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Research Article

The assessment of rapid palatal expansion using a remote monitoring software

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ABSTRACT

Objective: Dental Monitoring (DM) is a software system that allows orthodontists to remotely monitor a patient's treatment. This study evaluated the accuracy of DM software in assessing the achievement of treatment goals in patients undergoing rapid palatal expansion treatment and patient acceptance of DM.
Methods: Consecutively treated patients undergoing rapid palatal expansion were invited to participate. Participants were trained to capture intraoral photos/videos using the DM app. Maxillary intermolar width (mm) and posterior crossbite correction measured by DM were compared with digital models and intraoral measurements. Patient acceptance of the DM app was evaluated with a survey.
Results: Of the 30 patients enrolled, 20 patients completed the study. DM accurately assessed the correction of posterior crossbite. There was no significant difference in intermolar width measurements obtained with DM, digital model, or intraoral examination. Overall, 71% of the participants found the DM app "easy" to work with and 43% of the patients preferred DM over a clinical visit.
Conclusion: In-person evaluation of maxillary expansion with a Hyrax expander can be replaced with remote monitoring using the DM software, yet challenges associated with digital imaging hinder the use of this remote evaluation for some patients.

1. Introduction

"Teledentistry" is a new era in dentistry that combines telecommunication technology and dental care [1]. Teledentistry involves the sharing of digital information such as photographs and radiographs between a patient and a provider through communication technology to provide dental care when distance separates the patient and the doctor [2]. Some of the potential advantages of teledentistry include increased access to oral care, better patient education, earlier diagnosis, increased collaboration among health care providers, advanced dental education, savings in travel time and costs, efficiency of treatment, and elimination of unnecessary patient visits [1–7].

One of the newest advancements of teledentistry in the field of orthodontics is remote treatment monitoring. With remote monitoring, the scheduling of in-office visits can be personalized for each patient, creating a more efficient workflow that can not only reduce chair time for the orthodontist but also increases patient convenience [8]. Dental Monitoring (DM) is one of the software systems that allows an orthodontist to monitor a patient's treatment progress from the start of treatment to the retention period [9].

DM, marketed as the "world's first connected orthodontics solution," is a French company started in 2015 for remote monitoring of orthodontic treatment [9]. The DM software system consists of three integrated platforms: a patient app, an analysis platform, and a Doctor Dashboard [9]. The DM patient app guides the patients through the capture of quality intraoral photos/videos and functions as a communication platform where they can receive messages and updates about their treatment. The photos/videos are automatically uploaded and sent to the DM analysis platform. These

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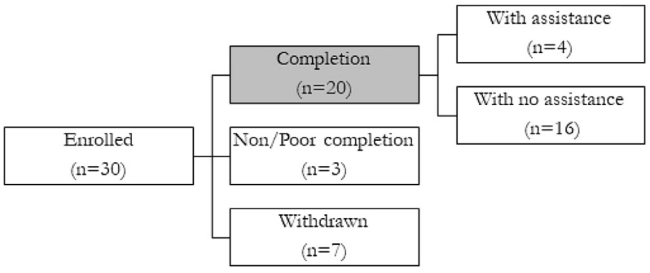

Fig. 1. Flow of participants in the study.

photos/videos are first pre-analyzed by specialists to detect any emergencies and if they are lacking in quality, the patient receives a message from the DM team with instructions to enhance the quality of the images [9]. The photos/videos are then processed, organized, and verified by human-assisted algorithms and are validated by the DM clinical team and qualified orthodontic specialists for several parameters, such as hygiene, appliance wear and tear, and tooth movements [9]. Enhanced images with a date-to-date comparison tool and tooth movement calculation from general intra-arch movements to single tooth analysis are published on the Doctor Dashboard within 48 to 72 hours, where the doctor can review and communicate with the patient as needed [9]. To monitor a patient using the DM software, an orthodontist provides DM with the patient's initial three-dimensional model in stereolithography and treatment objectives. The orthodontist also provides the patient with a cheek retractor, designed specifically for capturing photos or videos with the DM app. The DM examination can be taken either in a photo mode or video mode based on the compatibility of the patient's phone. The photo mode involves taking 10 to 13 photos and video mode involves taking three to four videos. Patients can take the DM examination by themselves in front of a mirror or with the help of someone. The DM app guides the patient through the process of capturing intraoral photos or videos, which are automatically uploaded to cloud-based servers [9].

One type of orthodontic treatment that requires close monitoring is rapid palatal expansion (RPE) using a palatal expander. In RPE, a rigid and fixed appliance, such as Hyrax expander, is used to produce heavy forces to obtain maximum orthopedic effect by opening the midpalatal suture with minimum dental movement [10]. After a rapid palatal expander is inserted, patients are asked to activate the appliance regularly. To avoid overactivation and to evaluate expansion progress, patients are reevaluated frequently, often weekly, until it is determined that adequate expansion has been obtained, after which the patient is instructed to terminate activation of the appliance. It is postulated that DM could be used to monitor the expansion progress remotely and could save patients several visits to the orthodontist and also may save the orthodontist valuable chair time.

However, to assess the accuracy of a remote monitoring software, such as DM, it is important to first establish the validity of digital models that will serve as the clinical reference in this study. A systematic review by Aragón et al. [11] showed that the intra- and inter-arch measurements from digital models acquired by an intraoral scanner to be as reliable and valid as the similar measurements achieved from dental models obtained through conventional intraoral impression. The American Board of Orthodontics (ABO) also has accepted digital models with universal digital formats of specific orientation and internal construction for pretreatment and interim models for the ABO clinical examination [12].

The objectives of this study were to evaluate the accuracy of DM software in assessing the achievement of treatment goals in patients undergoing RPE and patient acceptance associated with the use of the DM app.

2. Material and methods

The inclusion criteria for this study were being a patient seeking orthodontic treatment at University of Washington Orthodontics clinic with the following criteria: 1) in mixed or permanent dentition treated with a Hyrax palatal expander; 2) have a pretreatment digital model taken within 3 months before the start of RPE; 3) have a compatible smartphone or device to download the DM app; 4) be willing to participate in the research study. Approval to conduct the study was obtained from the Institutional Review Board (IRB) at University of Washington. Informed consent was obtained from legal guardians and adult subjects, and assent was obtained from minor subjects.

All patients undergoing treatment with a Hyrax palatal expander at University of Washington Orthodontics clinic between August 2017 and February 2019 were invited to participate in the study. The design of the Hyrax expander and the protocol for RPE (e.g., number of turns per day) were determined by the clinical faculty supervising treatment. The orthodontic provider (supervising faculty/graduate orthodontic student) specified and recorded the goal of RPE before the start of treatment as follows: how much expansion is desired (in mm), or what is the goal of the maxillary intermolar width (in mm) after expansion (measured from the highest point of contour of the mesio-lingual cusp of the maxillary first molars), and/or what clinical goal is hoped to be achieved (e.g., correction of bilateral posterior crossbite relationship, which is defined as achieving normal cusp fossa relationship).

After recruitment into the study, patients and/or parents were instructed to download the DM app and trained to capture intraoral photos/videos by the principal investigator (PI) at the delivery appointment of the Hyrax expander. The first set of intraoral photos/videos were captured on the same day by the patient or parent along with the PI. An intraoral scan with Itero Element was completed after the delivery of the Hyrax expander to obtain an initial digital model, and maxillary intermolar width (in mm) was measured intraorally with a digital caliper by the graduate orthodontic resident. Patients were instructed to capture intraoral photos every week and on the morning of the return appointment. These

Table 1
Demographics of the participants in the study

	Total (n = 30)		Completed (n = 20)		Noncompleted (n = 10)	
	n	%	n	%	n	%
Sex						
Male	14	47	10	50	4	40
Female	16	53	10	50	6	60
Age, y						
Mean (range)	11.5 (7–17)		11.8 (8–17)		10.9 (7–17)	
Median	11.0		11.5		10.5	

Table 2
Characteristics of the users of the Dental Monitoring (DM) app and expansion check visits

	Total (n = 30)		Completed (n = 20)		Noncompleted (n = 10)	
	n	%	n	%	n	%
Users of DM app						
Parent	24	80	16	80	8	80
Patient	5	17	3	15	2	20
Other (older sibling)	1	3	1	5	0	0
Expansion check visits						
Mean (range)	2.4 (1–7)		2.1 (1–5)		3.1 (1–7)	
Median	2		2		3	

weekly scans were requested not only to verify if the treatment objectives were achieved, but also to gather data on the individual tooth movement occurring during RPE. Patient return visits were scheduled as per the supervising faculty's instruction. When the patient returned to the clinic, the following were obtained during the intraoral clinical examination by the graduate orthodontic resident: achievement of the treatment goals (or not), correction of cross-bites (or not), maxillary intermolar width in millimeters (measured intraorally with a digital caliper), other (such as loose molar bands, broken appliance). If treatment goals were achieved, the patient was instructed to stop activation and an intraoral scan with the Itero Element was completed at the same appointment to obtain a final digital model. If the goals were not achieved, the patient was instructed to continue the expansion until a set number of turns or time as determined by the provider. The DM examinations continued, and the patient was instructed to return to the clinic for additional visits until the treatment goals were achieved. A single examiner (PI) measured maxillary intermolar width (in millimeters) on the initial and final digital models. A survey to evaluate patient acceptance of DM was completed by the user of the DM app (parent or patient) at the completion of RPE. All patients who completed the study were compensated with a gift card.

2.1. Statistical analyses

All statistical analyses were done using R 3.5.1 [13] and the *gee* [14] and longpower [15,16] packages. Intergroup (DM vs. intraoral exam and DM vs. digital model) linear association and mean differences were estimated using Generalized Estimating Equations (GEE) analysis with unstructured working correlation matrix to account for the correlation between repeated measurements in this study.

In the statistical analysis, the DM measurements were compared with intraoral measurements that occurred in the same week. Because digital model measurements were taken only at the beginning and end of data collection, the first and last DM measurements were compared with the first and last digital model measurements. A post hoc analysis was conducted to assess further differences among the groups.

3. Results

3.1. Participants

Figure 1 shows the flow of participants in the study. A total of 30 patients were enrolled in the study. Seven patients withdrew from the study for the following reasons: technical difficulty with phone camera (n = 1), parent being “too busy” (n = 1), or patients not wanting to continue participation for unspecified reasons (n = 5). Two participants did not take the weekly DM examinations throughout the study and one participant took poor-quality examinations that were rejected by DM software (parent was unavailable during expansion check appointment for additional assistance). A participant was determined to have “completed” the study if he or she had successfully captured (with or without assistance from PI) at least two DM examinations, one at the beginning and one at the end of RPE treatment. Therefore, the sample size of this study was 20.

Of the 20 participants (66%) who completed the study, 16 (53%) completed with no additional assistance from PI and 4 (13%) completed with assistance (PI help during expansion check visits). Therefore, 14 (47%) participants were unsuccessful in independently using the DM app to capture photos/videos. Table 1 compares the demographics between the participants who completed the study (n = 20) and those who did not complete the study (withdrawn/non/poor completion, n = 10). Total participants enrolled in the study had similar gender distribution with a median age of 11 years. There was slight decrease in median age and increase in number of girls in the group of participants who did not complete the study compared with the group that completed the study.

3.2. DM app users and average expansion check visits

Most of the users of the DM app were parents of the patients (80%). Table 2 shows the characteristics of the users of the DM app. The percentage of parents and patients was similar in the completed and noncompleted groups. There was a slight increase in the number expansion check visits of patients who did not complete the study compared with those who completed the study.

3.3. Maxillary intermolar width measurements outcome

Table 3 shows the linear association and mean differences in the maxillary intermolar width measurements between DM versus intraoral exam and DM versus digital model. Results indicate that DM intermolar width measurements are significantly linearly associated with intraoral examination and digital model intermolar width measurements ($P < 0.01$). Figure 2A and 2B show the scatterplots describing the linear relationship of the maxillary intermolar width measurements between each group. The results indicate that the mean difference between DM-intraoral

Table 3
Linear association and mean differences of intermolar width measurements between Dental Monitoring (DM) versus intraoral examination and DM vs digital model

		Robust 95% CI	*P*
Slope DM/intraoral examination	0.93	(0.83 to 1.03)	<0.01
Mean DM-intraoral examination	−0.20 mm	(−0.99 mm to 0.59 mm)	0.63
Slope DM/digital model	1.02	(0.96 to 1.07)	<0.01
Mean DM-digital model	0.01 mm	(−0.27 mm to 0.30 mm)	0.92

CI, confidence interval.

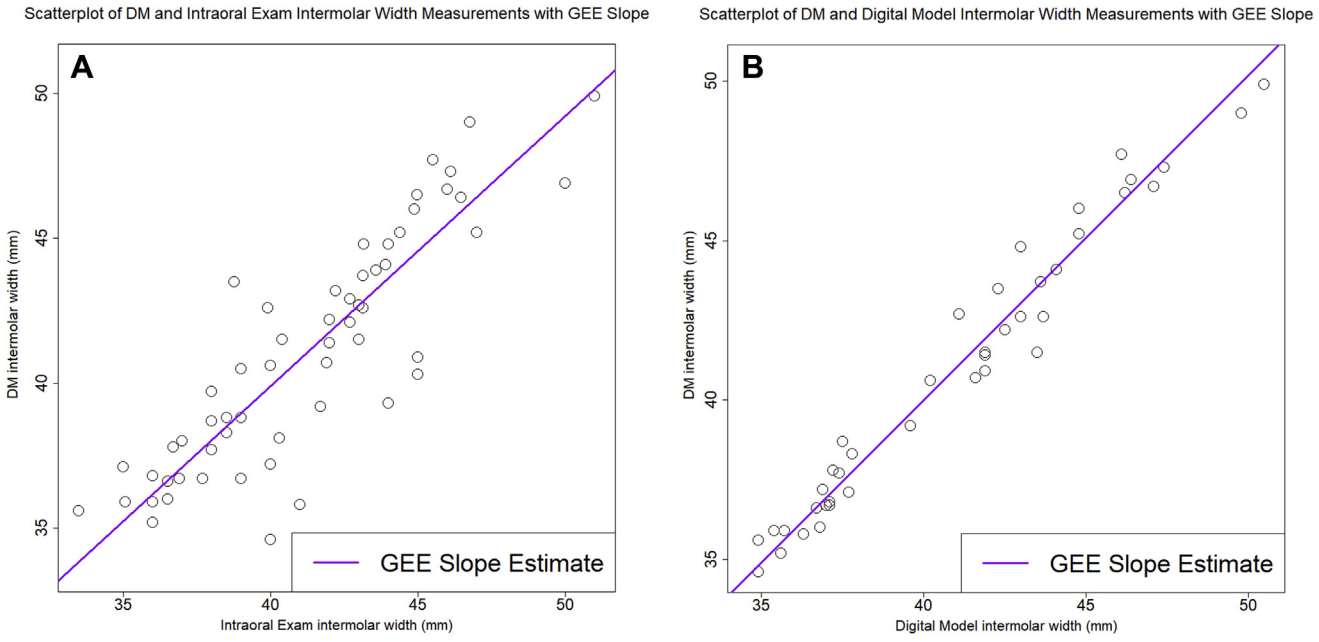

Fig. 2. (A, B) Scatterplots describing linear relationship of the maxillary intermolar width measurements between DM and intraoral examination (A) and DM and digital model (B).

examination and DM-digital model is not significantly different from 0 ($P = 0.95$ and $P = 0.77$, respectively). DM was successful (100%) in remotely identifying the correction of posterior crossbite for six participants who had posterior crossbite. The intraclass correlation coefficient of the measurements made by the single examiner (PI) on digital models for 10 randomly selected

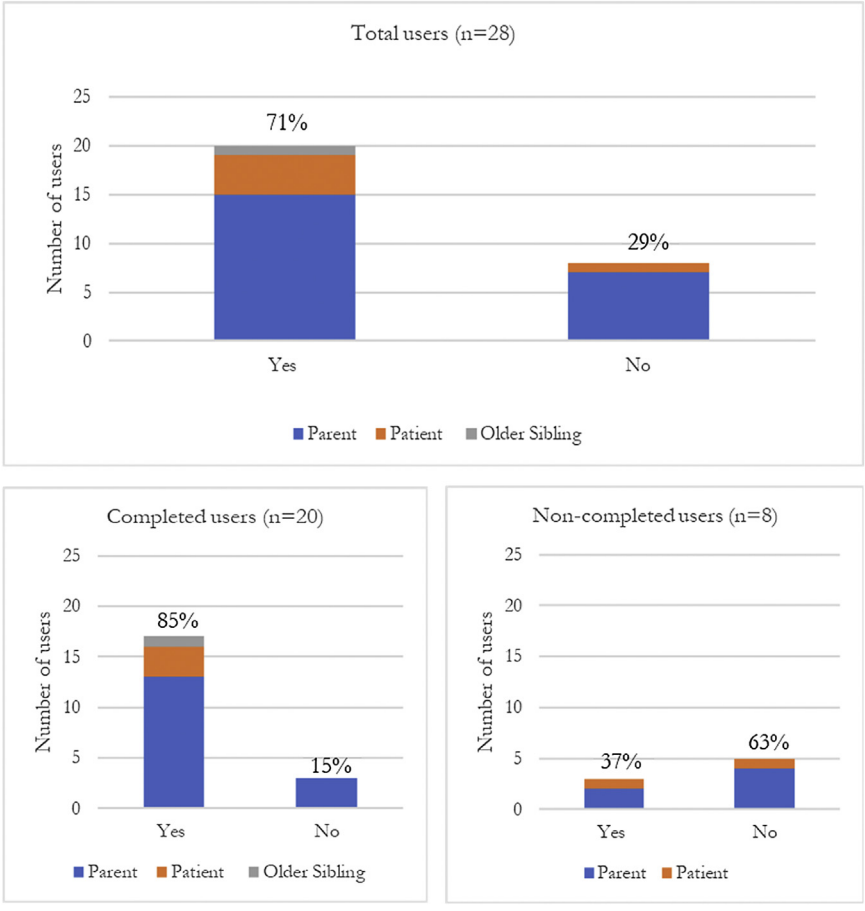

Fig. 3. Results to the survey question: "Was the DM app easy to use?"

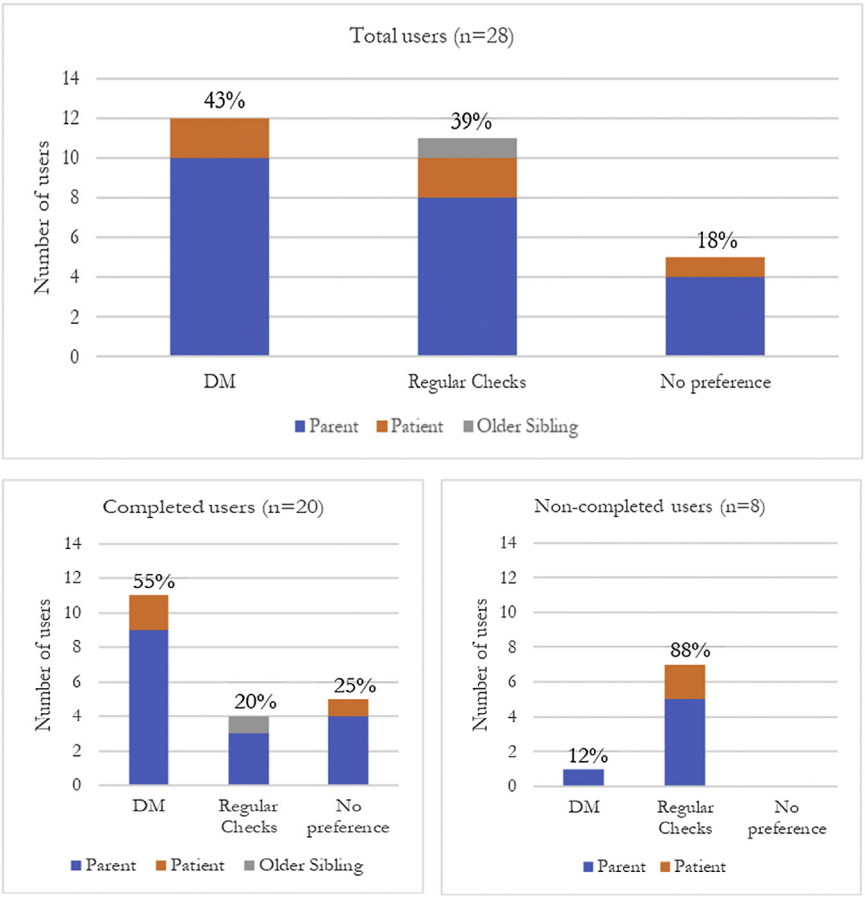

Fig. 4. Results to the survey question: "How do you compare using the DM app versus coming in for regular checks during RPE?"

individuals was calculated to be 0.998 (95% confidence interval 0.993–1) with $P < 0.01$.

3.4. Patient acceptance of DM

Two patients who withdrew from the study were unable to be reached for the completion of the patient acceptance survey. Figures 3 and 4 show the responses to some of the questions asked on the patient acceptance questionnaire of all participants (n = 28/30), participants who completed the study (n = 20), and participants who did not complete the study (n = 8/10). Overall, 71% of the participants found the DM app easy to use and 43% indicated that they prefer to use the DM app instead of coming in for regular expansion check visits. Participants who completed the study indicated more positive responses to DM app use compared with participants who did not complete the study.

4. Discussion

The results of this study indicate that DM software is accurate in assessing the achievement of treatment goals in patients undergoing RPE. Although only six of 20 participants who completed the study had a posterior crossbite, DM correctly identified the correction of the crossbites. No significant difference was found in the intermolar width measurements obtained with DM, intraoral examination, and digital model. There was a larger variation in the measurements between intraoral and DM compared with the digital model and DM (Fig. 2), although there was no significant difference in the linearity and mean difference. This variation in the measurements may be due to multiple raters who completed the intraoral measurements compared with a single examiner for digital model measurements and the inherent difficulty in accurately identifying the mesio-lingual cusp tips of the maxillary first molars intraorally compared with a digital model.

Although 30 subjects enrolled in the study, only 16 (53%) successfully (without assistance from the PI) completed the study. Participants in this study were predominantly young (median age 11 years) and only five (of 30) participants were able to take DM scans on their own. This may have contributed to the larger number of participants who withdrew or did not complete the study. The review of the open-ended comments on the survey show that generally participants found the DM app user-friendly and efficient. Five users specifically stated that the app's "instructions" and "videos" on how to take scans was very helpful. Other participants who did not find the app "easy" indicated several factors that contributed to the difficulty of use. Two users of the DM app found phone camera "slow" and "not clear" when using the DM app, which hindered their ability to take quality video or photos. Two parents indicated that their children found the cheek retractor to be too "painful" during DM app use. Most of the negative remarks (specifically stated by 10 of the users) on the use of the DM app was the difficulty in capturing photos/videos that were acceptable by DM. One parent summarized it well by saying, "straightforward directions but making videos acceptable by the app was tricky." Overall, most of the users (78%) found that it required between 2 and 10 minutes to capture the weekly scans. Only approximately half of all the users found the ease and time of capturing photos/videos to improve over

time. Fewer than half of all the users (43%) indicated that they would prefer the DM app over regular expansion checks and 18% of the users indicated that they had no preference between using the DM app or expansion check visits. One parent stated that for "a single-mother of three who works 60 hours/week and with my son living in two households, it (the DM app) was not necessarily as convenient as it was intended to be." Another parent indicated his preference for expert evaluation for his child by stating that he prefers his child to be "to be seen in person by the doctor" than monitored through an app. A recent study evaluated patient acceptance of the DM app in patients undergoing treatment with Invisalign and found that 86% of the participants found the DM app "easy" or "very easy" to use and 84% of the patients found the DM app to be "beneficial" or "very beneficial" [8]. The reported study similarly found that the most common problem perceived by patients using the DM app was related to the "difficulty of taking scans (DM examinations)" [8]. Overall, many factors seem to play a role in the success and preference for the use of DM app by the users.

4.1. Limitations

This study had a limited sample size because of high dropout rate. Most of the users of the DM app in this study were parents of the patients, which may have contributed to the high dropout rate. The results may differ in young adult or adult subjects who can take their own DM examinations. This study did not control for proficiency of participants with photography or comfort level with technology. In addition, the results of this study are based on the unique patient population of an academic institution. Therefore, these outcomes may not be generalizable to a private practice setting.

5. Conclusion

DM can remotely identify the correction of posterior crossbite. There was no significant difference in intermolar width measurements obtained with DM, digital model, or intraoral examination. In-person evaluation of maxillary expansion with a Hyrax expander can be replaced with remote monitoring using the DM software, yet challenges associated with digital imaging hinder the use of this remote evaluation for some patients.

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