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ORIGINAL ARTICLE

Development of an artificial intelligence platform to improve compliance in periodontal maintenance patients: A proof-of-concept study

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Abstract

Background: The purpose of this study is to report on the development of an artificial intelligence (AI) model designed to improve compliance in periodontal maintenance patients.

Methods: Fifty adult patients (32 females and 18 males; aged 25 to 78 years) with diagnosis and treatment of Generalized or Localized Periodontitis stages I, II, or III; grades A–C who were following a 3-month periodontal maintenance interval were provided an AI-based smartphone application (app) that provided personalized educational, motivational, and risk-awareness information every week between maintenance visits. Recession (REC), probing pocket depth (PPD), clinical attachment level (CAL), plaque index (PI), bleeding on probing (BOP), and gingival index (GI) captured at each maintenance visit out to 6 months were compared with baseline. In-office interviews were conducted to assess subjective data points, and cognitive interviews were conducted to validate patient-reported outcomes (PRO).

Results: REC, PPD, and CAL remained stable through all timepoints. PI, BOP, and GI demonstrated significant improvement compared with baseline ($p < 0.01$). PRO were validated and revealed that most subjects found the app to be easy to use, desired more interaction, perceived it as educational by raising their awareness of their oral hygiene, and would recommend the use of the app to a friend.

Conclusions: An AI-based smartphone application was trained on a private practice maintenance population of three periodontists. The subjects demonstrated improvements in PI, BOP, and GI with no changes in REC, PPD, or CAL. Patients found the app to be educational and beneficial by improving their understanding of their periodontal disease risk.

KEYWORDS
artificial intelligence, patient compliance, periodontal maintenance, periodontitis

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Plain language summary

An artificial intelligence model (AI) was developed to improve periodontal maintenance compliance. Compliance with periodontal maintenance in patients decreases dramatically after 1 year. This is a proof-of-concept study using an AI-based smartphone application (app) that communicates individualized periodontal disease risk awareness messages that were educational and motivational to effect a behavioral change in hopes of improving compliance. Measurements of disease stability/instability, such as gum inflammation, bleeding, bone loss, and assessment of brushing effectiveness, were captured at baseline and at subsequent office visits every 3 months for a total of 6 months. Subjective patient information was captured via in-office interviews to supplement clinical data and provide the AI model with multimodal data points. Patient-reported outcome surveys were developed via cognitive interviews. Results showed improvements in brushing effectiveness, which translated to less gum bleeding and inflammation. Other clinical measurements of disease activity showed no change, which could translate to a lack of disease progression. Patient-reported outcome development revealed that most of the subjects found the interaction with the app to be positive and beneficial. This proof-of-concept study demonstrates a novel approach using an AI-based smartphone app to be worthy of further investigation on efficacy and possibly defines an objective measure of patient compliance.

1 | INTRODUCTION

Periodontal maintenance is provided to patients to prevent or minimize the recurrence of periodontitis and maintain stability of the periodontium via control of risk and biofilm. While a high level of patient compliance with periodontal maintenance is correlated with increased tooth survival, the level of compliance has been demonstrated to consistently decrease over time.[1] In addition, some studies have determined that compliance with periodontal maintenance alone is not necessarily the sole factor that ensures less loss of teeth.[2,3]

A 2015 consensus report of the 11th European Workshop on the principles in prevention of periodontal diseases made the following statement on improving oral health behaviors, "Oral health professionals need to identify and adopt effective techniques that help patients change oral health behavior, but there is consensus that, in general, oral health care providers lack a structured, proven approach to facilitate behavioral changes that improve plaque control."[4] To effect this change in a patient's oral health behavior, educational information should include assessments on the patient's perception of the following: consequences of not adhering to treatment recommendations (risk awareness), their own susceptibility to periodontal disease, their benefits of changes in oral health behaviors, and their effectiveness at providing self-care.[4] Currently, this education only takes place in the context of the patient's periodontal maintenance visit.

Artificial intelligence (AI) has been proposed as a tool to identify risk and inform clinicians on treatment for the dental patient. In the field of periodontics, AI is transforming the education of dental students with respect to diagnosis and classification of disease via instruction on proper clinical examination techniques, use of ultrasonographic periodontal probes, evaluation of radiographs, analyzing oral malodor, and prediction of periodontally compromised teeth.[5] To our knowledge, there is no existing study in the field of periodontics to assess the effect of communication on periodontal maintenance adherence and related risk management to improve patient compliance using an AI-based smartphone platform.

An AI platform was developed to objectively assess and quantify a patient's compliance level, followed by effectively and repeatedly communicating personalized oral health concepts to the subject outside of the routine periodontal maintenance appointment via a smartphone application (app[*]). Similar to smoking cessation support

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delivered via mobile phone text messaging,[6] AI-facilitated communication of a technical, behavioral, and educational nature with patients may achieve improved compliance with the instructions and recommendations provided by the patient's oral health care expert.

The purpose of this proof-of-concept study was to provide the AI model with a real-world training population based on multimodal data gathered from periodontal maintenance patients using the smartphone app for 6 months. Additional goals included: assessment of clinical measures from baseline to 6 months, training of a novel AI-determined compliance score compared with the subject's treating registered dental hygienist (RDH) assessment of compliance, identification of input variables the AI utilized to assess compliance, and evaluation of the study design in anticipation of future investigations on clinical efficacy.

2 | MATERIALS AND METHODS

The study, initiated in September 2021, was designated a prospective, multicenter, single-masked (examiners), controlled clinical trial of 6 months duration. The study protocol was reviewed and approved by Sterling Institutional Review Board (IRB) protocol number: 9180 and registered at ClinicalTrials.gov under ID NCT05068778. The study complied with the guidelines of the Helsinki Declaration of 1975, as revised in 2013. Written informed consent was obtained from each subject.

The study population consisted of 50 patients from the private practices of three periodontists (T.M., M.M., and E.S.) at two locations in the continental United States. The inclusion criteria were: (1) Adult subjects aged 19 to 78 years; (2) Diagnosis and treatment of Generalized and/or Localized Periodontitis stages I, II, or III; grades A–C[7] who were following a periodontal maintenance interval of every 3 months; (3) Subjects are able to provide self-care (OH) without disabilities requiring assistance; (4) Subjects were required to read, understand and sign an IRB approved Informed Consent Form (ICF); (5) Subjects were able and willing to follow study procedures and instructions.

The exclusion criteria were: (1) Subjects who did not own or were incapable of interacting with a smart phone or device; (2) Subjects incapable of operating an application on a smart phone or device; (3) Subjects who required active periodontal therapy during the study; (4) Subjects on immunosuppressive medications, chemotherapy, or radiation therapy which would adversely affect their periodontal stability; (5) Subjects participating in other clinical studies involving therapeutic intervention (either medical or dental).

The inclusion of 50 subjects was planned to provide an adequate data set for the initial training of the AI model from objective, subjective, and inference sources captured at baseline and each subsequent 3-month maintenance visit for a total of 6 months.

2.1 | Description and function of AI model

In this proof-of-concept study, the AI model was trained via a process considered case-based learning, and is best described as an entropy-based AI algorithm.[8] This AI model is widely used in the automobile industry, known as a "Connected Car[†]".

Briefly, the algorithm is based on J. Ross Quinlan's ID3 as the basic logic for generating decision trees in combination with C.E. Shannon's mathematical theory of communication.[9,10] The incorporation of Shannon's entropy formula facilitates the measurement of the amount of information included in a message. According to Ali et al., "Entropy, the measure of information in information theory…can expose challenges in information technology, notably in information transmission, assuring the proper transfer of information in the quickest method, and making judgements in data storage and artificial learning with fewer bits. It helps produce trees."[8]

It should be noted that it is a type of "data mining tool" that uses several statistical methods centered on ID3 to determine the amount of information that makes up the acquired cases and generates decision trees (i.e., rule trees). The requirements for implementing a case learning agent are that it automatically generates rules. Thus, AI engineers enhanced the function of the algorithm to output numerical conclusions for the purposes of this study. Furthermore, they implemented safety measures to avoid generating erroneous rules by automatic example learning.

The function of the AI model was enhanced to generate rules via the entropy method as independently executable agent programs. Thus, this case-based learning AI used for the app can generate consulting agents that observe a list of dynamically linked rules and continue to repeat local evaluations using their own rules (executable rules).

The concept of the AI's interaction with the subjects through the app is the AI operating as an extension of their treating RDH outside the context of routine maintenance visits via personalized weekly contact and interactions. Each contact event was intended to fulfill the necessary education of each subject on a variety of topics based on changes in risks, clinical findings, or personal stressors that may further inhibit the subject's compliance. Figure 1

[†] Toyota Inc., Nagoya, Japan.

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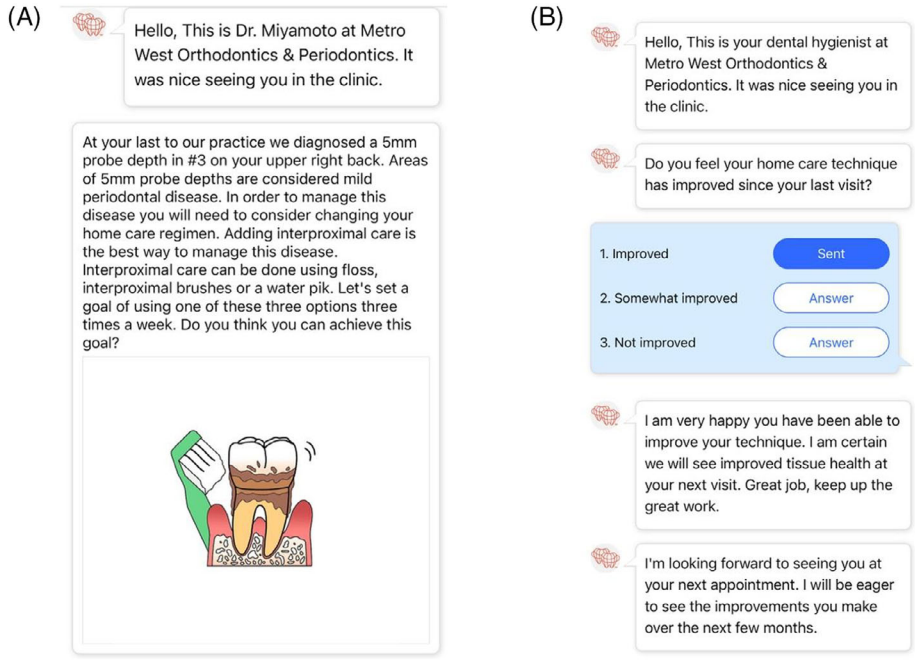

FIGURE 1 Example screenshots of the AI-based smartphone application: (A) A follow-up message after the subject was seen for periodontal maintenance care, which emphasizes an area at risk. Additional educational information is provided on methods that can be used at home by the subject to improve their disease management. (B) A survey was sent prior to the subject's next maintenance visit, inquiring about the subject's perception of their home care technique. Subsequent responses of encouragement and reinforcement are seen below the patient's response to the survey.

demonstrates examples of the app interaction with subjects. The type of message sent was determined by the AI based on multimodal data on the subject to improve their compliance score.

2.2 | Objective data points

Objective data were acquired from the subject's medical, dental, and social history at each visit. Medical diagnoses resulting in conditions and medications that affected the current oral health diagnosis, such as diabetes mellitus, autoimmune disorders, and other systemic diseases known to affect oral health, were captured. The following clinical parameters were assessed by single-masked, calibrated examiners for each study center using a UNC-15 periodontal probe[‡]: probing pocket depth (PPD), gingival recession (REC), clinical attachment level (CAL), modified gingival index (MGI), plaque index (PI),[11] bleeding on probing (BOP), furcation grade (FG), and mobility (MOB).[12] Following a comprehensive periodontal examination, subjects were classified according to the Joint Periodontal staging and grading system by the American Academy of Periodontology's and the European Federation of Periodontology's.[7] Dental diagnoses such as periodontitis and trauma from occlusion were captured. Social history reported by subjects included tobacco or equivalent use, with the amount used per day. Table 1 details the data point categories captured on each subject.

2.3 | Subjective data points

Subjective data were acquired via an in-office interview conducted by the subject's treating RDH on their perceptions, emotions, and value of oral health, and the potential influence each category may have on their compliance. Table S1 in the online *Journal of Periodontology* details the RDH interview questions and quantification of subject responses. Additional subjective data on the subject's perception of their oral health, their understanding of periodontitis, their home care technique, the techniques improvement level, and the impact of home care on their disease was captured via the AI's communication with the subject via the app prior to their next periodontal maintenance appointment. The app would then send corresponding messages relative to the subject's answers that were designed to be affirming for positive answers, encouraging for neutral answers, or informative for subjects who indicated little change or knowledge had been gained since their last visit. Table 2 illustrates the messages sent

[‡] PCPUNC15, Hu-Friedy Mfg. Co., LLC, Chicago, IL, USA.

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TABLE 1 Data points uploaded to AI portal.

Subject Interview data
• Demographics
• Medical history
• Dental history
• Oral health practices
• Medications
• Smoking status
• Smoking rate and type
• Work-related stress assessment
• Family-related stress assessment
• Catastrophic health event
• Accident resulting in physical injury
• Periodontal inflammation (gingival bleeding)
• Tooth sensitivity
• HbA1c / Diabetic control perception
• Dental fear
• Level of dental pain / discomfort
• Financial value of oral health
• Time available for oral hygiene
• Confidence in treatment
• Motivation to seek dental care and provide self-care
• Compliance with dentist's or hygienist's recommendations
• Ai Subject Interview prior to maintenance appointment
Treating Hygienist Assessments (Intuitive)
• Plaque index changes compared with prior visit
• Bleeding on probing changes compared with prior visit
• Proposed treatment
• Greatest area of concern in mouth
• Dental hygienist patient survey
• Changes in patient interview from prior visit
Masked-Examiner Assessments
• Oral examination findings
• Periodontal staging and grading
• Peri-implantitis diagnosis
• Probing depths
• Recession
• Clinical attachment levels
• Gingival index
• Plaque index
• Mobility scores
• Suppuration
• Relative bone loss
• Radiographic bone loss

Note: Table of objective, subjective, and inference data points collected at baseline and subsequent visits, which were uploaded to the AI portal for each subject.

to each subject, the response options offered, and the corresponding AI-determined replies.

2.4 | Inference data points and conceptualization of the compliance score

One feature of the AI model is to assign a novel compliance score via the decision tree method in combination with entropy-based convergence analysis of multimodal data inputs. Therefore to train the AI on a dental care provider's assessment of a subject's compliance level, the subject's compliance level was determined by the treating RDH at each visit using their own intuitive assessment of compliance per Wilson et al, 1984.[13] Each category of compliance per Wilson et al. was then quantified using a numerical score range by the RDH as follows: Noncompliant: 0–33; Erratically compliant: 34–66; and Compliant: 67–100. The clinician's assignment of a compliance score in combination with the multi-modal data analysis was used to train the AI on quantifying a subject's compliance level. Training was accomplished using data captured at the baseline, 3-, and 6-month visits.

2.5 | Data upload to AI portal

All captured data were deidentified and uploaded to the AI database via a secure cloud-based portal at each visit. Subjects were tracked by the AI using a unique ID.

2.6 | Treatment modalities

Subjects received periodontal maintenance care from their treating RDH every 3 months starting at baseline, with the final visit at 6 months for a total of three treatment visits. A comprehensive periodontal evaluation was accomplished at each visit, and the subjects were informed about areas at risk for future loss of attachment and areas in their mouth requiring better oral hygiene.

2.7 | Subject training on use of smartphone app

After the baseline maintenance visit, subjects were trained on installation and use of the app. They were provided a unique identifier number as their user ID, which correlated with the subject's ID number for AI tracking purposes in the portal.

2.8 | Patient-reported outcomes (PROs) development

Cognitive interviews were conducted with patients after visits two and three to develop validated patient-reported outcomes (PROs) for future investigations. These interviews were conducted by a third-party examiner not associated with their dental therapy. The intention of the PROs was to assess the subject's perception of the app design,

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TABLE 2 AI subject survey and responses.

Message to app user	App user answer options			AI reply options		
	Positive	Neutral	No improvement/change	Affirming	Neutral	No improvement/change
Do you feel your home care technique has improved since your last visit?	Improved	Somewhat improved	Not improved	I am very happy you have been able to improve your technique. I am certain we will see improved tissue health at your next visit. Great job, keep up the great work.	Changing a habit we have had for many years can be difficult. Keep working at it, and if you still have questions at your next visit to office, I am happy to keep working with you. Don't give up, you can do it.	Don't give up, you can do this. Remember, a thorough job is important to prevent missing spots that are hard to get. Keep working at it, and I will review your home care technique at your next visit to our office. See you soon!
Do you think your home care routine has improved since your last visit?	Improved	Somewhat improved	Not improved	This is great news! I am so glad that you have been able to be more consistent with your home care. I know we will see a big improvement at your next visit to our office.	Creating a new habit is always hard. If you keep working hard and keep setting goals to improve your home care, we will see improved periodontal pockets as well as tissue inflammation. Keep working hard to find the right routine that works for you!	It is so hard to have a good home care routine when you have not established a consistent habit. Just continue to work to find the right routine that works for you. Remember, brushing and interproximal cleaning do not have to be done just morning or at night. As long as bacteria are disrupted at least once daily, we will see an improved result in your oral health.
Do you feel you have a better understanding of your disease?	Better understanding	Same understanding		It is so important to understand periodontal disease and how it impacts your oral health. I am glad that you have a better understanding of what is going on so that you can work to keep your gums and teeth healthy! Remember, I am always here if you have any questions.	Understanding your disease can empower you to take responsibility in your oral health. My goal is to always provide you with the education you need to make all the informed decisions you need to accept the proper treatment needed to improve your oral health!	
How much impact do you feel home care has on your disease?	Has an impact	Has somewhat of an impact	Has very little impact	I am very happy that you understand the importance of oral health. Bacteria that are associated with periodontal disease need to be removed from the teeth daily to keep your periodontal disease stable. Keep up the good work!	As your oral health coach, my ability to help you manage your disease is limited on managing your disease since I am only seeing you once every 3–6 months. We need to work as a team to have a true impact on your oral health. I know that it is hard to create consistent home care routines, but I know you can do it!	Home care is the key to the success of managing your periodontal disease. Sometimes finding the time can be difficult. However, it is the key to managing your disease. I am happy to help come up with some ideas that are flexible and easy to implement, so it is easier for you to be consistent with your homecare!

Note: SUBJECTIVE data on the subject's perception of their oral health, their understanding of periodontitis, their home care technique, the techniques improvement level, and the impact of home care on their disease were captured via the AI's communication with the subject via the app prior to their next periodontal maintenance appointment. The app would respond to the subjects with messages relative to their answers. The responses from AI were sent from the perspective of the treating hygienist and were designed to be affirming for positive answers, encouraging for neutral answers, or informative for subjects who indicated little change or knowledge had been gained since their last visit.

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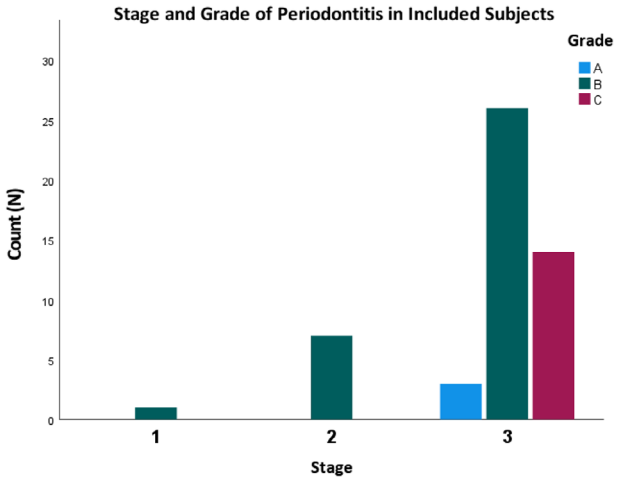

FIGURE 2 Periodontitis case classifications of the included participants and baseline demographics of the included participants at both centers.

their experiences using the app, and their perception of their oral health relative to use of the app.

3 | CLINICAL DATA ASSESSMENT AND ANALYSIS

The de-identified patient data from both centers (demographic, clinical, PROs, exam, etc.) were organized in a spreadsheet. Descriptive analyses were used to assess the overall collected data via means and standard deviations (SDs). Plots were used to visualize the clinical data and outcomes of the study. PROs were also assessed descriptively, per patient, to learn about the interaction with the app.

To assess the longitudinal change in the clinical measurements (PD, REC, CAL, GI, PI, mobility) throughout the study (from baseline, 3-, and 6-month), generalized mixed-regression models were used, which also accounted for the compliance assessment of the participants. This was done to model the trajectory of each clinical measure throughout the study time points.

Model estimates with their 95% confidence intervals were recorded, and a *p*-value of 0.05 was set for statistical significance. All analyses were performed in Rstudio[§] by a separate investigator who was not part of the clinical assessments or data gathering (S.B.).

4 | RESULTS

Figure 2 describes the demographic information and periodontal condition/diagnosis of the included participants at baseline. A total of 50 patients (25 in each center) were included and followed for 6 months. The average age of the cohort was 59.9 ± 12.3 years (58.46 ± 10, vs. 61.4 ± 14.4, $p > 0.05$). As for prior periodontal procedures (surgical or nonsurgical) reported by participants, there was one patient who reported no prior periodontal procedures. The remaining number of patients by the number of past periodontal procedures (PPP) was as follows: 37 patients had 1–3 PPP; 9 patients had 4–6 PPP, and 3 patients had 7 or more PPP.

Among the baseline characteristics between the two centers, the only statistically significant differences were with regard to sex (higher number of females in Center 1), smoking status (higher number of smokers in Center 2), and weight (higher average weight in Center 1). All other factors were similar between the groups.

The majority of the patients were categorized as stage 3, grade B periodontitis. Additional information regarding each stage and grade, per center, can also be found in Table S2 in the online *Journal of Periodontology*.

4.1 | Assessment of clinical outcomes throughout the study

Figure 3 shows the evaluated clinical measures at each time interval. Table 3 presents the results of the mixed models for the investigated outcomes. Overall, CAL showed to be sustained without change among the participants and in the intervals. Aside from a slight (approximately 0.2 mm) decrease in 3 months, PPD was also qualitatively unchanged, and REC also showed to be stable overtime. However, GI, PI, and BOP all showed consistent statistically significant reductions, both in the 3- and 6-month time points.

4.2 | Training of AI-determined compliance scores

AI-determined compliance scores were expressed as a range at each visit to allow for training of the model. As demonstrated in Figure S1 in the online *Journal of Periodontology*, patient datapoints were weighted by the algorithm to arrive at a compliance score range. RDH-determined compliance scores were used as a reference value to train the model's selection of datapoints and score assignment. AI-determined compliance scores were noted to align with the RDH-determined compliance scores by 92% at the 6-month timepoint, indicating adequate training of the model.

[§] Rstudio Version 2023.12.1+402, Rstudio, Inc., Boston, MA, USA.

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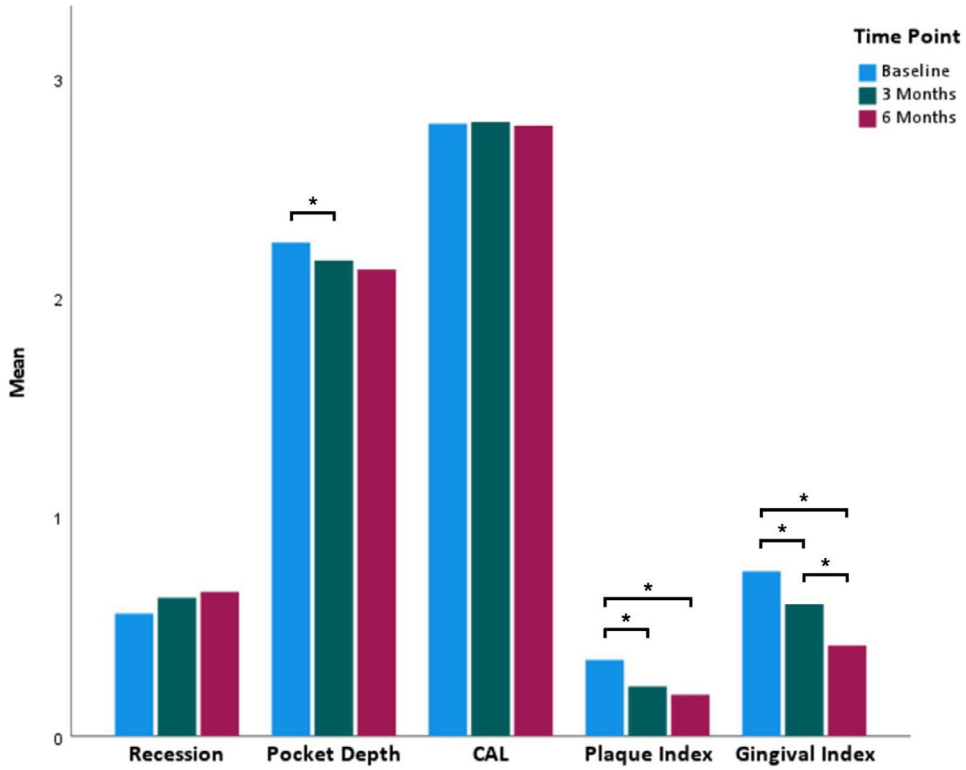

FIGURE 3 The changes in the investigated outcome variables between the different time points of the study. Statistically significant changes, as per the mixed model, are presented with lines and asterisk.

TABLE 3 Results of the mixed models investigating the change in the clinical measures throughout the study time points.

Outcome	Variable	Estimate	Std. error	95% CI lower	95% CI upper	*p* value
CAL	Intercept	3.364	0.535	2.315	4.414	<0.01
	3 months	0.018	0.018	−0.017	0.053	0.312
	6 months	−0.014	0.018	−0.05	0.021	0.431
PPD	Intercept	2.8592	0.1328	2.5985	3.1191	<0.01
	3 months	−0.2434	0.1282	−1.8990	0.0576	**0.0078**
	6 months	0.0158	0.4505	0.0350	0.9719	0.8983
GI	Intercept	0.676	0.285	0.116	1.235	0.018
	3 months	−0.134	0.023	−0.18	−0.089	**<0.01**
	6 months	−0.325	0.023	−0.37	−0.279	**<0.01**
PI	Intercept	0.451	0.122	0.211	0.69	<0.01
	3 months	−0.154	0.007	−0.167	−0.14	**<0.01**
	6 months	−0.205	0.007	−0.219	−0.191	**<0.01**
BOP	Intercept	0.201	0.157	0.256	0.201	<0.01
	3 months	0.654	0.598	0.715	0.654	**<0.01**
	6 months	0.47	0.426	0.518	0.47	**<0.01**
REC	Intercept	0.163	0.1407	−0.1118	0.4393	0.245
	3 months	0.0626	0.1458	−0.2235	0.3482	0.668
	6 months	0.0297	0.5094	−0.9690	1.0274	0.954

Abbreviations: BOP, bleeding on probing; CAL, clinical attachment level; CI, confidence interval; GI, gingival index; PI, plaque index; PPD, pocket probing depth; REC, recession; Std. Error, standard error.

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5 | DISCUSSION

The results of this proof-of-concept study demonstrate the use of a novel application of an AI-based smartphone application to improve compliance with periodontal maintenance therapy. While a limitation of the study is that subjects were recruited from an existing maintenance pool who were considered compliant "complete compliers" based on Wilson's classification with their recall intervals, the clinical findings demonstrate improvements in PI, BOP, and GI from baseline to subsequent assessments until the study concluded. This analysis of clinical measures allowed for assessment of the study design in anticipation of future studies on efficacy. In addition, the development of PROs identified that subjects found the app to be easy to use, desired more interaction, perceived it as educational by raising their awareness of their oral hygiene, and all would recommend the use of the app to a friend.

Individualized periodontal risk communication (PRC) has been shown to be an effective behavioral intervention.[14] The most frequently reported reason by patients for non-compliance is inadequate information/motivation.[1] Given this reason for non-compliance, it is not surprising that studies found the communication of individualized PRC with awareness of the benefits of behavior change to be an effective method.[15,16] The AI model and associated app were developed to supplement the PRC provided in the office by the patient's dental care provider by creating the perception of a line of communication with their care provider throughout their time away from the dental office.

The issue of patient compliance is not a unique feature of periodontal disease. Besides other diseases dependent on compliance in dentistry, therapeutic compliance challenges with chronic systemic diseases are documented throughout the literature. Compliance rates amongst chronic diseases such as bronchial asthma, hypertension, type 2 diabetes, and cancer range from 49%–65%.[17] Compliance beyond prescribed therapy, that is, medications, extends to diet, exercise, and lifestyle changes.[17] Mobile health applications (mHealth) have been used effectively to collect dynamic health-related data, deliver intervention content in the patient's natural environment, and tailor interventions in real-time.[18] The majority have been studied on adherence to medication via SMS text phone communication in patients with asthma, diabetes, infectious disease, psoriasis, organ transplants, and hypertension.[19] Even with the limitations of SMS text communication, improvements in medication adherence were demonstrated in patients receiving information relative to their disease management and pharmacotherapy.[19] The use of AI-assisted smartphone mHealth platforms is being deployed in similar chronic diseases with the goal of improving adherence, informing, motivating, reminding, preventing, building a care network, and entertaining.[20] Therefore, this study's AI model may be adaptable to a multitude of diseases that require behavioral changes to achieve better therapeutic outcomes.

Limitations of the current study are inherent due to this being a proof-of-concept design intended to train an AI model on real-world data. Therefore, there is no control arm, which necessitates caution in drawing conclusions about the findings reported herein.

The challenge of maintenance care as part of disease management, being professionally administered and separated by several months between visits, supports conducting further studies using this AI model. The authors suggest that a randomized clinical trial using a crossover design on subjects with a variety of compliance levels could assess the efficacy and role this intervention could serve in periodontal therapy. Long-term studies would also be informative on changes in clinical measures, use of the app, and assessment of behavioral modifications. As ethics in AI models require validation and further training, the model should be expanded to include a more diverse population of periodontal patients to ensure that there is not an underrepresented segment of patients.

The novel AI-assigned compliance score was found to align with the subject's treating RDH at a minimum of 92% following training of the model. The AI-determined compliance score assignment was found to be most influenced by work / family-related stress, tobacco use, toothbrushing / flossing frequency, BOP, bone loss presence/extent, and the number of remaining teeth. Interestingly, the factors influencing score assignment were found to be dynamic between time points, with stress, examination findings, disease severity, AI-subject survey results, and RDH subject survey results found to have the greatest influence on a subject's compliance at 3 and 6 months. Compared to baseline, an increase in relative influence was observed in these factors as they changed by 40%. Smoking frequency was initially found to have a high degree of influence on compliance at baseline but was subsequently found to have no influence at 3 and 6 months (see Figure S1). While it is currently in development, further training and validation may find this compliance score to be an objective, reproducible, and accurate method of assessing a patient's level of compliance as well as the factors influencing an individual's ability to comply with treatment recommendations.

Many possibilities for future applications deploying this method of improving patient compliance can be envisioned. The use of mobile devices with this unique AI model might (1) provide real-time monitoring of patient behavior, (2) calculate an objective compliance score, and (3) assess a patient's individualized periodontal risk that may confer protection against specific diseases. Impor-

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tantly, it might create a real opportunity for the healthcare provider to apply the concept of Precision Medicine, "prevention and treatment strategies that take individual variability into account" for their everyday practice.[21] Furthermore, such innovation could be dramatically improved by the recent development of large scale biologic databases, methods for characterizing patients, that is, genetic testing, and use of AI for analyzing large sets of data.

6 | CONCLUSIONS

An AI-based smartphone application was trained on a private practice maintenance population of three periodontists. The subjects demonstrated improvements in PI, BOP, and GI, and all subjects found the app to be educational and beneficial by improving their understanding of their periodontal disease risk. Further studies are needed to assess the efficacy and the role this intervention may have in periodontal therapy.

AUTHOR CONTRIBUTIONS

All authors have made substantial contributions to the concept and design of the study. Takanari Miyamoto, Michael McGuire, E. Todd Scheyer, and Becki Cole participated as clinical investigators in addition to data collection and interpretation, drafting, and revising of the manuscript. Shayan Barootchi participated as biostatistician in addition to assistance in drafting the manuscript and tables. Rick Heard developed the study protocol and served as study director in addition to drafting the manuscript. All authors have given final approval of the version to be published.

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CONFLICT OF INTEREST STATEMENT

Authors M.M., E.T.S., R.H., and S.B. report no conflicts of interest related to this study. T.M. owns stock in ASUA, Inc. B.C. received consulting fees for development of the hygienist-related content of the AI-assisted app.

DATA AVAILABILITY STATEMENT

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

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SUPPORTING INFORMATION

Additional supporting information can be found online in the Supporting Information section at the end of this article.

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