index <20%.[119]
- Minimum number of PPDs of greater than 3 mm and correspondingly adjusted SPT interval of three to 12 months.[120]
- Low level of inflammation with %-BOP <20% (non-smokers, former smokers: <23% or smokers: <16%).[68]
- Optimal risk factor reduction.[121]

14.1.2 | At the level of individual periodontal sites

- PPD of 4 mm or less without BOP.[122]
- Furcation involvement of grade 1 or less (horizontal probing depth < 3 mm).[56]

The ideal threshold for stability is likely to vary according to patient-specific factors such as risk factors and initial disease severity. Stability can be classified as initial (up to 12 months post-treatment), definite (2–5 years with consistent parameters), and prolonged (beyond 5 years). Establishing definitive stability could justify extending maintenance intervals to 6–12 months, depending on the individual case. Researchers advocate using a combination of parameters such as BOP, clinical attachment, and radiographic bone levels to define stability, using complex statistical modelling techniques for a more nuanced understanding.

In summary, achieving periodontal stability signals a positive long-term prognosis, but persistent compliance with maintenance is essential to maintain results and prevent disease recurrence. The use of validated parameters and longitudinal studies facilitates the objective identification of therapeutic outcomes in clinical practice, ensuring a thorough and patient-centred approach to periodontal health management.

15 | PERI-IMPLANT STABILITY: A CLOSER LOOK

Peri-implant stability, like its counterpart in periodontal health, is critical in assessing the success of implant therapy and guiding post-treatment maintenance.[123] However, establishing reliable criteria for peri-implant stability presents unique challenges due to the relatively limited data available compared to periodontal health.[124] This section explores the nuances of peri-implant stability, integrating findings from current consensus reports to provide a more nuanced understanding.

The 2017 World Workshop on the Classification of Periodontal and Peri-implant Diseases and Conditions provided updated definitions and diagnostic criteria for peri-implant mucositis and peri-implantitis, which are essential for understanding peri-implant stability. According to the consensus report, peri-implant mucositis is characterized by bleeding on gentle probing, with possible signs of erythema, swelling, and suppuration, but without accompanying bone loss beyond initial remodeling.[125] In contrast, peri-implantitis involves both clinical signs of inflammation (BOP, suppuration) and progressive bone loss. For peri-implant health, the absence of erythema, BOP, swelling, and suppuration are critical indicators, while peri-implant probing depths are generally deeper than around natural teeth but do not increase over time if the implant is stable. These definitions highlight the importance of distinguishing between physiological bone remodeling and pathological bone loss when assessing implant stability.[125]

However, consensus in the literature remains elusive, partly due to the heterogeneity of the studies and the lack of large longitudinal cohort studies correlating specific thresholds with long-term stability.[126] Some researchers argue against the universal use of crestal bone loss >2 mm as a definitive marker of peri-implantitis, considering that up to 1.5 mm may physiologically occur during initial healing.[127] Recent studies have proposed novel approaches, such as the use of bone- or tissue-level implants to more accurately correlate mucosal margin changes with peri-implant bone levels, and the use of machine learning to establish highly accurate thresholds.[128–130] In addition, multifactorial criteria that take into account patient-specific risk factors are increasingly recognized as important due to the variability in individual prognosis.

Current evidence suggests that defining peri-implant stability based on PPDs of less than 5 mm, absence of bleeding or suppuration, and less than 2 mm bone loss from baseline measurements is effective for assessing stability.[131,132] Larger cohort studies correlating peri-implant parameters with long-term success rates are expected to refine our ability to monitor peri-implant health over time.[133]

In summary, peri-implant stability is a multifaceted concept that integrates clinical, radiographic, and patient-specific factors. While a universal consensus on its definition is still evolving, current research points to a combination of mechanical and biological responses as key indicators.[4] Ongoing research and advancements in diagnostic technologies promise to further refine our understanding and management of peri-implant stability and ensure better outcomes in dental implant therapy.

16 | RECALL INTERVAL: A CLOSER LOOK

Diagnostic measures to monitor periodontal and peri-implant conditions are critical, but understanding the impact of the interval between SPT visits is equally important. Previous studies assessing the impact of compliance in patients undergoing SPT for periodontal and dental implant care have categorized patients as compliant, partially compliant, or non-compliant. However, these studies often overlooked the inclusion of specific calendar dates, which are essential for adjusting statistical analyses to reflect the exact number of days between each SPT visit. In contrast, the retrospective analysis by Ramseier et al.[120] incorporated this detail using a mixed effects model analysis. Their analysis showed a significant dependence of PPD change on the interval between SPT visits. Specifically, longer intervals between visits were positively associated with increases in PPD, whereas shorter intervals were associated with decreases in PPD, on average. This finding, based on data from 11 842 SPT visits, led to the establishment of thresholds for periodontal stability. It is noteworthy that these thresholds relate to both the percentage of PPDs of 4 mm or greater and the time between two SPT visits (Figure 6).

Using these thresholds, the reported SPT interval was calculated for all consecutive SPT visits as shown in Figures 7–9. The mean %-BOP and residual PPDs for patients with moderate and severe chronic periodontitis (categories II and III) who returned at least 1 month earlier than calculated for their first 5-year SPT and for patients who returned at least 1 month later are shown in Figure 10. Figure 11 shows the mean tooth loss rate over 20 years of SPT. Patients who attended more than 50% of their SPT appointments at least one month earlier than scheduled had a lower mean tooth loss rate of 0.60 (±0.93) over 20 years compared to those who attended later (1.45 ± 2.07), with a significant statistical difference ($p < 0.0001$). Specifically, smokers who attended early SPT visits experienced a

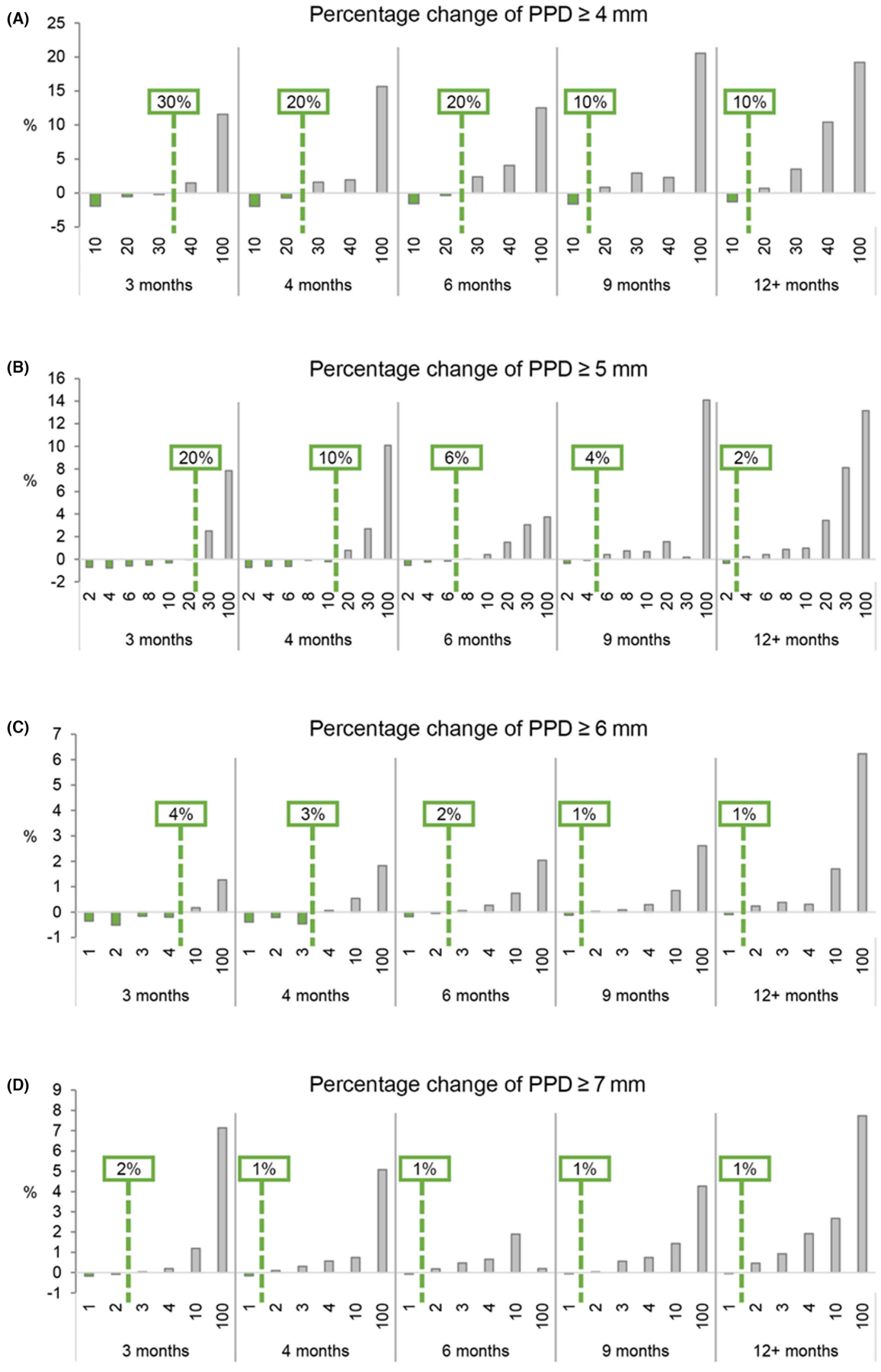
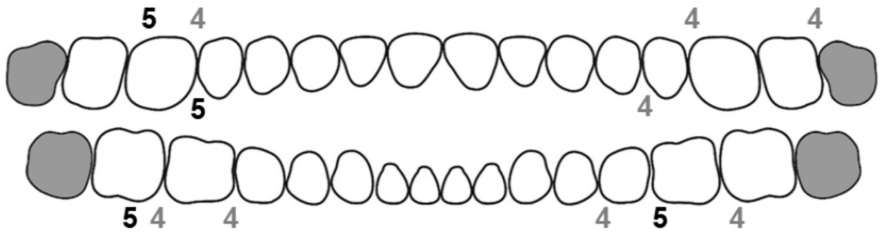


FIGURE 6 Percent change increase (+) and decrease (−) of residual PPDs from 11 842 SPT visits and $n = 883$ patients in relation to the length of SPT intervals (3, 4, 6,9, and 12+ months) and the category of residual PPD recorded at the previous SPT visit.[120] Empirically determined thresholds of no change of PPD are labelled and indicated by dashed lines in (A) for %-PPD ≥4 mm (−5% to 25%), (B) for %-PPD ≥5 mm (−2% to 16%), (C) for %-PPD ≥6 mm (−1% to 7%), and (D) for %-PPD ≥7 mm (−1% to 9%).[120]

FIGURE 7 Patient presenting with 28 teeth (168 sites) and his/her PPDs (in mm) as recorded. Example 1: Computing the SPT interval based on the patient's comprehensive PPD profile recorded at a respective SPT visit. Cumulative % values will be applied in the algorithm table representing the thresholds for no expected change of residual PPD between two consecutive SPT visits at the respective SPT interval. The maximum (%, as highlighted in green) per column and the minimum (months, as highlighted in yellow) on patient level will be selected. Computed SPT interval: 9 months.



	4 mm	5 mm	≥6 mm
Sites (*n*)	8	4	0
Sites (%)	4.8	2.4	0
Cumulative (%)	7.2	2.4	0

	≥4 mm	≥5 mm	≥6 mm
3 months	≤30%	≤20%	≤4%
4 months	≤20%	≤10%	≤3%
6 months	≤20%	≤6%	≤2%
9 months	≤10%	≤4%	≤1%
12 months	≤10%	≤2%	≤1%

significantly higher rate of tooth loss than non-smokers or former smokers in the first 10 years after SPT ($p < 0.0001$), but this difference was not observed in the subsequent 10 years (Figure 11A, left). Conversely, patients who attended later SPT visits had an increased rate of tooth loss over 20 years, with smokers showing a particularly significant increase in the last 5 years of the 20-year period ($p = 0.0044$). Interestingly, former smokers who attended later than scheduled eventually matched the tooth loss rates of non-smokers ($p < 0.0001$) (Figure 11A, right).

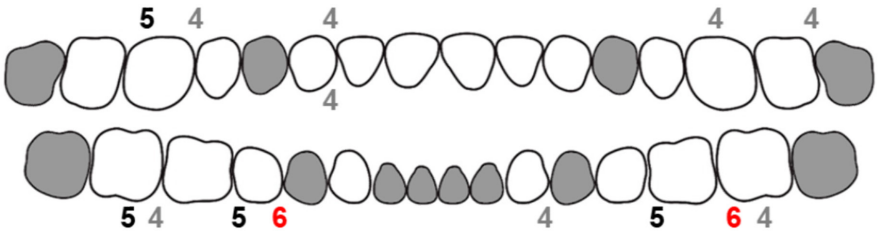
Finally, the impact of residual probing pocket depths (PPDs) of ≥6 mm at the first SPT visit is also shown in Figure 11B. Patients with these initial PPDs who had more than 50% of their SPT visits earlier had a significantly higher tooth loss rate in the first 10 years compared to those without such PPDs ($p < 0.0001$). However, in the latter 10 years, their tooth loss rates converged with those of those without initial PPDs ≥6 mm (Figure 11B left). Patients in this retrospective study who attended later SPT visits had consistently higher tooth loss rates over the 20 years, especially if they had PPDs ≥6 mm at the first visit ($p < 0.0001$) (Figure 11B right).

17 | SUPPORTIVE PERIODONTAL THERAPY (SPT) ONLINE TOOL

The use of an online tool to determine personalized SPT intervals represents a significant advancement in the field of periodontology, particularly in terms of personalizing patient care and optimizing treatment outcomes (Figure 12).

17.1 | Introduction to the SPT online tool

The evidence-based online SPT interval tool (www.perio-tools.com/spt) is designed to calculate individualized recall intervals for



	4 mm	5 mm	≥6 mm
Sites (*n*)	8	4	2
Sites (%)	6.7	3.3	1.7
Cumulative (%)	11.7	5.0	1.7

SPT interval	≥4 mm	≥5 mm	≥6 mm
3 months	≤30%	≤20%	≤4%
4 months	≤20%	≤10%	≤3%
6 months	≤20%	≤6%	≤2%
9 months	≤10%	≤4%	≤1%
12 months	≤10%	≤2%	≤1%

FIGURE 8 Patient presenting with 20 teeth (120 sites) and his/her PPDs (in mm) as recorded. Example 2: Computing the SPT interval based on the patient's comprehensive PPD profile recorded at a respective SPT visit. Cumulative % values will be applied in the algorithm table representing the thresholds for no expected change of residual PPD between two consecutive SPT visits at the respective SPT interval. The maximum (%, as highlighted in green) per column and the minimum (months, as highlighted in yellow) on patient level will be selected. Computed SPT interval: 6 months.

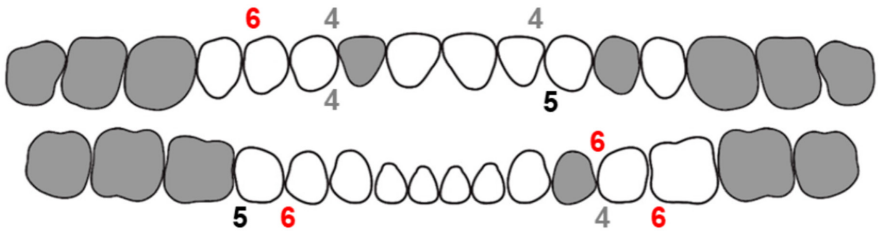
patients undergoing periodontal maintenance, thereby increasing the precision and effectiveness of periodontal therapy.[120] The basic principle of this tool is to incorporate various patient-specific factors and clinical measurements, including PPD, BOP, furcation involvement, plaque accumulation, smoking status, and diabetes findings, to generate a tailored SPT interval for each patient. These parameters are essential as they have a direct impact on the progression of periodontal disease and the effectiveness of treatment strategies.

In practice, the tool works by allowing the clinician to enter these critical clinical indicators into an online interface. The algorithm, developed through extensive research and validation studies, processes these data to determine an optimal recall interval ranging from 3 to 12 months. This interval is not static but is dynamically adjusted based on the patient's changing clinical status, ensuring that the treatment plan remains responsive to the patient's current periodontal health. This dynamic adjustment is a cornerstone of the tool and reflects the understanding that periodontal health is not a fixed state but can fluctuate based on various internal and external factors.

The importance of the online tool lies not only in its clinical utility, but also in its role in patient education and engagement. By providing a clear, evidence-based rationale for recommended recall intervals, the tool helps to improve patient understanding and compliance with periodontal treatment plans. This is particularly important in periodontal therapy, where patient adherence to maintenance protocols plays a critical role in the long-term success of treatment. The tool also serves as a valuable resource for clinicians, providing a systematic and standardized approach to determining SPT intervals, thereby reducing variability in clinical decision-making and ensuring a high standard of care.

In addition, the online nature of the tool ensures ease of access and use, facilitating its integration into routine clinical practice. It also opens avenues for further research and development, as the data collected by the tool can contribute to a deeper understanding of periodontal disease progression and treatment response. This ongoing accumulation of data and insights can lead to continuous refinement of the algorithm, making it a constantly evolving tool that keeps pace with the latest developments in periodontology.

In essence, the online SPT interval tool follows the principles of personalized medicine. Using patient-specific data to determine SPT intervals it ensures that each patient receives the most appropriate level of care, thereby optimizing clinical outcomes in periodontal



	4 mm	5 mm	≥6 mm
Sites (*n*)	4	2	4
Sites (%)	3.7	1.9	3.7
Cumulative (%)	9.3	5.6	3.7

SPT interval	≥4 mm	≥5 mm	≥6 mm
3 months	≤30%	≤20%	≤4%
4 months	≤20%	≤10%	≤3%
6 months	≤20%	≤6%	≤2%
9 months	≤10%	≤4%	≤1%
12 months	≤10%	≤2%	≤1%

FIGURE 9 Patient presenting with 18 teeth (108 sites) and his/her PPDs (in mm) as recorded. Example 3: Computing the SPT interval based on the patient's comprehensive PPD profile recorded at a respective SPT visit. Cumulative % values will be applied in the algorithm table representing the thresholds for no expected change of residual PPD between two consecutive SPT visits at the respective SPT interval. The maximum (%, as highlighted in green) per column and the minimum (months, as highlighted in yellow) on patient level will be selected. Computed SPT interval: 3 months.

maintenance therapy. This tool not only improves clinical effectiveness, but also promotes patient engagement and adherence, contributing to the overall improvement of periodontal health management.

18 | PERIODONTAL RISK ASSESSMENT (PRA) TOOL

The periodontal risk assessment (PRA) tool (www.perio-tools.com/pra) is a comprehensive system designed to monitor and evaluate the risk of periodontitis progression in patients.[134] This tool is based on a multifunctional chart that incorporates several parameters, each of which contributes to the overall risk profile of a patient (Figure 13A). These parameters include %-BOP, prevalence of residual pockets greater than 4 mm, tooth loss, loss of periodontal support in relation to the patient's age, systemic and genetic conditions, and environmental factors such as smoking.

The PRA has been the subject of extensive research, with several studies validating its effectiveness in predicting periodontitis progression and tooth loss. A systematic review by Lang et al.[121] highlights the utility of the PRA, noting that it was included in 12 publications and was one of the five main risk assessment tools identified. The PRA and its modifications have been shown to be effective in separating subjects with different probabilities of disease progression and tooth loss, with the observed effect being dose-dependent, as higher risk estimates correlate with higher levels of disease progression.

The predictive value of the PRA has been confirmed in several cohort studies involving large numbers of subjects. These studies have provided longitudinal external validation of the PRA as a predictive tool for periodontitis progression and tooth loss. It was shown that subjects with a higher risk profile as defined by the PRA experience more tooth loss and faster disease progression than those with a lower risk profile. For example, Matuliene et al.[135] reported varying degrees of tooth loss across different risk profiles, with high-risk individuals showing significantly more tooth loss than low-risk individuals.

In summary, the PRA tool is an important tool in periodontal risk assessment, helping clinicians to predict the progression of periodontitis and plan appropriate treatment strategies. Its multifaceted approach, considering both local periodontal factors and systemic health influences, makes it a robust tool in periodontal risk management.

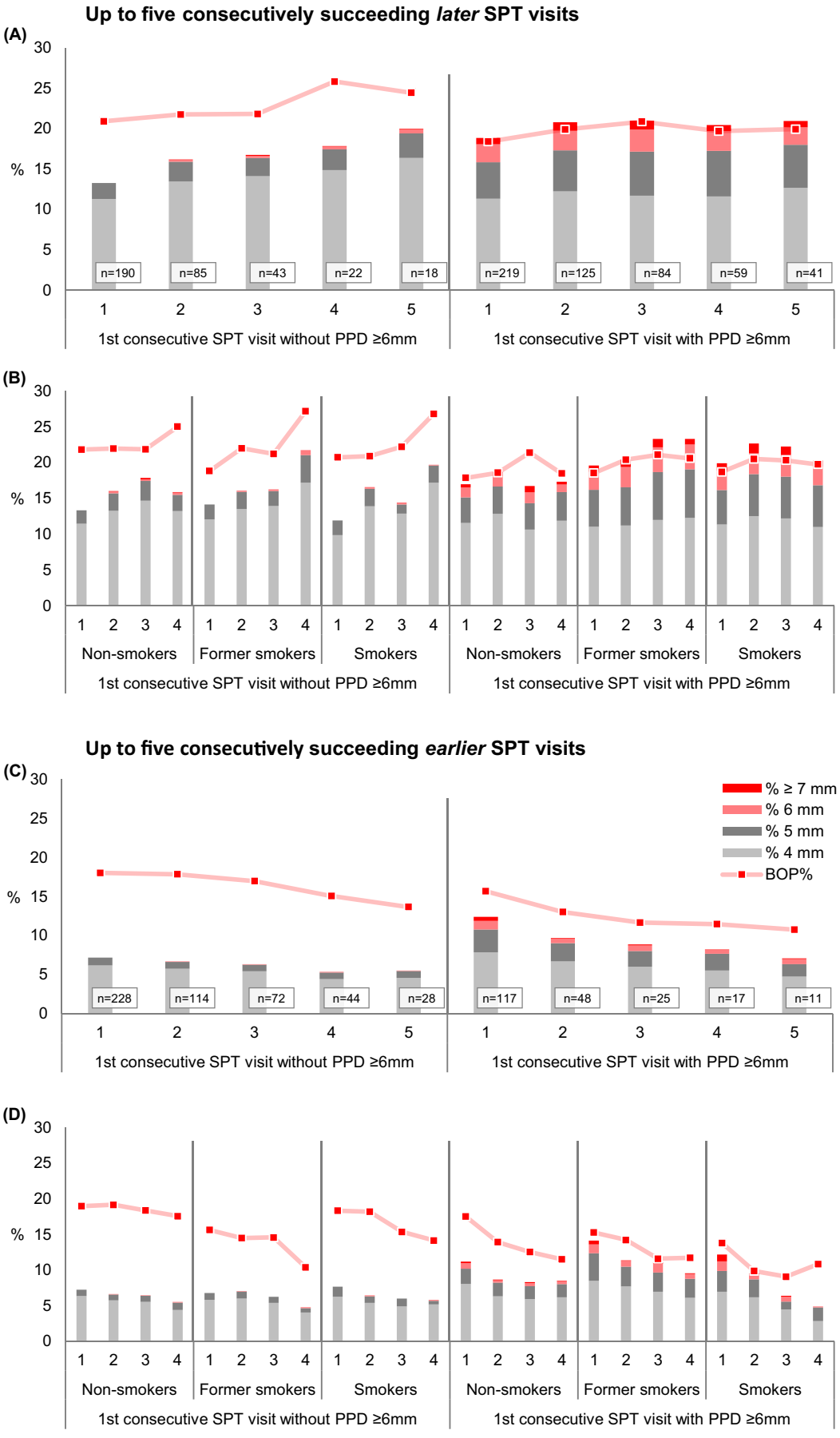


FIGURE 10 Frequencies for both %-PPDs and %-BOP in patients with moderate to severe chronic periodontitis (disease category II and III) and no tooth loss over consecutive visits and 5 years of SPT.[120] (A) Absence of PPD ≥6 mm at the first out of five consecutively succeeding later SPT visits (left) and presence of PPD ≥6 mm at the first out of five consecutively succeeding later SPT visits (right). (B) respective plots of (A) by smoking status. (C) Absence of PPD ≥6 mm at the first out of five consecutively succeeding earlier SPT visits (left) and presence of PPD ≥6 mm at the first out of five consecutively succeeding earlier SPT visits (right). (D) respective plots of (C) by smoking status.[120]

19 | IMPLANT DISEASE RISK ASSESSMENT (IDRA) TOOL

The implant disease risk assessment (IDRA) tool is a significant development in the field of implant dentistry, specifically designed to monitor and estimate a patient's risk of developing peri-implantitis during SPT.

19.1 | Introduction to the IDRA risk assessment tool

A treatment concept study introduces IDRA as a tool that incorporates eight parameters, each of which has documented evidence of an association with peri-implantitis. These parameters include a history of periodontitis, BOP, PPDs ≥5 mm, periodontal bone loss divided by the patient's age, susceptibility to periodontitis, compliance with SPT, distance from the implant restorative margin to the marginal bone crest, and prosthesis-related factors. This combination of factors in IDRA may be useful in identifying individuals at risk of developing peri-implantitis.[136]

19.2 | Using IDRA: a practical approach

Detailed instructions for using IDRA (www.perio-tools.com/idra) include entering data such as history of periodontitis, number of sites with BOP, PPDs ≥5 mm, estimated alveolar bone loss, periodontitis susceptibility according to the 2017 World Workshop on Classification of Periodontal Diseases, patient compliance with SPT, and factors related to the implant prosthesis. This comprehensive approach suggests that IDRA considers both patient-specific and implant-specific factors in assessing the risk of peri-implant disease (Figure 13B).

19.3 | Integrated evaluation of IDRA in treated periodontal patients

The efficacy and utility of the IDRA tool have been investigated in several important studies, each providing unique insights into its application and predictive accuracy.

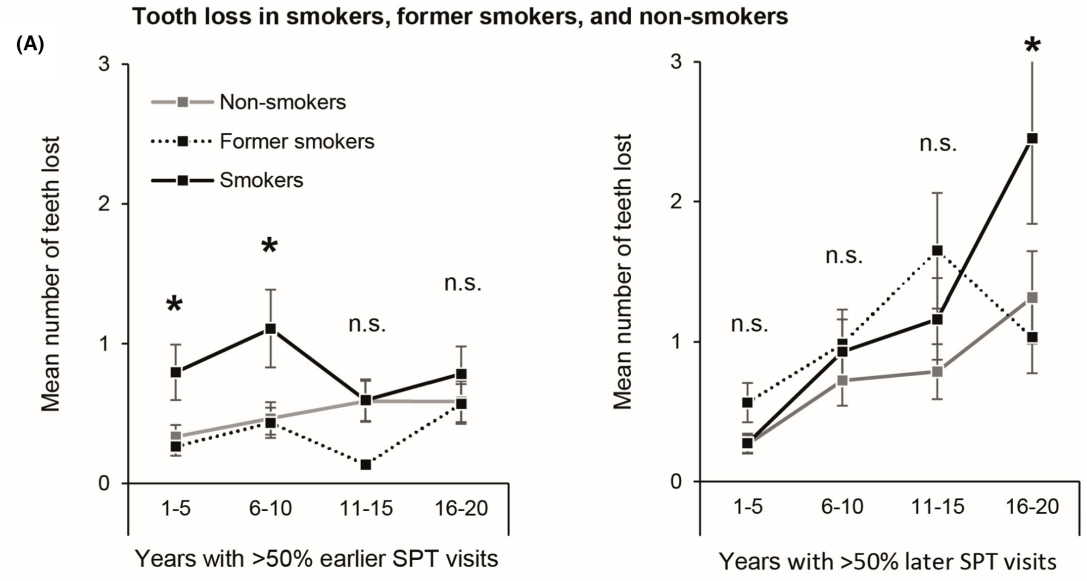
De Ry et al.[137] conducted a pivotal retrospective evaluation of IDRA, focusing on a cohort of 239 patients with implant-supported fixed dentures under SPT. The study focused on a cohort of 239 patients who had been part of a SPT programme for at least 5 years, 80 of whom met the study's inclusion criteria. The patient demographics were diverse, including 43 males, 36 females and 8 smokers, with a mean age of 59 years at baseline. The core of the study was the IDRA risk assessment, which categorized patients into risk levels: 34 (42.5%) at intermediate risk and 45 (56.3%) at high risk, with one low-risk patient excluded. A critical finding was the prevalence of peri-implantitis—12% in the moderate-risk group and 27% in the high-risk group. Notably, while the odds' ratio for developing peri-implantitis was 2.727 for high-risk patients compared to moderate risk, this difference was not statistically significant. In conclusion, the study shows that the IDRA tool is potentially useful in identifying patients at increased risk of peri-implantitis. However, the lack of significant differences between risk groups and the absence of a low-risk cohort requires further studies to fully validate the IDRA and its efficacy in clinical practice. This research is important in improving the understanding of the risk of peri-implantitis in patients with treated periodontitis and fixed partial dentures.[137]

Following on from this, Mo et al.[138] investigated the association of IDRA with biological complications and implant survival in patients with short dental implants over a 10-year period. This study included 110 patients and demonstrated a significant correlation between higher IDRA risk profiles and increased implant failure and biological complications. The overall implant survival rate was found to be 90.9%, highlighting the potential of IDRA in long-term implant prognosis. Meanwhile, Sarbacher et al.[139] provided a comparative perspective by evaluating the IDRA alongside another risk assessment model. Their study included 73 patients representing 232 implants and highlighted that both the PRA and the Implant Risk Assessment (IRA)—an extension of the IDRA—had similar predictive values in predicting peri-implantitis. The high-risk scores in these models were significantly associated with the incidence of peri-implantitis, highlighting their usefulness in clinical practice for identifying high-risk patients.

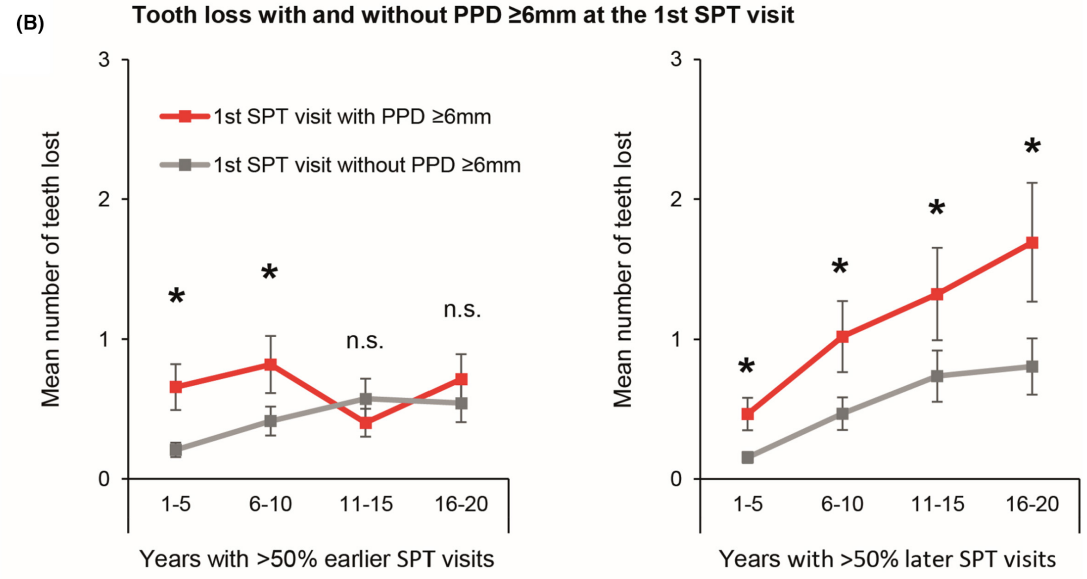
In summary, IDRA appears to be a versatile tool that incorporates a range of clinical indicators to assess the risk of peri-implantitis. The studies suggest that IDRA can be an asset in preventive strategies for peri-implant disease, helping clinicians to identify patients at risk and tailor their management strategies accordingly.

20 | FUTURE PERSPECTIVES

In the evolving environment of periodontal and implant dentistry, Artificial Intelligence (AI) has emerged as an important adjunct to diagnostic measures and monitoring.[140,141] AI tools, particularly those based on deep learning algorithms, show remarkable potential in automating the assessment of periodontal and peri-implant parameters



Years	1-5	6-10	11-15	16-20	1-5	6-10	11-15	16-20
Smokers								
Patients (n)	22	22	11	6	61	62	34	15
Visits (n)	195	155	84	45	412	363	190	94
Former smokers								
Patients (n)	32	32	16	9	59	55	37	25
Visits (n)	176	176	101	58	389	335	227	128
Non-smokers								
Patients (n)	74	74	37	20	70	71	46	31
Visits (n)	617	458	244	101	438	381	266	158



Years	1-5	6-10	11-15	16-20	1-5	6-10	11-15	16-20
1st SPT visits with PPD≥6mm								
Patients (n)	40	40	21	15	114	114	74	47
Visits (n)	436	307	180	91	847	783	499	286
1st SPT visits without PPD≥6mm								
Patients (n)	88	88	43	20	76	74	43	24
Visits (n)	644	482	249	113	392	296	184	94

FIGURE 11 Mean tooth loss over 20 years of SPT. (A) Tooth loss in smokers, former smokers, and non-smokers with >50% earlier SPT visits (left) and with >50% later SPT visits (right).[120] (B) Tooth loss in patients with and without PPD ≥6 mm at their first SPT visit and with >50% earlier visits (left) and with >50% later SPT visits (right), respectively. * Statistically significant difference ($p < 0.05$).[120]

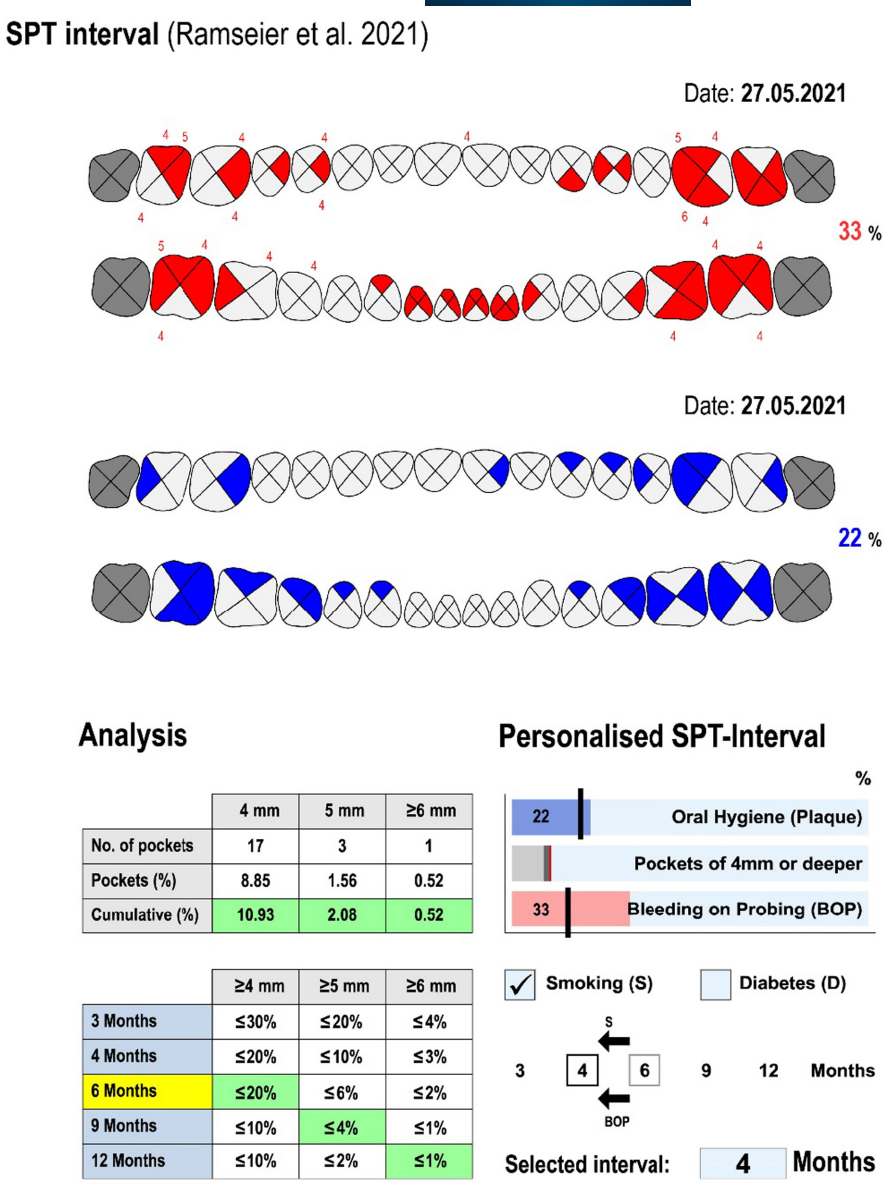


FIGURE 12 Determining the indicated interval SPT of a periodontitis patient (male smoker, age 41 years) according to Ramseier et al.[120] using the SPT interval tool (www.perio-tools.com/spt). Residual PPDs of 4, 5, and 6 mm reveal an algorithm-based interval of 6 months. Considering a %-BOP of 33% and a positive smoking status (S) suggest (arrows) an SPT interval of 4 months.[120]

that are traditionally measured manually. These algorithms are particularly effective at identifying signs of inflammation, calculus, recession, bleeding, and bone loss from dental images such as intraoral photographs and cone beam computed tomography scans.[142]

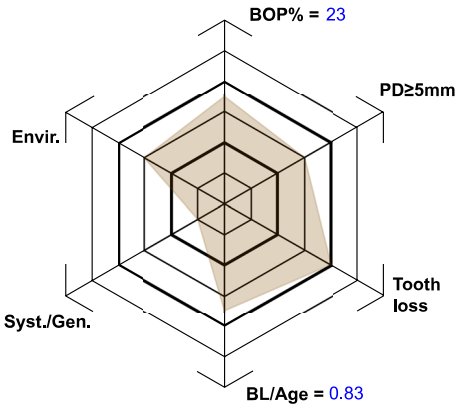
The future role of AI will extend beyond the clinical setting to include frequent home monitoring.[143] Patients can take intraoral photographs that can be uploaded to cloud-based AI systems for analysis. These systems can track changes in soft tissue appearance over time, flagging deteriorating areas for earlier re-evaluation. The potential of AI in analysing full-mouth series or panoramic radiographs to detect early signs of interdental biofilm, bone resorption or periapical lesions could lead to more conservative treatment approaches.[144]

In addition, longitudinal tracking of AI-evaluated images may allow differentiation between stable, improving, and deteriorating periodontal sites, helping to formulate tailored treatment plans. AI, in conjunction with clinical parameters and other diagnostic tools, could also influence decisions about surgical and non-surgical therapies, SPT intervals, and complication management. The integration of AI into teledentistry platforms is particularly promising for extending specialized periodontal and implant monitoring services to remote or underserved areas.

Despite its promising applications, AI in dental diagnostics is still in its infancy. Ongoing research focuses on validating algorithms against large reference datasets to achieve diagnostic accuracy equal to or better than human experts. Future developments may see the emergence of multimodal AI, combining imaging with clinical measurements, medical history, or 3D scans. An important aspect of future AI models will be their ability to provide explanations for scores, thereby increasing clinician confidence. Standardization of image acquisition protocols and outcome assessments will further refine AI training.

In summary, AI has the potential to revolutionize periodontal and implant follow-up. Its accuracy, reliability, cost-effectiveness, and ease of use could make specialized care more accessible. As AI continues to reshape periodontal and peri-implant practice, its impact

(A) Periodontal Risk Assessment (PRA) (Lang & Tonetti 2004)



Polygon surface: 64.08587

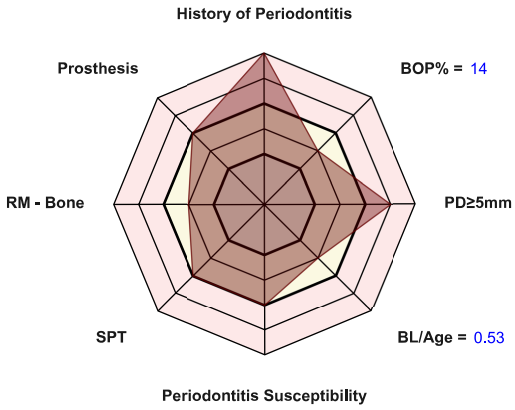
Periodontal Risk: medium

Recommendation: **consider attention on modifiable risks**

Personalized SPT-Interval: www.perio-tools.com/spt

Age	60
Number of teeth and implants	20 (1 - 32)
Number of sites per tooth / implant	○ 2 ○ 4 ◉ 6
Number of BOP-pos. sites	28 of 120
Number of sites with PPD≥5mm	6
Number of missing teeth	8
% alveolar bone loss (estimated in % or 10% per 1mm)	50 %
Syst./Gen.	○ Yes ◉ No
Envir.	○ Non-smoker (NS) ○ Former smoker (FS) ◉ Occasional smoker (OS) ○ Smoker (S) ○ Heavy smoker (HS)

(B) Implant Disease Risk Assessment (IDRA) (Heitz-Mayfield et al. 2020)



Overall Risk Rating: High

attention on reducing modifiable risks

Age (years)	76
Number of teeth	18 (1 - 32)
Probing sites per tooth	○ 2 ○ 4 ◉ 6
Number of implants	6
Probing sites per implant	○ 2 ○ 4 ◉ 6
Number of BOP-pos. sites	20 of 144
History of periodontitis	○ No ◉ Yes ○
Periodontitis susceptibility (according to the 2017 classification)	○ Health ○ Stage I ○ Grade A ○ Stage II ◉ Grade B ◉ Stage III ○ Grade C ○ Stage IV
Number of sites with PD≥5mm (tooth and implant site)	8
% Alveolar bone loss (BL) (estimated in % or 10% per 1mm at the worst site)	40 %
Supportive periodontal therapy (SPT)	○ Compliant ○ 5 months or less ◉ 6 months ○ Casual ○ None
Restorative margin (RM) to bone	○ Soft Tissue Level Implant ◉ >1.5mm ○ <1.5mm
Implant prosthesis	○ Cleanable ◉ Poor fit with supramucosal restoration margins ○ Poor fit with submucosal restoration margins / cement excess ○ Not cleanable

FIGURE 13 (A) Periodontal risk assessment (PRA) online tool (www.perio-tools.com/pra) showing a moderate periodontal risk in a 60-year-old patient (occasional smoker, systemically healthy). The recommendation is to consider attention to modifiable risks.[134] (B) Periimplant disease risk assessment (IDRA) online tool (www.perio-tools.com/idra) showing a high risk of periimplant disease in a 76-year-old patient (stage 3, grade B periodontitis). The recommendation is to focus on reducing modifiable risks.[136]

on diagnostic accuracy, early detection, and personalized treatment plans is becoming increasingly apparent. Future studies will still need to investigate the efficacy of AI in periodontal and peri-implant diagnostics, predictive assessments, and its impact on dental practices, emphasizing its role in disease management.

21 | CONCLUSION

In conclusion, the management of periodontal disease and peri-implantitis requires a multifaceted approach that emphasizes the importance of regular diagnostic monitoring, patient education, and personalized treatment strategies. Diagnostic measures play a crucial role in the early detection, ongoing evaluation, and long-term monitoring of these conditions. Techniques such as periodontal probing, dental radiography, and advanced 3D imaging provide invaluable insight into the health of the periodontium and peri-implant tissues. BOP and the use of various indices further refine the diagnostic process and provide a comprehensive assessment of tissue health. The effective management of these conditions also depends on the understanding and application of specific diagnostic parameters, with a focus on oral hygiene, PPDs, and the safety of probing techniques, particularly around dental implants. The use of non-metallic probes and minimal probing force are recommended to ensure accurate and safe measurements. In addition, the monitoring of furcations and inflammation, the use of laboratory diagnostics such as GCF and salivary biomarkers, and the understanding of microbial dynamics are integral to the comprehensive management of periodontal and implant therapies.

Patient compliance is emerging as a critical factor influencing the outcome of periodontal and implant treatment. Studies have shown that regular adherence to SPT has a significant impact on the long-term success of these treatments. Addressing factors that influence patient compliance, such as socioeconomic variables and lifestyle choices such as smoking, is essential to improve treatment outcomes. Periodontal and peri-implant stability are key indicators of successful therapy and maintenance. Regular assessment of clinical parameters and radiographic evaluations play a critical role in ensuring that these conditions remain stable over time. The PRA and IDRA tools provide structured approaches to assessing and managing the risks associated with periodontal disease and peri-implantitis, respectively. The future of diagnostic measures in periodontology and implant dentistry lies in the integration of technology and personalized care. Continued research and development in this area is essential to improve diagnostic accuracy and treatment efficacy. It is also important to bridge the gap between emerging technologies and their practical application in clinical practice.

In summary, successful management of periodontal disease and peri-implantitis depends on a comprehensive diagnostic approach, patient education, adherence to therapy, and regular monitoring. Advancements in diagnostic tools and techniques, together with a deeper understanding of patient-specific factors, will continue to refine treatment strategies and improve the long-term health and stability of periodontal and peri-implant tissues.

CONFLICT OF INTEREST STATEMENT

The author has no direct conflict of interest to declare.

DATA AVAILABILITY STATEMENT

Data available on request from the author.

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