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Implementation of a software application in staging and grading of periodontitis cases

Lorenzo Marini[1] | Maurizio S. Tonetti[2,3] | Luigi Nibali[4] | Nicola M. Sforza[5] | Luca Landi[6] | Raffaele Cavalcanti[7] | Mariana A. Rojas[1] | Andrea Pilloni[1]

[1]Section of Periodontics, Department of Oral and Maxillofacial Sciences, Sapienza University of Rome, Rome, Italy

[2]Division of Periodontology and Implant Dentistry, Faculty of Dentistry, The University of Hong Kong, Hong Kong, China

[3]Department of Oral and Maxillo-facial Implantology, Shanghai Key Laboratory of Stomatology, National Clinical Research Centre for Stomatology, Shanghai Ninth People Hospital, School of Medicine, Shanghai Jiao Tong University, Shanghai, China

[4]Periodontology Unit, Centre for Host-Microbiome Interactions, Faculty of Dental and Craniofacial Sciences, King's College London, London, UK

[5]Private Practice, Bologna, Italy

[6]Private Practice, Rome, Italy

[7]Section of Periodontology, Department of General Surgery and Medical-Surgical Specialties, School of Dentistry, University of Catania, Catania, Italy

Correspondence
Lorenzo Marini, Section of Periodontics, Department of Oral and Maxillofacial Sciences, Sapienza University of Rome, 6 Caserta Street, Rome 00161, Italy.
Email: lorenzo.marini@uniroma1.it

Abstract

Objectives: The purpose of this study was to assess the diagnostic accuracy and the inter-rater agreement among general dentists when staging and grading periodontitis cases with the aid of a software application (SA) developed by the Italian Society of Periodontology and Implantology.

Materials and methods: Ten general dentists were asked to independently assess 25 periodontitis cases using the SA. Accuracy was estimated using quadratic weighted kappa and examiners' percentage of agreement with a reference diagnosis provided by a gold standard examiner. Inter-rater agreement was evaluated using Fleiss kappa statistics.

Results: The overall case definition agreed with the reference diagnosis in 53.6% of cases. The agreements for each general dentist's pairwise comparisons against the reference definition were at least substantial in 100% of cases for stage, in 70% of cases for grade and in none of the cases for extent. Fleiss kappa was 0.818, 0.608, and 0.632 for stage, extent, and grade, respectively. The study recognized possible reasons that could lead to decreased accuracy using the SA.

Conclusions: Supported by the SA, general dentists have reached substantial inter-rater agreement and highly accurate assignments of stage and grade. However, complete case definitions were correctly diagnosed in slightly over half of the cases.

KEYWORDS
classification, diagnosis, mobile applications, periodontitis, reproducibility of results, software

1 | INTRODUCTION

A periodontitis case should be defined using the staging and grading system proposed in the 2018 Classification of Periodontal and Peri-Implant Diseases and Conditions (Caton et al., 2018; Tonetti et al., 2018). Accurate and consistent case definitions are critically important, as they can have an impact in estimating the prevalence of periodontitis (Stødle et al., 2021), in assessing the actual need for periodontal therapy (Herrera et al., 2022; Sanz, Herrera, et al., 2020),

in the definition of the periodontal prognosis (Saleh et al., 2022; Takedachi et al., 2022) and may influence the results and associations presented in the studies (Deng et al., 2021; Goergen et al., 2021).

The consistency and accuracy among periodontal experts, general dentists and undergraduate dental students in defining periodontitis cases using the staging and grading system were first evaluated by Marini et al. (2021). It was showed that intra-rater agreement was almost perfect, whilst inter-rater agreement was moderate. In addition, the definition of stage was more accurate

than those of grade or extent. In particular, the lower consistency and accuracy in the grading component were due to the assessment of the bone loss by age ratio. Overall, the ability to recognize severe forms of periodontitis (stage III and IV) was greater than that of mild forms (stage I and II). However, more difficulties were observed in discriminating between stage III and IV compared to stage I and II. General dentists showed a lower accuracy than either periodontists or senior dental students and they took longer to define each case. Ravidà et al. (2021) and Abrahamian et al. (2022) showed comparable results among periodontal experts, although a more limited number of cases and almost only severe forms of periodontitis were included in their investigations. Conversely, Gandhi et al. (2022) reported a lower rate of accurate diagnosis among undergraduate students of three different dental schools compared with the previous study. All the above-mentioned studies concluded that efforts are needed to improve diagnostic agreement in the case definition of periodontitis by identifying and clarifying the "grey zones" and implementing education and training, especially for general dentists.

Recently, a software application (SA) for digital devices was developed by the Italian Society of Periodontology and Implantology (SIdP). Using SA, clinicians have the opportunity to be guided through the staging and grading process by answering multiple choice questions with reference to the case anamnesis, clinical and radiographic data. After responding all the queries, the stage, extent, and grade are automatically generated. However, this tool does not replace the diagnostic activity of the clinician and the final report must be certified by a dentist before being considered a medical diagnosis.

Up to date, the effectiveness on the diagnostic accuracy and on the inter-rater agreement as well as the time required for case definition using the SA introduced by the SIdP has not been evaluated. Therefore, the primary aim of this study is to evaluate the accuracy and the inter-rater agreement among general dentists in defining the stage, extent, and grade of periodontitis cases with the support of a SA.

2 | MATERIALS AND METHODS

2.1 | Study design

The study was based on the case definition of 25 untreated periodontitis cases with the support of a SA introduced by the SIdP. All cases were examined by 10 general dentists to determine the diagnostic accuracy and the inter-rater agreement.

The study was conducted according to the Guidelines for Reporting Reliability and Agreement Studies (GRRAS) (Kottner et al., 2011).

2.2 | Ethical considerations

The same documentation used for a previous study that assessed the inter-rater and intra-rater agreement and the accuracy in defining the stage, extent, and grade of 25 periodontitis cases using the 2018 Classification was used for this investigation (Marini et al., 2021). Only anonymous and non-identifiable data that were not collected for the currently proposed project were used in this study, which therefore does not constitute a human subject research (U.S. Department of Health and Human Services). All subjects had provided informed consent to the use of the collected data in the context of training and research. The research protocol was approved by the Department of Oral and Maxillofacial Sciences of Sapienza, University of Rome (Prot. n. 0000203/2022). Prior to starting the study, all the general dentists signed an informed consent.

2.3 | Examiners

The 10 general dentists who participated in the study that assessed the inter-rater and intra-rater agreement and the accuracy in defining the stage, extent, and grade of 25 periodontitis cases using the 2018 Classification were recruited to participate in this study (Marini et al., 2021). The examiners were chosen from the network of private practitioners in Italy at the invitation of the study coordinator (LM). The characteristics of the participants were the following: (a) >10 years of clinical experience; (b) not having attended advanced graduate education programs in periodontology; and (c) not exclusively focused on any specific field of dentistry in their own practice.

2.4 | Procedures

2.4.1 | Selection and preparation of the documentation of the periodontitis cases

The same documentation of the 25 periodontitis cases used for the assessment of the reliability and the diagnostic accuracy using the staging and grading system without SA were used for this study (Marini et al., 2021). It was collected in the context of routine care in the Section of Periodontology of Sapienza University of Rome from patients suffering from periodontitis according to the definition of the 2018 Classification (Tonetti et al., 2018). Documentation was assembled in a slideshow presentation file which provided for each case:

1. Personal data (age and gender);
2. History of systemic diseases (glycated hemoglobin values <7% or ≥7% have been reported in patients with diabetes), pharmacological treatment, and smoking (0, ≤10/day or >10/day cigarette consumption);
3. Dental history (including the number of teeth lost due to periodontitis 0, ≤4 or ≥5);
4. Intra-oral photographs;
5. Full-mouth periapical radiographs;
6. Periodontal charting showing probing depth (PD), clinical attachment level (CAL), and bleeding on probing (BOP) recorded at six sites per tooth of the entire dentition, furcation involvement (F), tooth mobility (M), full-mouth plaque score (FMPS), and full-mouth bleeding score (FMBS).

A representative example of case documentation is shown in Figure 1.

For each case, the reference diagnosis was considered the one assigned by a gold standard examiner without the aid of the SA (MST).

2.4.2 | Training of examiners on the use of SA as a support to periodontitis case definition

Before beginning the study, all examiners received a copy of the study protocol. Participants had to download the SA developed by the SIdP (SIdP PowerUP, Version 1.0.2) and received a username and password for the login. Then, they received instructions for its use by one study coordinator (LM). First, participants had to select the pathway for diagnosis of "periodontitis." Then, they had to answer multiple choice questions related to the case anamnesis, clinical and radiographic data subdivided in 5 phases. The phase 1 included questions needed to define if the patient was a periodontitis case, and by which form of periodontitis was affected. Phase 2 and 3 investigated, by means of specific queries, the stage of periodontitis in terms of severity and complexity,

respectively. Phase 4 assessed the extent of periodontitis. Finally, phase 5 aimed at identifying, by selecting one of the possible answers, the rate of progression of periodontitis and the presence of risk modifiers in order to establish the grade of periodontitis. Once completed, the application automatically provided a report with case definition (stage, extent, and grade) of the periodontitis case. Participants were asked to train themselves through the definition of 3 periodontitis cases not included in the study with the aid of the SA.

An example of a case of periodontitis defined using SA, showing all multiple-choice questions and possible related answers, is shown in Figure 2.

2.4.3 | Staging and grading of periodontitis cases using SA

From their own workstations, blinded to each other and without time limits, the general dentists independently assessed all the periodontitis cases using the SA and finally returned the recording file containing their diagnosis to the study coordinator (LM). They had to report also the time taken for the evaluation of each case.
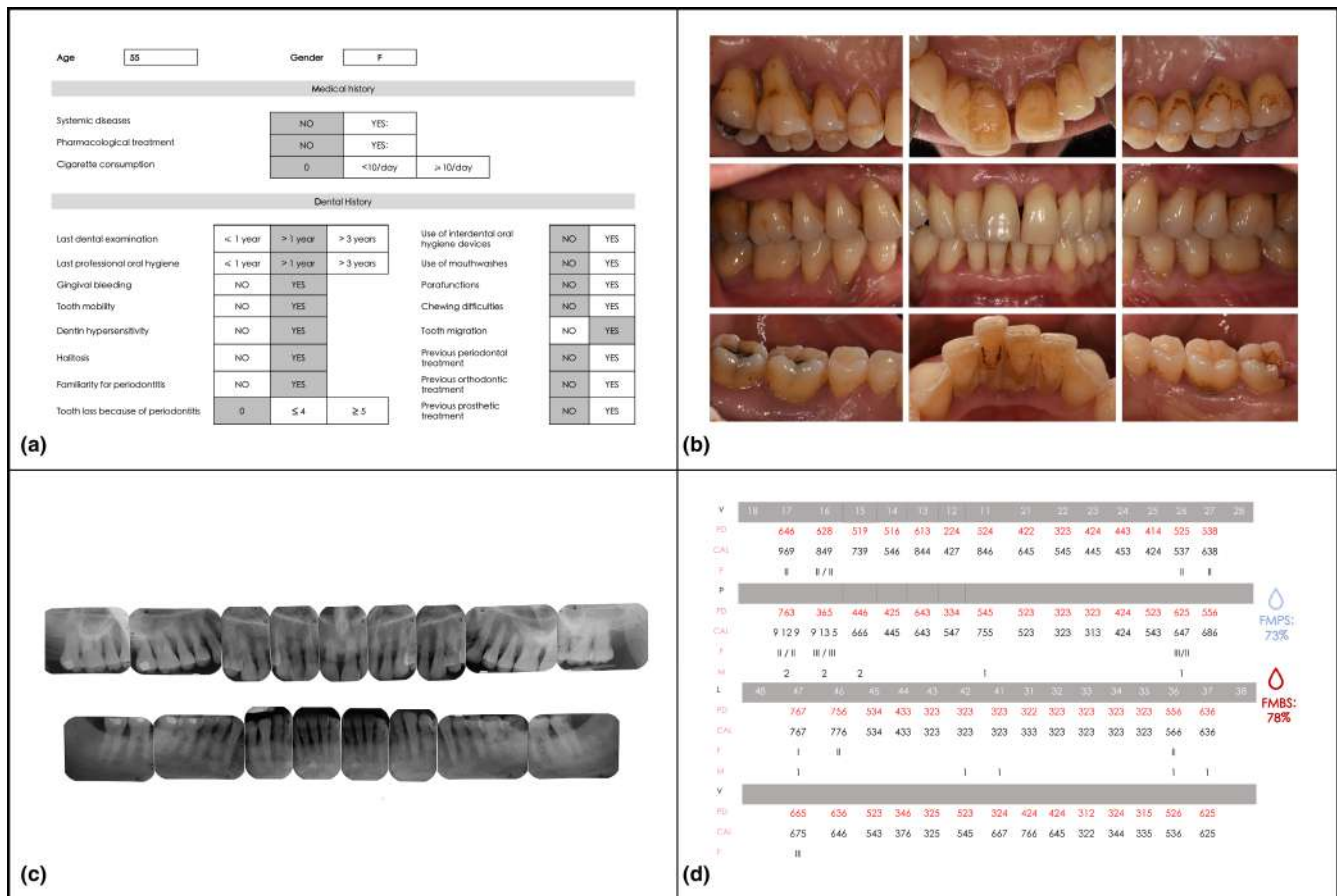

FIGURE 1 Representative example of documentation provided for each case. (a) Personal data and general and dental history. (b) Intraoral photographs. (c) Full-mouth periapical radiographs. (d) periodontal charts. CAL, clinical attachment level; F, furcation involvement; FMBS, full-mouth bleeding score; FMPS, full-mouth plaque score; M, mobility; PD, probing depth
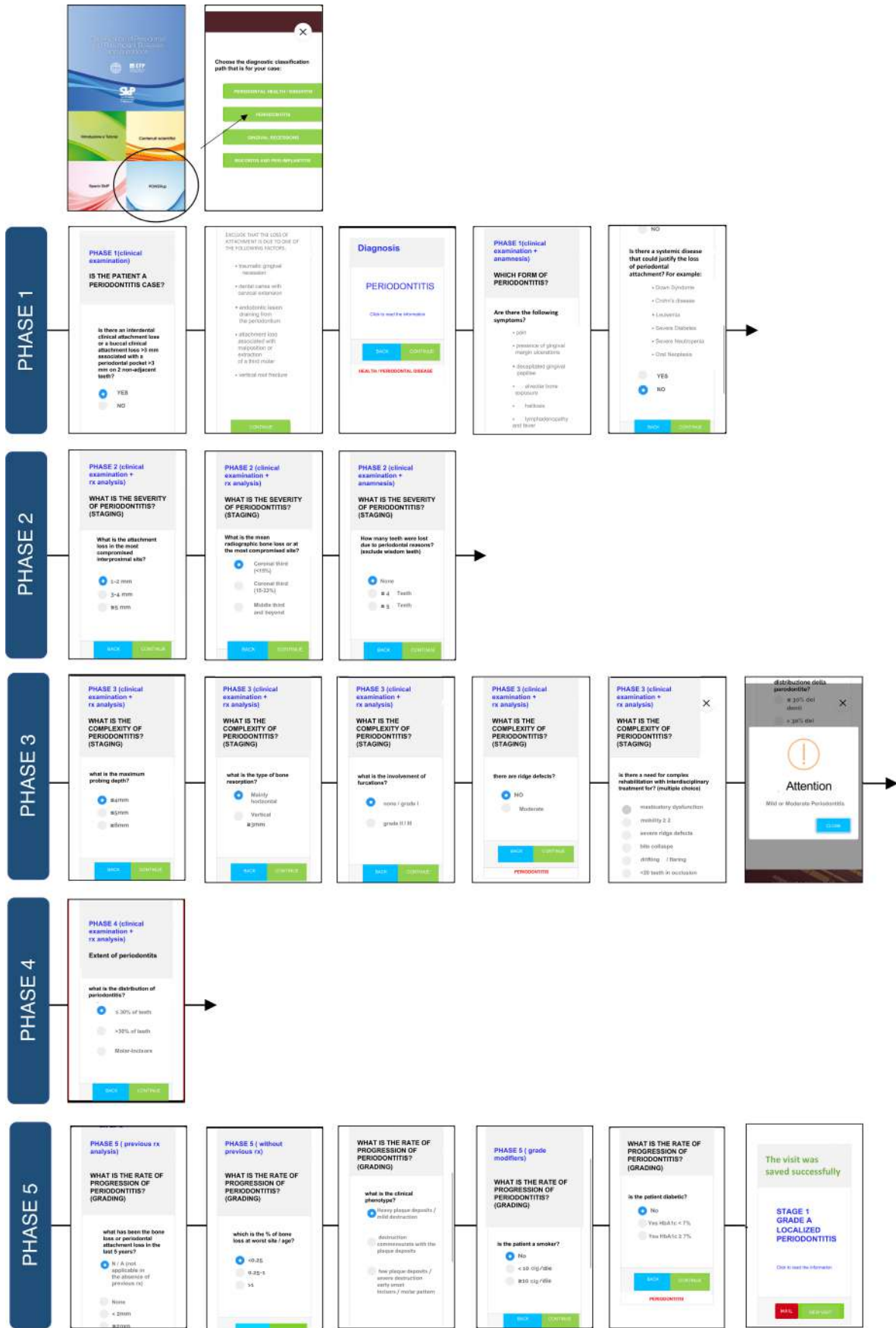
FIGURE 2 Example of periodontitis case defined using SA, showing all multiple-choice questions and possible related answers

2.5 | Outcomes

2.5.1 | Primary outcome

The primary outcome was the agreement between each general dentist and a refence diagnosis when defining stage, extent, and grade of each periodontitis case using a SA as a support.

2.5.2 | Secondary outcomes

The secondary outcomes were as follows: (a) the inter-rater agreement between general dentists when defining the stage, extent and grade of periodontitis cases using a SA as a support; (b) the time taken for staging and grading periodontitis cases using the SA.

2.6 | Statistical analysis

The primary outcome was estimated by evaluating the agreement between general dentists and a refence diagnosis when defining stage, extent, and grade of periodontitis case using the SA. Quadratic weighted kappa was assessed for pairwise comparisons (each general dentist vs reference stage, extent, and grade). The agreement of general dentists as a whole with the reference stage, extent, and grade was also expressed as frequencies and percentages. Statistically significant differences between the expected and the observed frequencies were evaluated using the chi-squared test [significance level (α) = 0.05].

The inter-rater agreement was evaluated using the Fleiss kappa statistics (Fleiss, 1981). Separate analysis was performed to determine agreements for stage, extent, and grade.

According to Landis and Koch (1977), the kappa values have been interpreted as follows: poor agreement = <0.00; slight agreement = 0.00 to 0.20; fair agreement = 0.21 to 0.40; moderate agreement = 0.41 to 0.60; substantial agreement = 0.61 to 0.80; and almost perfect agreement = 0.81 to 1.00. With reference to previous data in this field (Abrahamian et al., 2022; Marini et al., 2021; Ravidà et al., 2021), the expected kappa values were as a minimum of 0.61 for at least 50% of the pairwise comparisons with the reference diagnosis and at least of 0.41 for the inter-group agreement.

Average time (mean and standard deviation) taken for the diagnosis using the SA was presented. Separate analysis was also performed acccording the stage and grade components and the accuracy of diagnosis. According with Shapiro–Wilks test or Kolmogorov–Smirnov test, in the absence of normally-distributed variables, differences were compared with Kruskal–Wallis test [significance level (α) = 0.05].

A statistical software package (IBM Corp. Released 2017. IBM SPSS Statistics for Macintosh, Version 25.0. Armonk, NY: IBM Corp.) was used for the statistical analysis.

2.7 | Sample size

The sample size was calculated on data from a previous related study (Marini et al., 2021). Consequently, the convenience number of examiners was estimated at 10 based on comparable studies (Cairo et al., 2010; Isaia et al., 2018; Rotundo et al., 2015). Regarding the number of cases of periodontitis, it was established at 25 using pairwise comparisons with a required kappa of 0.61, the lower end of the 95% confidence interval (CI) for kappa as 0.28 and the expected concordance 50% of the time. (Donner & Rotondi, 2010).

3 | RESULTS

3.1 | Descriptive characteristics of periodontitis cases

The 25 cases selected for this study comprised a full spectrum of the stages of periodontitis. Descriptive characteristics of the periodontitis cases are resumed in the Table 1.

TABLE 1 Descriptive characteristics of the twenty-five periodontitis cases

| Characteristics	Frequency (n)	Percentage (%)
Age		
Years; mean ± SD	47.6 ± 13.3	
Years; range	29–74	
Gender		
Males	11	44%
Females	14	56%
Stage		
I	2	8%
II	5	20%
III	12	48%
IV	6	24%
Extent		
Localized	4	16%
Generalized	21	84%
Grade		
A	–	–
B	10	40%
C	15	60%
Smoking		
Non-smokers	14	68%
Smokers <10 cigarettes/day	4	8%
Smokers ≥10 cigarettes/day	4	8%
Diabetes		
Normoglycemic/no diabetes	22	88%
Diabetes with HbA1c <7%	2	8%
Diabetes with HbA1c ≥7%	1	4%
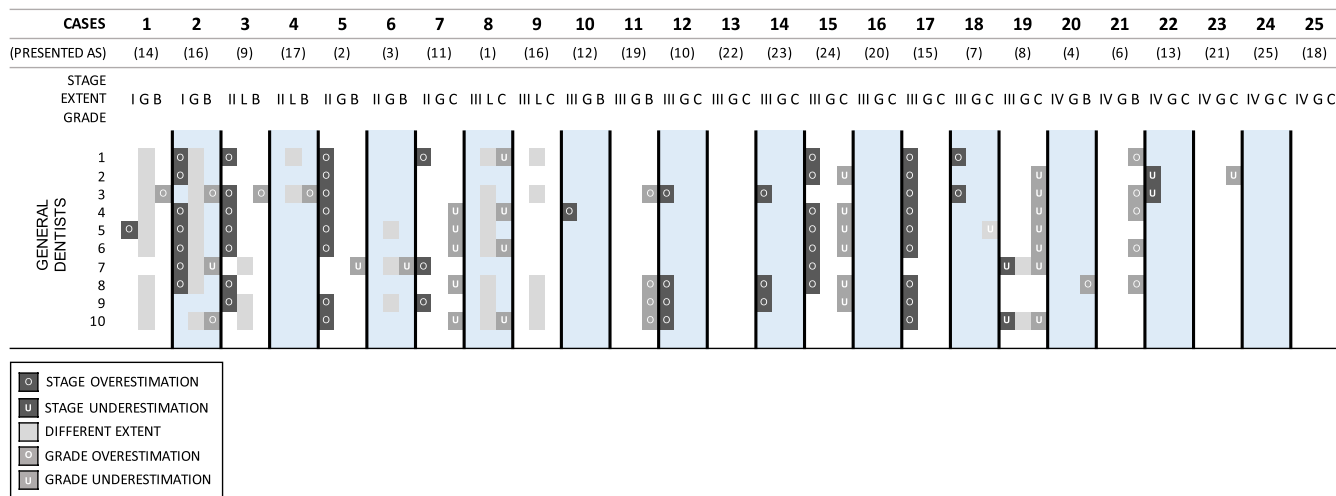
FIGURE 3 Reference stage, extent, and grade of the twenty-five periodontitis cases and comparison against general dentists. The cases are ordered from the least severe to the most severe form of periodontitis. The order in which they were shown to the examiners is also provided.
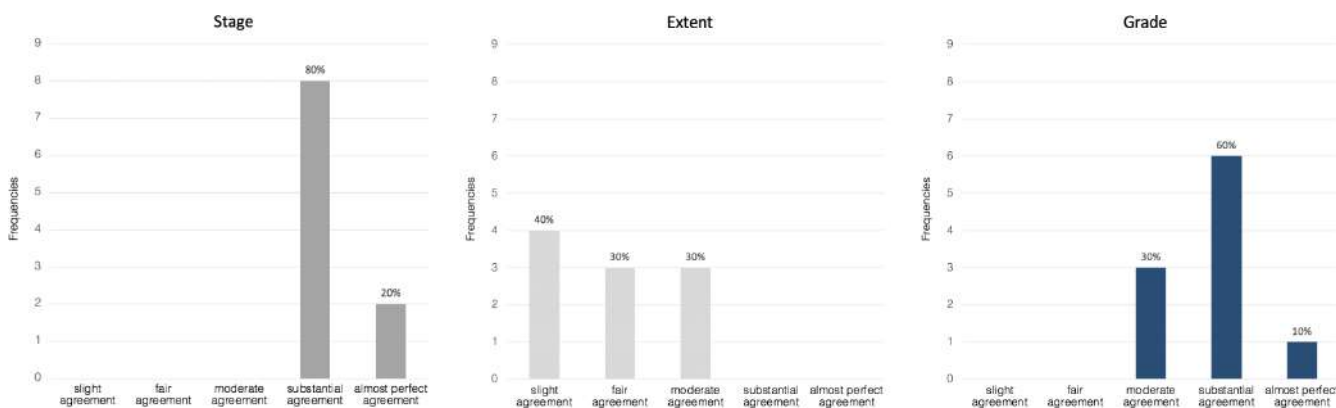

FIGURE 4 Frequency and percentage of agreements achieved by pairwise comparisons of each general dentist against reference stage, extent, and grade using quadratic weighted kappa.

3.2 | Agreement between general dentists and reference stage, extent and grade definitions using the SA

Figure 3 shows the reference stage, extent, and grade of the 25 cases of periodontitis and, for each of them, the respective concordance, overestimation, and underestimation by the 10 general dentists.

Frequency and percentage of agreements achieved by pairwise comparisons of each general dentist against reference stage, extent, and grade is presented in Figure 4. Mean values of quadratic weighted kappa for stage and grade led to substantial agreement while for extent into a fair agreement.

Percentages of agreement with reference stage, extent, and grade definitions are shown in Table 2. Complete agreement for overall diagnosis (stage + extent + grade) was achieved in the 53.6% of cases. The less severe the stage the lower was the chance of an accurate definition ($p < 0.001$). No difference was found in the ability to get the correct diagnosis in relation to the grading ($p = 0.097$).

Frequencies and percentages of definitions by the general dentists with respect to the reference stage are presented in Table 3.

Presence of grade C modifying factors (smoking ≥10 cigarettes/day and/or diabetes with HbA1c ≥7%) allowed the chance of achieving agreement with reference grade in 100% of cases. In other cases, the agreement for grade was statistically lower ($p = 0.005$) (Figure 5).

3.3 | Inter-rater agreement for stage, extent and grade definitions among general dentists using the SA

Table 4 presents the results of Fleiss kappa statistics. The inter-rater agreement between general dentists was almost perfect for stage, substantial for grade, and moderate for extent.

3.4 | Time taken for diagnosis using the SA

Table 5 shows the mean and SD of the time taken by the general dentists for each complete case definition (stage, extent, and grade).

Data from a sub-analysis performed based on the reference stage and reference grade of periodontitis cases, as well as on the

accuracy of the diagnosis, are also presented. The time to case assignment was significantly shorter when the stage and grade were higher ($p < 0.001$ and $p = 0.002$, respectively), and when the definitions agreed with the gold standard diagnosis ($p = 0.002$).

4 | DISCUSSION

The main findings of this study on the use of a SA to aid general dentists in defining periodontitis cases are: (i) overall diagnosis is accurate in more than half of the cases; (ii) assignment of stage and grade is substantially accurate, while it is worse in terms of extent; (iii) the less severe is the form of periodontitis, the harder is the chance to properly diagnose each case; (iv) the inaccurate definitions are mostly due to overestimation of stage and/or grade; (v) presence of high risk modifiers are positively associated to the chance of correctly assign the grade in all the cases; and (vi) the agreement between general dentists is high for stage and grade but it is lower for extent.

This investigation was carried out only on the general dentists since it was shown that their accuracy and inter-rater agreement was the lowest when staging and grading periodontitis cases compared with periodontal experts and dental students (Marini et al., 2021). Therefore, they could have been the ones who most benefited from support during the diagnostic process. However, more recent studies have found unsatisfactory diagnostic skills even among undergraduate students (Gandhi et al., 2022).

In this study, each examiner's case definitions were compared against a reference stage, extent, and grade, which were considered to be those assigned by an examiner gold standard. The gold standard examiner was one the authors of the staging and grading system developed in the context of the 2017 World Workshop on the Classification of Periodontal and Peri-Implant Diseases and Conditions (Tonetti et al., 2018). The expected agreement (quadratic weighted kappa ≥0.61 for at least 50% of the pairwise comparisons) was achieved by the general dentists for stage and grade but not for extent. Otherwise, the expected value for inter-rater agreement (kappa ≥0.41) was obtained for all the case definition components. On the whole, the results seem to indicate that the use of the SA allows to reach satisfactory levels of accuracy and concordance. Precision in the definition of staging can translate into in the possibility of framing and planning the treatment of periodontal patients in accordance with the guidelines issued by the European Federation of Periodontology (Herrera et al., 2022; Sanz, Herrera, et al., 2020). Similarly, the accuracy of grading may mean being able to attribute and communicate to the patient his periodontal prognosis (Saleh et al., 2022; Takedachi et al., 2022).

The advantage offered by SA is the automated assignment of a periodontitis case definition, once the clinician has been guided step by step in considering the parameters to be evaluated in order to assign both the stage and the grade. Failure to achieve a correct diagnosis can in any case occur and be mainly due to three reasons. First reason is the incorrect answer to the multiple-choice question

of the SA by the clinician due to inappropriate identification of clinical and/or radiographic data in the documentation of each case (e.g., the calculation of the bone/age ratio). The second reason relies on the fact that the application of the 2018 Classification by the SA appears to be somehow too stringent when considering the following: (a) only one site necessary for any parameter to shift the stage (e.g., one site with PD >6 mm is sufficient to move from stage II to III), with a consequent tendency to overestimate the stages; (b) the clinical phenotype based on destruction in relation to the amount of plaque deposits sufficient to modify the grade, making it very difficult to assign a case to grade A. In this regard, it has been suggested that upstaging due to complexity factors requires a comprehensive evaluation of these parameters by an experienced clinician. Furthermore, the use of automated checkbox-based algorithms based on the presence / absence of isolated elements in the staging and grading process was not recommended (Kornman & Papapanou, 2020). The third reason is the extent assignment on the basis of the distribution of periodontitis and not of the stage, reducing the number of localized cases properly identified (Sanz, Papapanou, et al., 2020). This latter aspect would require a reprogramming of the SA.

The major strength of the study is represented by the selection of the same 25 cases of periodontitis and the same 10 general dentists enrolled for the evaluations of a previously published paper on the accuracy and consistency in the definition of periodontitis cases

TABLE 2 Percentages of agreement with reference stage, extent, and grade definitions

Variable	% Agreement with reference diagnosis
Stage (I–IV)	74.4
Stage[b]	
I	60.0
II	64.0
III	70.0
IV	96.7
p value between stages[a]	<0.001[*]
Extent	82.8
Localized	50.0
Generalized	89.0
p value between extent[a]	<0.001[*]
Grade (A–C)	84.0
Grade[b]	
A	–
B	80.0
C	87.6
p value between grades[a]	0.097
Overall diagnosis	53.6

[a]Chi-square test.
[b]Reference diagnosis.
[*]Statistically significant.

using the 2018 Classification without any implementation tool (Marini et al., 2021). It provided an opportunity for direct comparison of results with and without the support of the SA. In this regard, the results related to staging, extent and grading showed an increase in the percentage of cases in which the definition was accurate of 10%, 6.4%, and 18.4%, respectively. The reached values corresponded to those obtained by periodontal experts and dental students in the previous study. The same occurs when quadratic weighted kappa values were applied. As far as the stage component, there was an improved accuracy in the definition of stage III, although there has also been a worsening in the definition of stage I. This could be partly due to the aforementioned trend to overestimation using the SA. As for the grade, it was the component that most benefited from the use of SA. In fact, there was an increase in the percentage of correct assignment in grade B. This could be affected by the almost eliminated possibility of identifying cases as grade A. Concerning the agreement between examiners, superior consistencies for stage, extent, and grade were observed.

With respect to the time required for overall case definition, general dentists took a reasonable amount of time for diagnosing using the SA. It was slightly longer than the time recorded in the previous comparable study without any support (Marini et al., 2021) but seemed acceptable since the use of the SA allowed an increase in accuracy. Although a comprehensive user-friendliness evaluation of the present SA has not been carried out, which should be considered when planning further studies, the time taken for case

definition could indirectly demonstrate how the use by the examiners was quite simple. Moreover, the time was shorter when diagnosing the most severe periodontitis cases (Stage IV and Grade C). This was likely due to the greater ease in detecting the data required by the application when they were more remarkable (i.e., when probing depths and clinical attachment levels were greater and radiographic bone loss more evident as well as grade C modifying factors present).

Among the limitations of this study, the small number of examiners must be considered. Even though this number has already been justified (i.e., it facilitates comparisons with a previous study), the present investigation should be understood as a pilot study. Consequently, a further survey with a larger sample size is needed to confirm and deepen the findings of the present investigation. Another weakness of the study was the additional time that general dentists had to learn the classification compared to the previous attempt. However, they were not aware about the staging and grading from the previous evaluation. Furthermore, the documentation evaluated by the examiners was collected from patients only affected by periodontitis, not offering the possibility to test the diagnostic accuracy of the SA in distinguishing between periodontal health, gingivitis, and periodontitis. However, it should be mentioned that the present SA does not provide a single route for all three conditions. On the contrary, it proposes two distinct periodontal diagnostic paths to be selected a priori: "periodontal health and gingivitis" or "periodontitis." Once the "periodontitis" path is chosen, then it is asked to answer whether or

TABLE 3 Frequencies and percentages of definitions by the general dentists with respect to the reference stage

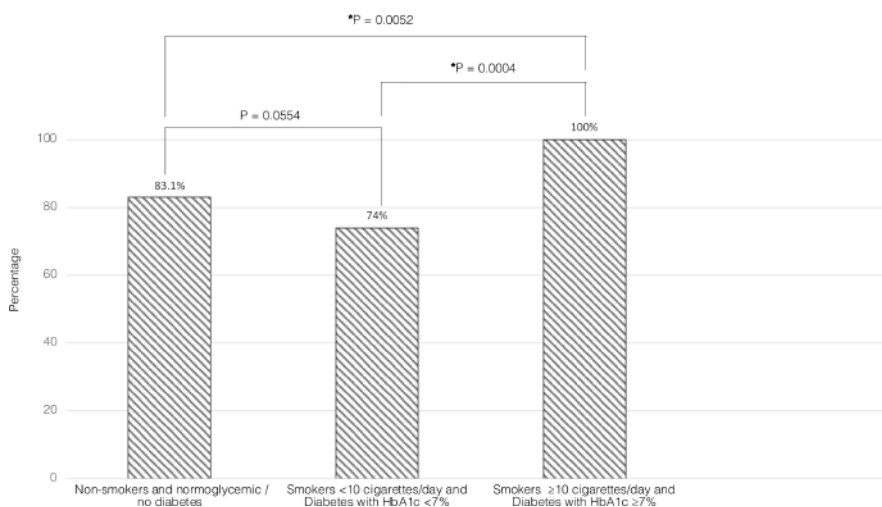| Variable	Stage definition by the general dentists					
	I	II	I+II	III	IV	III+IV
Stage[a]	n (%)	n (%)	n (%)	n (%)	n (%)	n (%)
I+II			44 (75.9%)			14 (24.1%)
III+IV			16 (8.3%)			176 (91.7%)
I	12 (60%)	8 (40%)		0	0	
II	0	32 (64%)		12 (24%)	6 (12%)	
III	2 (1.7%)	0		84 (70%)	34 (28.3%)	
IV	0	0		2 (3.3%)	58 (96.7%)	

[a]Reference diagnosis.

FIGURE 5 Percentage of complete agreement with the reference grade according to the presence of grade modifiers. *Statistically significant using chi-square test; HbA1c, Haemoglobin A1c values

TABLE 4 Fleiss kappa statistics (95% confidence interval) for stage, extent, and grade

Examiners	Stage	Extent	Grade
General dentists ($n = 10$)	0.818 (0.722–0.900)	0.608 (0.461–0.763)	0.632 (0.491–0.777)

TABLE 5 Average time taken for assessments according with different groups of examiners, stage, grade, and exact diagnosis

Variable	Minutes, seconds (Mean ± SD)	p value[a]
General dentists	2:45 ± 0:57	–
Stage[b]		
I	2:53 ± 0:49	<0.001[*]
II	3:12 ± 0:54	
III	2:40 ± 0:58	
IV	2:29 ± 0:55	
Grade[b]		
A	–	0.002[*]
B	2:53 ± 0:54	
C	2:37 ± 0:59	
Complete diagnosis[b]		
Accurate	2:35 ± 0:54	0.002[*]
Inaccurate	2:56 ± 1:00	

Abbreviation: SD, standard deviation.

[a]Kruskal–Wallis test.

[b]Reference diagnosis.

[*]Statistically significant.

not the criteria for the definition of periodontitis are met, allowing the user to continue or not the diagnostic process. If the criteria are not met, the diagnostic process is concluded and the user is asked to select the appropriate "periodontal health and gingivitis" path. In addition to the aforementioned limitations, anamnestic, clinical, and radiographic data were not collected by the examiners. Therefore, the real benefit of using SA may be overestimated in this study. In fact, periodontal probing is known to require training and calibration to provide accurate measurements (Grossi et al., 1996). Similarly, reliable methods for masticatory function assessment in patients with periodontitis are not yet implemented in daily practice (Deng et al., 2022). Moreover, clinical judgment on the implications of previous tooth loss and the near-term risk of losing additional teeth could affect the staging (Sirinirund et al., 2021), just as an incomprehensive collection of medical history could impact the grading (Steigmann et al., 2021). Finally, future studies should compare the cost–benefit of using this SA with other E-Supports for periodontal diagnosis.

5 | CONCLUSIONS

Within its limits, this study shows that the SA developed by the SIdP can be a valid tool in supporting general dentists in defining patients suffering from periodontitis. In fact, their diagnosis generally agreed. Furthermore, if staging and grading were considered separately, general dentists were extremely accurate. Conversely, when combining stage with extent and grade, their accuracy in the overall case definition was reduced.

CONFLICT OF INTEREST

The authors declare no competing interests.

DATA AVAILABILITY STATEMENT

The data that support the findings of this study are available from the corresponding author upon reasonable request.

PEER REVIEW

The peer review history for this article is available at https://publons.com/publon/10.1111/odi.14370.

ORCID

Lorenzo Marini https://orcid.org/0000-0001-6662-2644

Maurizio S. Tonetti https://orcid.org/0000-0002-2743-0137

Luigi Nibali https://orcid.org/0000-0002-7750-5010

Mariana A. Rojas https://orcid.org/0000-0002-8712-0958

Andrea Pilloni https://orcid.org/0000-0002-6268-1863

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