Received: 2 February 2022 | Revised: 11 May 2022 | Accepted: 18 May 2022

DOI: 10.1111/jcpe.13672

ORIGINAL ARTICLE

Journal of Clinical Periodontology WILEY

# Comparison of the efficacy of periodontal prognostic systems in predicting tooth loss

Selai Saydzai[1] | Zoe Buontempo[1] | Pankti Patel[1] | Fatemah Hasan[1] | Chuanming Sun[2] | Aliye Akcalı[3,4] | Guo-Hao Lin[5] | Nikos Donos[4] | Luigi Nibali[1]

[1]Periodontology Unit, Centre for Host-Microbiome Interactions, Dental Institute, King's College London, London, UK

[2]Department of Periodontology, Faculty of Dentistry, Suzhou Health College, Suzhou, China

[3]Department of Periodontology, Faculty of Dentistry, Dokuz Eylul University, Izmir, Turkey

[4]Centre for Oral Clinical Research, Barts and The London School of Medicine & Dentistry, Institute of Dentistry, Queen Mary University of London (QMUL), London, UK

[5]Department of Orofacial Sciences, School of Dentistry, University of California San Francisco, San Francisco, California, USA

**Correspondence**
Luigi Nibali, King's College London Dental Institute, Guy's Hospital, Great Maze Pond, London, UK.
Email: luigi.nibali@kcl.ac.uk

**Funding information**
King's Undegraduate Research Fellowship

## Abstract

**Aim:** The aim of this analysis was to assess how different tooth-prognosis systems could predict tooth loss in a cohort of periodontitis patients followed up prospectively during supportive periodontal care (SPC).

**Materials and Methods:** Clinical and radiographic data of 97 patients undergoing regular SPC for 5 years were used to assign tooth prognosis using four different systems (McGuire & Nunn, 1996; Kwok & Caton, 2007; Graetz et al., 2011; Nibali et al., 2017). Three independent examiners assigned tooth prognosis using all four systems, following a calibration exercise. The association between prognostic categories and tooth loss was tested for each prognostic system separately and across prognostic systems.

**Results:** All four systems showed good reproducibility and could identify teeth at higher risk of being lost during 5 years of SPC; the risk of tooth loss increased with the worsening of tooth-prognosis category ($p < .0001$). Although specificity and negative predictive values were good, low sensitivity and positive predictive values were detected for all systems.

**Conclusions:** Previously published periodontal prognostic systems exhibited good reproducibility and predictive ability for tooth retention. However, low sensitivity was detected, with several teeth in the worst prognosis category being retained at 5 years. Some modifications in the number of categories and their definitions are suggested.

Selai Saydzai, Zoe Buontempo and Pankti Patel should be equally contributing.

KEYWORDS
periodontitis, prognosis, tooth loss

**Clinical Relevance**

*Scientific rationale for study*: Evidence is limited on reproducibility and predictive ability of simple periodontal tooth prognostic systems for chair-side use.

*Principal findings*: The studied prognostic systems showed good reproducibility and ability to identify teeth at high risk of tooth loss during 5 years of supportive periodontal care. However, their sensitivity was low, as many teeth identified as hopeless were retained.

*Practical implications*: The use of these prognostic systems, with some suggested modifications, is advisable as a means to establish tooth prognosis.

## 1 | INTRODUCTION

A recent systematic review concluded that a small proportion of patients with stage III/IV periodontitis experience tooth loss during supportive periodontal care (SPC) (Leow et al., 2021). Assigning prognosis can be an effective tool for more predictable long-term planning and management of a patient, particularly in the context of life-long SPC as the fourth step of periodontal therapy (Sanz et al., 2020). Therefore, prognostic systems can aid in treatment planning by taking into consideration patient-specific factors and evidence-based knowledge. By assigning tooth prognosis, clinicians can discriminate between low-risk and high-risk teeth that could be lost due to progressive and untreated periodontal disease. This allows specific teeth in any one patient to be treated differently despite the overall diagnosis and prognosis of a patient. However, predicting periodontal patient and tooth prognosis accurately is a challenge for clinicians (Kwok & Caton, 2007) and may not always be time-efficient.

In the era of personalized medicine, assigning prognosis is an integral part of treatment planning as it instantly creates a more tailored plan that is tooth-/arch-specific. Therefore, the identification of prognostic factors is of crucial importance (Fardal & Linden, 2005; Chambrone et al., 2010; Costa et al., 2012) alongside the clinical information that is collected from the patient to guide an effective treatment plan. It can also allow discussion with the patient related to the indication of chances of long-term tooth survival, thus potentially improving motivation to improve their oral hygiene and aid in informed consent. Traditionally, prognosis systems identified teeth that were at high risk of being lost. McGuire and Nunn proposed a periodontal prognostic system in 1996 and tested its association with tooth loss in a cohort of patients with periodontitis (McGuire & Nunn, 1996). They identified that there were key clinical parameters with significant association for tooth loss, including probing depths, furcation involvement (FI), and crown/root ratio. Their paper highlighted that a limitation of their study was the variable follow-up times for each patient and, as such, they felt that the most significant clinical parameters should be weighted more heavily when assigning prognosis and this would need to be investigated further. Furthermore, patient factors were not considered. Kwok and Caton (2007) developed another prognostic system that incorporated several systemic and local factors, assigning one of four prognostic categories to each tooth. They acknowledged that their evidence-based system needed to be adapted into clinical practice to verify the system's efficacy. Nguyen and co-workers analysed the Kwok and Caton system retrospectively in a periodontitis patient cohort (Nguyen et al., 2020). The study determined that the system could accurately predict tooth survival within a 5-year period, but they acknowledged that a long-term analysis was needed to further investigate prognosis prediction accuracy. Graetz et al. (2011) conducted a study comparing patients with "aggressive" and "chronic" periodontitis, assigning their prognosis based on just the extent of bone loss alone with a two-category system, showing increasing tooth loss rates for "hopeless" compared with "questionable" teeth. In fact, complexity and that number of factors included in the prognostic system do not necessarily affect accuracy (Pretzl et al., 2008; Krois et al., 2019). Nibali et al. (2017) retrospectively assigned tooth prognosis, using the available clinical and radiographic data, by adapting the findings of previous prognostic systems and adding also non-periodontal factors such as endodontic status and restorability. Their tooth-prognosis system was associated with tooth loss in a retrospective analysis with at least 5 years of follow-up. Other authors proposed prediction models of tooth loss determined by patient and tooth factors (Avila et al. 2009; Martinez-Canut & Llobell, 2018).

Overall, there is still uncertainty over the usefulness of any of these suggested tooth-prognosis systems. The aim of the current paper was to assess inter-examiner reproducibility of four different but relatively simple tooth-prognosis systems and to analyse how they could predict tooth loss in a cohort of chronic periodontitis patients undergoing SPC in a UK private practice setting.

## 2 | MATERIALS AND METHODS

### 2.1 | Patient population

This paper reports an analysis conducted on data from a subset of patients taking part in a larger prospective study. The STROBE guidelines have been followed for reporting this paper (see Supplemental Material 1). All patients had been under care by the same operator

(author Luigi Nibali) in three different private clinics in London and Hertfordshire (United Kingdom), after being referred by their general dental practitioners. Ethics opinion was sought from the London City & East NHS Research Ethics Committee, which gave a favourable opinion for the analysis to be carried out as service evaluation (reference 14 LO 0629). Each patient gave written consent to be included in this study. Inclusion criteria were as follows: (i) initial diagnosis of chronic or aggressive periodontitis (Lang et al., 1999); (ii) with at least two sites with probing pocket depth (PPD) and clinical attachment level (CAL) ≥5 mm; (iii) diagnosed and treated by author Luigi Nibali; (iv) willing to give written informed consent for study participation and to undergo SPC as per standard of care for at least 5 years. Exclusion criteria were as follows: (i) serious medical history that prevents patients from undergoing dental treatment (e.g., recent history of stroke under investigation); (ii) history of rheumatic fever, heart murmur, mitral valve prolapse, artificial heart valve or other conditions requiring prophylactic antibiotic coverage before invasive dental procedures; (iii) current alcohol or drug abuse; (iv) self-reported pregnancy or lactation, (v) other severe acute or chronic medical or psychiatric condition or laboratory abnormality that may compromise trial participation and/or interpretation of trial results and, in the judgement of the investigator, would make the subject inappropriate for entry into this trial. Results of the study on a total of 200 patients originally included in the study will be reported separately. Data relative to the 97 patients who had attended every study visit including the 5-year follow-up with no delays (within 2 months of the arranged appointments every 12 months) are included in this report. The exclusion of non-compliant patients reduces the potential bias introduced by missed visits.

## 2.2 | Clinical examinations

Clinical and radiographic data from all patients were recorded, and the following visits and procedures were carried out:

- Baseline (start of prospective SPC): self-reported medical and smoking histories were recorded. "Never smokers" were those who had never been regular smokers, "former" were those who had given up at any time before starting SPC and "current" were those who were still regularly smoking at the start of SPC. Treatment before baseline included oral hygiene instructions, non-surgical periodontal therapy (occasionally with adjuncts) and, in some cases, extractions and surgical periodontal therapy according to patient needs. For 18 patients, the baseline appointment coincided with the start of SPC. All other patients had already started SPC (average time of SPC before baseline 36 ± 33 months). However, only from this time point (baseline) were they followed up prospectively as part of the study. The following periodontal measurements were taken by author Luigi Nibali at six sites/tooth: dichotomous full-mouth plaque scores (Guerrero et al., 2005), full-mouth PPD, recession (REC) of the gingival margin from the cemento-enamel junction, bleeding on probing (Ainamo & Bay, 1975), tooth mobility (Laster et al., 1975) and FI (Hamp et al., 1975). CAL was calculated as PPD + REC. Clinical parameters were assessed by gentle probing using a UNC-15 periodontal probe and a Nabers probe for FI. Dental radiographs of each patient were obtained for diagnosis and treatment planning purposes at this visit, when considered clinically necessary. Alternatively, existing radiographs were consulted. Following the clinical and radiographic assessments, a plan for SPC was discussed with the patients.

SPC followed an individualized interval of 3–12 months and consisted of medical, smoking and dental history updates, clinical and (if considered necessary) radiographic data collection as above, oral hygiene re-instructions and motivation and supra- and sub-gingival debridement (under local anaesthesia when necessary). SPC recall intervals were individualized based on the periodontal risk assessment system (Lang & Tonetti, 2003) combined with patient preferences. Additional visits with the hygienist were occasionally arranged for some of the patients, according to clinical needs (e.g., worsening in plaque scores). If deterioration in periodontal parameters was detected, further treatment (including periodontal surgeries, extraction or endodontic therapy) was carried out. Clinical measurements were taken at least 1/year for 5 years, until the last study follow-up. The reason and time of tooth loss were recorded throughout the study.

## 2.3 | Radiographic analyses

Periapical radiographs from all patients included in the study were screened, entered in a dedicated database, transferred into a dedicated software system (Autodesk, AutoCAD 2019 for MAC) and analysed by one designated examiner (Aliye Akcalı) as described before (Nibali et al., 2011) at all sites (mesial and distal) to calculate the percentage of bone loss by root length. The presence of intra-bony defects, existing restorations and previous endodontic treatment were also recorded.

## 2.4 | Assignment of tooth prognosis

Tooth prognosis was assigned to all teeth with available clinical and radiographic data at the start of SPC. Four different tooth-prognosis systems were used (McGuire & Nunn, 1996; Kwok & Caton, 2007; Graetz et al., 2011; Nibali et al., 2017) (described in Supplemental Material 2). Clinical data including PPD, CAL, mobility, FI, percentage of bone loss, presence of intra-bony defects, periapical pathology, and restorability were used to assign tooth prognosis. Table 1 highlights which factors were considered in the four prognostic systems. The tested prognostic systems vary widely as they were conceived in different settings and for different applicability. They range from the system by Graetz et al., 2011, which considers only bone loss, to Nibali et al., 2017, which takes into account six different parameters. Some

**TABLE 1** Factors used for assignment of tooth prognosis in the four prognostic systems

| | McGuire and Nunn (1996) | Kwok and Caton (2007) | Nibali et al. (2017) | Graetz et al. (2011) |
|---|---|---|---|---|
| Probing pocket depth | | X | X | |
| Clinical attachment level | X | | | |
| Mobility | X | X | X | |
| Furcation involvement | X | X | X | |
| Radiographic bone levels | X | X | X | X |
| Endodontic status | | | X | |
| Restorability | | | X | |

**TABLE 2** Intra-class correlation coefficient for the four different systems

| | McGuire and Nunn (1996) | Kwok and Caton (2007) | Nibali et al. (2017) | Graetz et al. (2011) |
|---|---|---|---|---|
| Examiner 1 | 0.962 | 1.0 | 0.977 | 1.0 |
| Examiner 2 | 0.965 | 0.930 | 0.989 | 1.0 |
| Examiner 3 | 1.0 | 0.955 | 0.854 | 1.0 |
| Inter-agreement across examiners | 0.985 | 0.890 | 0.995 | 1.0 |

prognostic systems also include non-periodontal factors, such as endodontic and restorability parameters. In case of absence of radiographs, data on restoration combined with clinical periodontal data were used to assign tooth prognosis. When the lack of radiograph was considered crucial for tooth prognosis, the authors did not assign prognosis for that tooth.

## 2.5 | Examiner calibration

Following training for assignment of tooth prognosis, three undergraduate student examiners (Saydzai S, Buontempo Z, and Patel P) underwent a calibration exercise. All teeth from two patients with stage III periodontitis were assigned tooth prognosis with all four systems twice at a distance of 3 days. Inter- and intra-examiner agreement was calculated with intra-class correlation coefficient (ICC) and it is reported in Table 2. In all cases, the ICC was >0.8, for both intra- and inter-examiner reproducibility. Following this, authors Selai Saydzai, Zoe Buontempo and Pankti Patel assigned prognosis to 32 study patients each. One patient had tooth prognosis assigned by all three authors, for further calibration, which showed ICC of 1.0, 0.91, 0.88, and 1.0 for Nibali et al. (2017), McGuire and Nunn (1996), Kwok and Caton (2007), and Graetz et al. (2011), respectively.

## 2.6 | Sample size calculation

The overall study sample size was based on the effect of smoking on tooth loss, considering the evidence for smoking as a risk factor for periodontal progression and tooth loss (Chambrone et al., 2010). We supposed a tooth loss rate of 0.1 tooth/year (Hirschfeld & Wasserman, 1978; Nibali et al., 2013) in non-smokers, equivalent to 0.5 ± 0.5 teeth lost over 5 years. In the absence of exact data relative to smokers, we hypothesized an average tooth loss of 0.75 teeth over 5 years. Based on these parameters and using a two-sided unpaired t-test, a total sample size of 168 cases would have 90% power to detect a difference due to the smoking habit at a 5% significance level. Therefore, to allow for an estimated 15% dropout rate, the final sample size was 200 patients (calculation done at http://clincalc.com/Stats/SampleSize.aspx). This paper reports an explorative analysis on the "tooth-prognosis" outcome, only carried out on compliant patients who attended all study visits at the correct time as indicated above ($n = 97$) (flow chart as Supplemental Material 3).

**TABLE 3** Characteristics of the 97 patients included in this analysis

| | Frequency | Mean ± SD |
|---|---|---|
| Age | | 56.2 ± 8.7 |
| BMI | | 24.8 ± 3.9 |
| Gender | | |
| Male | 31 (31.9%) | — |
| Female | 66 (68.1%) | |
| Ethnicity | | |
| Caucasian | 93 (95.9%) | — |
| Asian | 3 (3.0%) | |
| Mixed | 1 (1.0%) | |
| Smoking | | |
| Never | 50 (51.5%) | — |
| Former | 33 (34.0%) | |
| Current | 14 (14.4%) | |

### 2.7 | Statistical analysis

Data from all patients were entered into a spreadsheet and proofed for entry errors. Continuous variables are reported as means and standard deviations. The primary outcome of the study was tooth loss. The risk ratio and 95% confidence interval for tooth loss of the similar prognosis category, that is, good and favourable, between different prognosis systems were calculated. One-way analysis of variance (ANOVA) with Turkey's post hoc test was also used to detect the inter-category difference within the same prognosis system. In addition, the difference of the risk ratio for tooth loss with the "best", the "second best" and the "second worst" initial prognosis for each system was compared to analyse the predictability of tooth loss among the systems. The sensitivity, specificity, positive predictive value and negative predictive value of the hopeless prognosis category in each system were calculated using a contingency table to demonstrate the predictability for tooth loss.

## 3 | RESULTS

### 3.1 | Baseline tooth prognosis

Table 3 reports the baseline demographic and clinical characteristics of the 97 patients included in this analysis. The majority of patients were female (68%), Caucasians and non-smokers and with an average age of 56 years old at the start of SPC. None of the patients had a diagnosis of diabetes mellitus. According to the current classification (Tonetti et al., 2018), 80 patients were diagnosed as stage III and 17 as stage IV; 56 were diagnosed as grade B and 41 as grade C. The 97 patients included in this report had 2318 teeth at baseline (excluding third molars). It was possible to assign baseline prognosis for 99.7%, 98.9%, 98.7% and 99.0% of teeth for Nibali et al. (2017), McGuire and Nunn (1996), Kwok and Caton (2007), and Graetz et al. (2011) prognostic systems, respectively. Most teeth were scored in the "good prognosis" categories, with only a few falling into the "hopeless" or "unfavourable" categories. Excluding the 65 teeth (in 23 patients) without complete prognosis assignment with all systems, a total of 2253 teeth were included in this analysis (25% molars, 28% premolars and 47% anteriors; 51% maxillary and 49% mandibular).

### 3.2 | Tooth loss

A total of 31 of the initial 2253 prognosticated teeth (1.37%) were extracted throughout the study. Reasons for tooth loss during SPC were progressing periodontal disease ($n = 9$), tooth fracture ($n = 7$), endodontic pathology ($n = 4$), caries ($n = 6$), orthodontic reasons ($n = 3$) and overcrowding of lower incisors ($n = 2$). "Progressing periodontal disease" did not have a specific definition, but depended on clinical judgement based on increased mobility, periodontal abscess or patient discomfort. All prognostic systems were associated with tooth loss over the 5-year follow-up period ($p < .001$).

**TABLE 4** Assignment of tooth prognosis based on the various systems and relative percentage of tooth loss per category over the 5 years of supportive periodontal care

| McGuire and Nunn (1996) ($n = 2289$) | | | Kwok and Caton (2007) ($n = 2284$) | | | Nibali et al. (2017) ($n = 2303$) | | | Graetz et al. (2011) ($n = 2285$) | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Tooth loss % | | | Tooth loss % | | | Tooth loss % | | | Tooth loss % |
| Good | 965 (42.1%) | 0.5% | Favourable | 1886 (82.6%) | 0.6% | Good | 1547 (67.2%) | 0.7% | Good | 2150 (94.1%) | 1.1% |
| Fair | 925 (40.4%) | 1.0% | Questionable | 395 (17.3%) | 4.7% | Fair | 561 (24.3%) | 1.5% | Questionable | 113 (4.9%) | 4.6% |
| Poor | 214 (9%) | 0.5% | Unfavourable | 3 (0.1%) | 33.3% | Questionable | 173 (7.5%) | 4.8% | Hopeless | 22 (1.0%) | 13.6% |
| Questionable | 181 (8%) | 8.4% | – | – | – | Unfavourable | 22 (1.0%) | 18.2% | – | – | – |
| Hopeless | 4 (0.2%) | 25.0% | – | – | – | – | – | – | – | – | – |

**TABLE 5** Sensitivity, specificity, positive predictive value (PPV) and negative predictive value (NPV) for outcome tooth loss at 5 years

| | McGuire and Nunn (1996) ($n = 2289$) | Kwok and Caton (2007) ($n = 2284$) | Nibali et al. (2017) ($n = 2303$) | Graetz et al. (2011) ($n = 2285$) |
|---|---|---|---|---|
| Sensitivity | 3.23% (0.08%–16.70%) | 3.23% (0.08%–16.70%) | 12.90% (3.63%–29.83%) | 9.68% (2.04%–25.75%) |
| Specificity | 99.86% (99.61%–99.97%) | 99.91% (99.68%–99.99%) | 99.19% (98.72%–99.52%) | 99.14% (98.67%–99.48%) |
| PPV | 25.00% (3.44%–75.71%) | 33.33% (4.45%–84.30%) | 18.18% (7.39%–38.22%) | 13.64% (4.69%–33.61%) |
| NPV | 98.67% (98.58%–98.75%) | 98.67% (98.58%–98.75%) | 98.79% (98.62%–98.94%) | 98.74% (98.59%–98.88%) |

*Note*: "Hopeless" (or "unfavourable") categories were compared with all other categories. Definitions: *Sensitivity*: ability to identify a hopeless tooth (if assigned a hopeless/unfavourable prognosis, it will be lost). Specificity: ability to identify a non-hopeless tooth (if assigned a non-hopeless/unfavourable prognosis, it will not be lost). *PPV*: If a tooth is in the hopeless/unfavourable categories, how likely the tooth is lost. *NPV*: If a tooth is in the non-hopeless/unfavourable category, how likely the tooth is not lost.

Table 4 outlines the predictability of tooth loss by reporting the percentage of teeth lost with different initial prognosis. One-way ANOVA with Turkey's post hoc test showed a statistically significant inter-category difference for the percentage of tooth loss between each prognosis category for the four prognosis systems. The *p*-value for the inter-category comparison all showed a $p < .0001$. A gradient increase of tooth loss can be observed for each prognostic system moving from the most to the least favourable category, with the exception of the category "poor" for McGuire and Nunn (1996), which registered only 0.47% tooth loss. The odds ratio for tooth loss during 5 years of SPC for teeth in the "worst" prognostic category versus teeth in the "best" prognostic category was 63.40 (95% CI: 5.59–718.58) for McGuire and Nunn (1996), 77.37 (95% CI: 6.57–911.70) for Kwok and Caton (2007), 14.41 (95% CI: 3.99–52.09) for Graetz et al. (2011) and 30.56 (95% CI: 8.89–105.11) for Nibali et al. (2017) (Supplemental Material 4).

The difference in the risk ratio for tooth loss with the "best" initial prognosis for each system was then analysed and no differences in tooth loss prediction were detected among the systems. In terms of the "second best" initial prognostic category, differences were noted when comparing both Nibali et al. (2017) and McGuire and Nunn (1996) with both Kwok and Caton (2007) and Graetz et al. (2011), due to the lack of the "fair" category in Kwok and Caton's and Graetz's systems (Supplemental Material 5). For the "second worst" prognostic category, categories "poor" and "questionable" for McGuire and Nunn (1996) were merged because these multiple stratifications could be redundant due to their high tendencies to change to other categories (Kwok & Caton, 2007). This merged initial prognosis was then compared with Kwok and Caton's "unfavourable" category, and no difference was found (Supplemental Material 5). When the worst prognosis of each system was compared, no differences were detected in the ability to predict tooth loss.

Categories "fair" and "questionable" from Nibali et al. (2017) and "fair", "poor" and "questionable" from McGuire and Nunn (1996) were then merged, to create three categories only for all four prognostic systems. This resulted in non-statistically significant pairwise differences in the ability to predict tooth loss for all the systems, except for McGuire and Nunn's versus Kwok and Caton's intermediate category, with Kwok and Caton's category (consisting of "questionable" and "unfavourable") being more accurate at predicting tooth loss than McGuire's intermediate category (consisting of "fair", "poor" and "questionable").

All four systems revealed high values of specificity (>99%) and negative predictive value (>98%) for the "tooth loss" outcome (Table 5). However, sensitivity (ranging between 3.2% and 12.9% using the four systems) was low, as was the positive predictive value (ranging between 13.6% and 33.3%).

## 4 | DISCUSSION

This study investigated how different tooth prognostic systems predicted the likelihood of survival of periodontally involved teeth. The main findings are that all tested tooth prognostic systems (McGuire & Nunn, 1996; Kwok & Caton, 2007; Graetz et al., 2011; Nibali et al., 2017) were very reproducible and were able to differentiate between teeth at low and high risk of tooth loss, suggesting their usefulness as clinical prognostic tools. Examiner experience did not hinder the reliability of the systems, as undergraduate dental students were able to utilize the systems to assign prognosis in a reproducible manner. A total of 18%, 25%, 33% and 14% respectively of teeth assigned to the "worst" prognostic category of each system were lost, compared with around or less than 1% of teeth in the "best" category. The risk of tooth loss for teeth in the worst prognostic category was 14–77 times higher than teeth in the best prognostic category, by using the different prognostic systems, confirming the ability of these systems to identify high-risk teeth. However, it is important to emphasize that low sensitivity and positive predictive value were detected for all four systems. In other words, the systems were not able to predictably indicate if a tooth would be lost, as the majority of "hopeless" teeth were still retained. Limited sensitivity for tooth loss predictive models has consistently been previously observed, in line with the low number of teeth lost during regular SPC (Martinez-Canut & Llobell, 2018; Krois et al., 2019). It has been argued that in populations with limited expected tooth loss, models with high specificity should be preferred, to err on the side of caution and not extract teeth that could be retained (Schwendicke et al., 2018). The Kwok and Caton system performed the best in terms of odds ratio of tooth loss, while the Graetz et al. (2011) performed the worst. However, due to the reduced power of the study and the large CIs in these analyses, they need to be interpreted with caution.

Further analyses were conducted to clarify the usefulness of the various prognostic categories in predicting tooth loss. It emerged that categories "fair" and "poor" from McGuire and Nunn (1996) prognostic system had similar tooth loss rates over 5 years. Therefore, merging these two categories should be considered. Furthermore, the definition of "poor" for McGuire and Nunn should be modified as the wording may be "unfortunate", because it is actually associated with minimal tooth loss risk (0.5%) at 5 years. The analysis revealed that four categories (with the addition of "fair" not present in Kwok & Caton, 2007 and Graetz et al., 2011) may be more appropriate to stratify the predictability of tooth loss, due to its increased association (with tooth loss) compared with the other neighbouring categories. When considering only three categories for all the systems (merging intermediate category for systems with two categories), Kwok and Caton's system showed better tooth loss predictability than McGuire and Nunn's system. However, all the other comparisons did not reach statistical significance, representing a similar predictability among almost all the systems when only three categories were used. Practical considerations also need to be made, as more complex systems with more categories may be less user-friendly and more time-consuming (Krois et al., 2019). Therefore, while comparisons between relatively complex "prediction models" for tooth loss have previously been published (Schwendicke et al., 2018), the present paper focused on simple prognostic systems that could be used chair-side. A recent study showed that studied prognostic systems generally exhibited good predictive capability for periodontal-associated tooth loss (Saleh et al., 2021). However, some of the systems tested were quite complex and time-consuming.

Factors such as FI (Nibali et al., 2016), residual pocket depths and bleeding on probing (Claffey & Egelberg, 1995; Matuliene et al., 2008), bone loss and use of the tooth as abutment (Pretzl et al., 2008) have clearly been associated with tooth loss. Previous papers had assessed the value of individual prognostic systems in predicting tooth loss. For example, the system proposed by McGuire and Nunn and trialled in a longitudinal study (McGuire & Nunn, 1996) includes CAL, FI, mobility, crown-to-root ratio and initial root form to assign prognosis. Kwok and Caton's system was developed to improve accuracy as it considered systemic factors, such as diabetes mellitus, and local factors including PPD, FI, crowding, mobility and bone loss (Kwok & Caton, 2007). Graetz et al. (2011) used a simple system that aimed to predict survival rates of teeth in patients with aggressive periodontitis and chronic periodontitis based solely on bone loss. This system used only two categories: questionable and hopeless, while all other teeth were considered "good". The system proposed by Nibali et al. (2017) includes bone loss, PPD, FI, mobility, periapical pathology (Ørstavik et al., 1986) and restorability (Esteves et al., 2011) and reflects a treatment philosophy aimed at tooth retention. This system had previously been associated with tooth loss in a retrospective study during SPC.

Assigning tooth prognosis is essential when treatment planning for patients with periodontal disease. Identifying teeth with poor or hopeless prognosis and being able to provide patients with an estimate of chances of survival could be extremely valuable for making treatment choices. Based on recent guidelines by the European Federation of Periodontology, it is crucial to distinguish between questionable and hopeless teeth, as early extraction of questionable teeth is discouraged, and only "hopeless" teeth should be extracted (Sanz et al., 2020). Using the prognostic systems to assign the prognosis can be a helpful tool to show patients what data collected from them are likely to influence their future periodontal conditions and how treatment decisions are rationalized. For example, this shows that teeth with the "worst" prognosis in each system had higher risk of being lost during 5 years of SPC compared with the benchmark of teeth with the "best" prognosis. This needs to be interpreted in light of the fact that very few teeth with "hopeless" or "unfavourable" prognosis were still present in this patient group at the beginning of SPC. The findings of this study may also suggest changing the term "questionable", because only a small proportion of these teeth were lost over 5 years, and certainly dropping the term "poor" used in McGuire and Nunn (1996) and associated with minimal tooth loss risk in this population. As the aim of periodontal therapy is to stop the attachment loss caused by inflammation, the possibility of moving teeth from one prognostic category to another during follow-up, according to changes in periodontal and restorative status (for example, attachment/bone gain or reduced mobility or FI), should also be considered. In this context, it is important to realize that patient factors may also vary during maintenance (e.g., changes in stress levels, motivation or in diabetes control), which could have an unexpected impact on the original prognosis.

The reason for tooth extraction is very important when assessing studies that evaluate the risk of tooth loss. In this respect, this was a very controlled group of patients regularly attending SPC, where tooth loss was not determined by dentists' restorative choices, but mainly guided by worsening in periodontal or endodontic conditions or tooth fracture. In fact, it is very interesting to notice that only 9 of 31 of extracted teeth were lost for periodontal reasons, emphasizing the importance of a 360° look at the conditions of teeth, including restorability, endodontic status (Petersson et al., 2016) and risk of fractures. For example, of 14 extracted teeth initially judged to have "good" or "fair" prognosis by McGuire and Nunn (1996), only 1 was extracted for periodontal reasons, while others were lost for fractures ($n = 6$), crowding/orthodontic reasons ($n = 5$) and caries ($n = 2$). Furthermore, relying on tooth data alone in these prognostic systems is not enough to provide optimal patient care, as patient factors are also very important, and a questionable tooth in the mouth of a "good prognosis" and very motivated patient (Donos et al., 2021) can have a better prognosis than in the mouth of a non-compliant patient with other risk factors (Eickholz et al., 2008; Morelli et al., 2017). Other studies have also tried to combine patient factors such as smoking and bruxism with tooth factors (Martinez-Canut & Llobell, 2018) or to use the staging and grading classification in order to predict tooth loss (Ravidà et al., 2019). The present study also shows that tooth assignment to a prognostic system was reproducible as the ICC was >0.8, for both intra- and inter-examiner reproducibility, despite the fact that three relatively inexperienced undergraduate students carried out the assessment.

The strength of this paper is the comparison of different but relatively simple prognostic systems, with the aim to provide an insight as to whether these prognostic systems are capable of assigning reproducible and accurate prognosis, which can indicate the likelihood of tooth loss. Furthermore, all patients over the 5-year period were assessed and treated by the same periodontist in a controlled environment of private practice. In contrast with previous comparisons (Schwendicke et al., 2018), a prospective sample was utilized. Only compliant patients who did not miss follow-up appointments were included in this analysis (just short of half of the initial sample), in order to reduce the potential effect of non-compliance on tooth loss. A limitation is that this reduces applicability to populations including patients not adhering to the proposed SPC. Furthermore, it should be noted that most included patients had already been on SPC for some time before the study baseline. Another limitation may be represented by the relatively small number of teeth lost during SPC, reducing statistical power, in addition to the fact that no specific sample size calculation was carried out for this analysis of prognostic systems.

In conclusion, this study shows that the investigated prognostic systems can be reliably used to identify teeth at higher risk of being lost in patients undergoing SPC, also when used by inexperienced dental students. Although the ability to correctly identify teeth that would not be lost was high, all systems could not predict well which of the "hopeless" teeth would actually be lost over 5 years (low sensitivity and positive predictive value). Prognostic systems may help to manage patient expectations, save time for both clinicians and patients and limit the financial implications of complex periodontal disease. The use of a system with four categories ("good", "fair", "questionable" and "unfavourable/hopeless") seems advisable. More research on a larger cohort of patients is warranted to confirm these findings and increase generalizability. The implementation of even more accurate yet simple systems, which incorporate patient and tooth factors (not just periodontal) (Martinez-Canut & Llobell, 2018), could be a welcome future development. In fact, the good performance of a simple system consisting of solely "bone loss" (Graetz et al., 2011) would support the development of less complicated prognostic systems. The use of artificial intelligence, which is being trialled in periodontology, may be a helpful tool for the development of more accurate tooth prognosis.

## AUTHOR CONTRIBUTIONS

Luigi Nibali conceived the study, co-drafted the protocol, carried out the clinical visits and interpreted the results. Selai Saydzai, Zoe Buontempo, Pankti Patel, Chuanming Sun, Fatemah Hasan and Aliye Akcalı performed prognosis, clinical and radiographic data acquisition. Selai Saydzai, Zoe Buontempo and Pankti Patel co-drafted the manuscript. Guo-Hao Lin performed the statistical analysis. Nikos Donos co-drafted the protocol. All authors revised the paper drafts and approved the final version of the manuscript.

## FUNDING INFORMATION

This study received funding from the King's Undergraduate Research Fellowship, King's College London, England.

## CONFLICT OF INTEREST

The authors have stated explicitly that there are no conflicts of interest in connection with this article.

## DATA AVAILABILITY STATEMENT

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

## ETHICS STATEMENT

Ethics opinion was sought from the London City & East NHS Research Ethics Committee, which gave a favourable opinion for the analysis to be carried out as service evaluation (reference 14 LO 0629). Each patient gave written consent to be included in this study.

## ORCID

*Aliye Akcalı* https://orcid.org/0000-0001-9811-0627
*Guo-Hao Lin* https://orcid.org/0000-0003-1290-9994
*Luigi Nibali* https://orcid.org/0000-0002-7750-5010

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## SUPPORTING INFORMATION

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**How to cite this article:** Saydzai, S., Buontempo, Z., Patel, P., Hasan, F., Sun, C., Akcalı, A., Lin, G.-H., Donos, N., & Nibali, L. (2022). Comparison of the efficacy of periodontal prognostic systems in predicting tooth loss. *Journal of Clinical Periodontology*, *49*(8), 740–748. https://doi.org/10.1111/jcpe.13672