

The Assessment of Rapid Palatal Expansion Using a Remote Monitoring Software

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Abstract

The Assessment of Rapid Palatal Expansion Using a Remote Monitoring Software

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Introduction: 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 (RPE) treatment and patient acceptance of DM.

Methods: Consecutively treated RPE patients 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 to digital models and intraoral measurements. Patient acceptance of the DM app was evaluated with a survey.

Results: Out 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 exam. 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.

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INTRODUCTION

‘Teledentistry’ is a new era in dentistry that combines telecommunication technology and dental care¹. Teledentistry involves the sharing of digital information such as photographs, radiographs between a patient and a provider through communication technology to provide dental care when distance separates the patient and the doctor². Teledentistry has been used for remote specialist consultations, diagnosis, treatment planning, coordination and continuity of dental care³. Some of the potential advantages of teledentistry include increased access to oral care, better patient education, earlier diagnosis, increased collaboration among health-care providers, cost effective access to specialists, advanced dental education, savings in travel time and costs, efficiency of treatment and elimination of unnecessary patient visits¹⁻⁷.

Technological advances in computers, smartphones and digital diagnostic imaging have made teledentistry widely applicable in the field of orthodontics. In recent studies, teledentistry has been identified as a valid and effective screening tool to identify patients requiring orthodontic treatment⁸ and to provide supervision to a sufficiently prepared general dentist providing interceptive orthodontic care in an offsite clinic⁹. One of the newest advancements of teledentistry in the field of orthodontics is remote treatment monitoring. Remote treatment monitoring is valuable as “efficiency” of orthodontic treatment has been emphasized more especially with the advent of prescription appliances, customized appliances systems and clear aligner therapy¹⁰. With remote monitoring, the scheduling of in-office visits can be personalized for each patient creating a more efficient workflow which can not only reduce chair time for the orthodontist but also increases patient convenience¹⁰. 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 period¹¹.

Dental Monitoring[®], marketed as the “world’s first connected orthodontics solution”, is a French company started in 2015 for remote monitoring of orthodontic treatment¹¹. DM uses a patented motion tracking algorithm utilizing digital macro-photogrammetry technology to calculate and quantify 3-dimensional (3D) tooth movements through photographs or videos that patients capture using a smartphone^{11,12}. This information as well as other parameters of treatment progress are communicated to the orthodontist who can remotely monitor a patient’s treatment away from the office.

The DM software system consists of three integrated platforms: a patient app, an analysis platform, and a Doctor Dashboard¹¹. The DM patient app guides the patients through the capture of quality intraoral photos/videos and functions as a communication platform where they can get messages and updates about their treatment. The photos/videos are automatically uploaded and sent to the DM analysis platform. These 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 images¹¹. 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, tooth movements etc¹¹. With 3D Monitoring, the images and patient’s 3D model go through a 3D calculation process to measure tooth movements. 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 48-72 hours where the doctor can review and communicate with the patient as needed¹¹.

To monitor a patient using the DM software, an orthodontist provides DM with the patient’s initial 3D model in stereolithography (STL) and treatment objectives. DM uses the initial 3D model as a

baseline to calculate future tooth movements and assess changes in occlusion. The orthodontist also provides the patient with a cheek retractor, designed specifically for capturing photos or videos with the DM app. The DM app is compatible with Ipad touch, Iphone® 4s running iOS® 7 or above, Android® 4.0.3 or higher and Google® phones like the Pixel¹¹. The DM exam can be taken either in a photo mode or video mode based on the compatibility of patient's phone. The photo mode involves taking 10-13 photos and video mode involves taking 3-4 videos. The number of photos or videos needed will depend on the type of monitoring required (photo vs 3D monitoring) and the type of prescription appliance (ex: clear aligners). A patient can take the DM exam 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 servers¹¹. The DM algorithm uses the new photos and the initial 3D digital model to generate a new 3D model of the current position of patient's teeth from which it calculates tooth movements, interarch relationships, overjet and overbite etc^{2,11}. The results are uploaded to the Doctor Dashboard in the forms of graphs, photos and 3D visualizations that allow an orthodontist to monitor treatment progress. The orthodontist can also identify adverse situations such as broken brackets, abnormal pathologies, unintended tooth movements or poor oral hygiene^{2,11}. Through the course of treatment, as a patient continues to submit intraoral photos or videos, a new 3D model is created which will serve as the basis for tooth movement calculations for the next set of photos^{2,11}. The DM software claims its error for tooth movement calculations to be less than 0.1mm for linear measurements and less than 0.5 degree for angular and rotational measurements².

One type of orthodontic treatment that requires close monitoring is rapid palatal expansion (RPE) using a palatal expander. RPE is used to correct transverse maxillary deficiency, often in situations where there is a unilateral or bilateral posterior cross-bite present¹³. 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 movement¹³. After a rapid palatal expander is inserted, patients are asked to activate the appliance regularly. To avoid over-activation and to evaluate expansion progress, patients are re-evaluated 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 may also save the orthodontist valuable chair time.

However, in order 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 Aragon et al. has shown 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 impression¹⁴. 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 exam¹⁵.

There are only few clinical studies that have evaluated the efficacy of a remote monitoring software to assess the achievement of treatment goals during orthodontic treatment. If verified as accurate, and accepted by patients, remote dental monitoring software such as DM has the potential to facilitate close monitoring of patients with less chair time and to reduce the overall costs and time burdens to the patient and orthodontist.

Objectives

The objectives of this study are as follows:

1. Evaluate the accuracy of DM software in assessing the achievement of treatment goals in patients undergoing RPE. This will be determined by comparing maxillary intermolar width measurements (mm) calculated by DM to intraoral exam and digital model as well as comparing the assessment of posterior crossbite correction (YES or NO) by DM to intraoral exam.
2. Evaluate patient acceptance associated with the use of the DM app
3. Describe observed crown movements occurring during RPE as reported by DM software

The null hypothesis of this study is:

1. There is no significant difference in the intermolar width measurements obtained with DM, intraoral exam and digital model.

MATERIAL AND METHODS

The inclusion criteria for this study were being a patient seeking orthodontic treatment at the University of Washington Orthodontics clinic with the following criteria: (1) in mixed or permanent dentition treated with a Hyrax[®] palatal expander; (2) have a pre-treatment digital model taken within 3 months before the start of RPE; (3) have a smartphone or device (Ipod touch, Iphone[®] 4s running iOS[®] 7 or above, Android[®] 4.0.3 or higher, Google phones like the Pixel) 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 the 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 the Graduate Orthodontic clinic at University of Washington between August 2017 and February 2019 were invited to participate in the study. The design of the Hyrax[®] expander and the protocol for RPE (ex: 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 prior to the start of treatment as following: 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 (ex: correction of bilateral posterior crossbite 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. Patient return visits were scheduled as per 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 mm (measured intraorally with a digital caliper), other (such as loose molar bands, broken appliance etc). If treatment goals were achieved, the patient was instructed to stop activation and an intraoral scan with 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 exams 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 (mm) 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 (Figure 1). All patients who completed the study were compensated with a gift card.

Patient Acceptance Survey

Patient ID: _____

We are interested in receiving your feedback regarding your experience in using Dental Monitoring® app during your orthodontic treatment. Please take a few minutes to complete this survey and return it to us. Your responses are important to us.

For each of the following questions, please circle your answer.

1. Who is filling out this survey?
 - a. Patient
 - b. Parent
2. On whose phone was the Dental Monitoring® app downloaded and used?
 - a. Patient
 - b. Parent
3. Was the Dental Monitoring® app easy to use?
 - a. Yes
 - i. Explain: _____
 - b. No
 - i. Explain: _____
4. How long did it take you to capture the weekly photos?
 - a. Less than 1 minute
 - b. 2-5 minutes
 - c. 6-10 minutes
 - d. More than 10 minutes
 - i. Please provide an estimation of time: _____
5. Did the time of capturing weekly photos improve over time?
 - a. Yes
 - b. No
 - c. No difference
 - i. Explain: _____
6. Did the ease of capturing weekly photos improve over time?
 - a. Yes
 - b. No
 - c. No difference
 - i. Explain: _____
7. How do you compare using Dental Monitoring® app with coming in for regular checkups during the rapid palatal expansion treatment?
 - a. I would prefer to use the Dental Monitoring® app instead of coming in for regular checkups during the rapid palatal expansion treatment
 - b. I would prefer to come in for checkups rather than using the Dental Monitoring® app during the rapid palatal expansion treatment
 - c. I have no preference between these two options
 - d. Other
 - i. Please explain: _____
8. If you would like to share any additional comments or experience about the use of Dental monitoring® app, please enter them below.

Figure 1: Patient acceptance survey

Statistical Analyses

All statistical analyses were done using R 3.5.1¹⁶ and the *gee*¹⁷ package. 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.

RESULTS

A. Participants

A total of forty-two patients were invited to participate in the study. Figure 2 shows the flow of participants in the study. Four patients were ineligible due to parent/patient not having a smartphone. Eight patients declined to participate with the most common reason being “too much hassle” and parents being “too busy” to take videos/photos at home. A total of 30 patients 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), patients not wanting to continue participation for unspecified reasons (n=5). Two participants did not take the weekly DM exams throughout the study and 1 participant took poor quality exams 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/she had successfully captured (w or w/o assistance from PI) at least two DM exams one at the beginning and end of RPE treatment.

Out 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 didn’t 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 females in the group of participants who didn't complete the study compared to the group who completed the study.

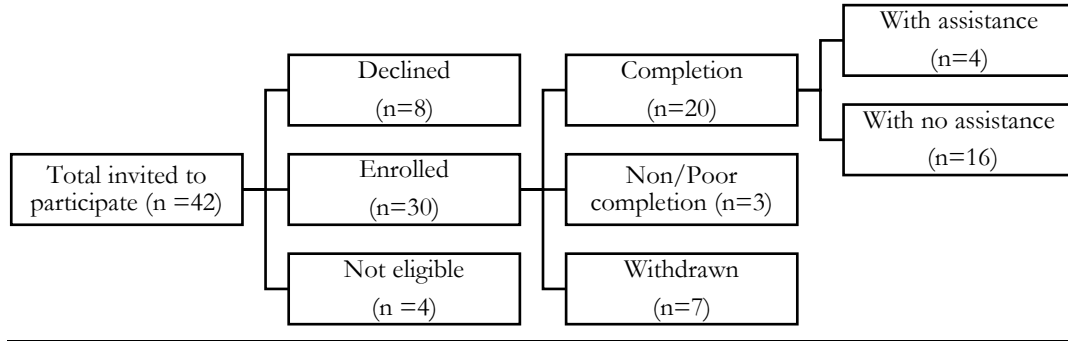


Figure 2: Flow of participants in the study

	Total (n=30)		Completed (n=20)		Non-completed (n=10)	
	n	%	n	%	n	%
Sex						
Male	14	47%	10	50%	4	40%
Female	16	53%	10	50%	6	60%
Age (years)						
Mean (Range)	11.5 (7-17)		11.8 (8-17)		10.9 (7-17)	
Median	11		11.5		10.5	

Table 1: Demographics of the participants in the study

B. 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 DM app. The percentage of parents and patients was similar in the completed and non-completed group. There was slight increase in the number expansion checks visits of patients who didn't complete the study compared to those who completed the study.

	Total (n=30)		Completed (n=20)		Non-completed (n=10)	
Users of DM app	n	%	n	%	n	%
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	

Table 2: Characteristics of the users of DM app and expansion check visits

C. Treatment characteristics of patients undergoing RPE treatment

The characteristics of patients who completed the study(n=20) is described in Table 3. Six out of the 20 completed participants started with a posterior crossbite for which they underwent RPE treatment. There was variation in the number of active turns prescribed and the use other appliances in addition to Hyrax[®] during RPE treatment.

Presence of Posterior Crossbite	n	%
Y	6	30%
N	14	70%
Goals of Expansion		
Correction of crossbite	6	30%
Other (increase in arch length/address relative transverse discrepancy/improve arch form)	14	70%
Active Turns Prescribed		
Mean (Range)	31.85 (10-70)	
Median	27.5	
Appliances		
Hyrax [®] only	9	45%
Hyrax [®] + Maxillary braces	3	15%
Hyrax [®] + Mandibular braces	4	20%
Hyrax [®] + Maxillary braces+ Mandibular braces	4	20%

Table 3: Treatment characteristics of the completed users of DM app (n=20)

D. Maxillary intermolar width measurements outcome

Table 4 shows the linear association and mean differences in the maxillary intermolar width measurements between DM vs intraoral exam and DM vs digital model. To obtain a measure of the linear association, a regression model was fitted with DM as the outcome and intraoral exam/digital model as the predictor to estimate the slope. Results indicate that DM intermolar width measurements are significantly linearly associated with intraoral exam and digital model intermolar width measurements. The mean differences between each group was estimated by taking the difference

(DM-intraoral exam or DM-digital model) for each pair of measurements, then fitting a regression model with the differences (DM-intraoral exam or DM-digital model) as the outcome and just an intercept. The results indicate that the mean difference between DM-intraoral exam and DM-digital model is not significantly different from 0. DM was successful (100%) in remotely identifying the correction of posterior crossbite for six participants who had posterior crossbite. The intraclass correlation coefficient (ICC) of the measurements made by the single examiner (PI) on digital models was calculated to be 0.998 (95% CI (0.993,1)) with $p < 0.01$

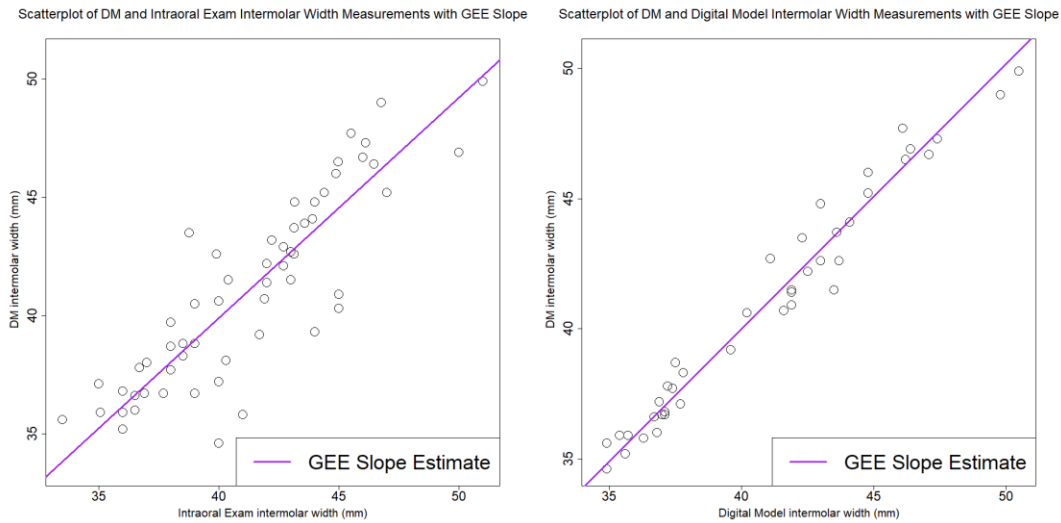


Figure 3: Scatterplot describing linear relationship of the maxillary intermolar width measurements (mm) between DM and intraoral exam and DM and digital model

		Robust 95% CI	p-value
Slope DM/Intraoral Exam	0.93	(0.83, 1.03)	<0.01
Mean DM-Intraoral Exam	-0.20 mm	(-0.99 mm, 0.59mm)	0.63
Slope DM/Digital Model	1.02	(0.96, 1.07)	<0.01
Mean DM-Digital Model	0.01 mm	(-0.27 mm, 0.30 mm)	0.92

Table 4: Linear association and mean differences of intermolar width measurements between DM vs intraoral exam and DM vs digital model

E. 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 4-8 show the responses of all participants (n= 28/30), participants who completed the study (n=20) and participants who didn't complete the study (n=8/10) to the patient acceptance questionnaire. Overall, 71% of the participants found 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. Most of the participants (78%) reported that the time of capturing weekly DM videos/photos was between 2-10 minutes. Around half of the participants found improvement in the ease and time of using the DM app. Participants who completed the study indicated more positive responses to the DM app use (in terms of ease, time, improvement, preference) compared to participants who didn't complete the study.

‘Was the DM app easy to use?’

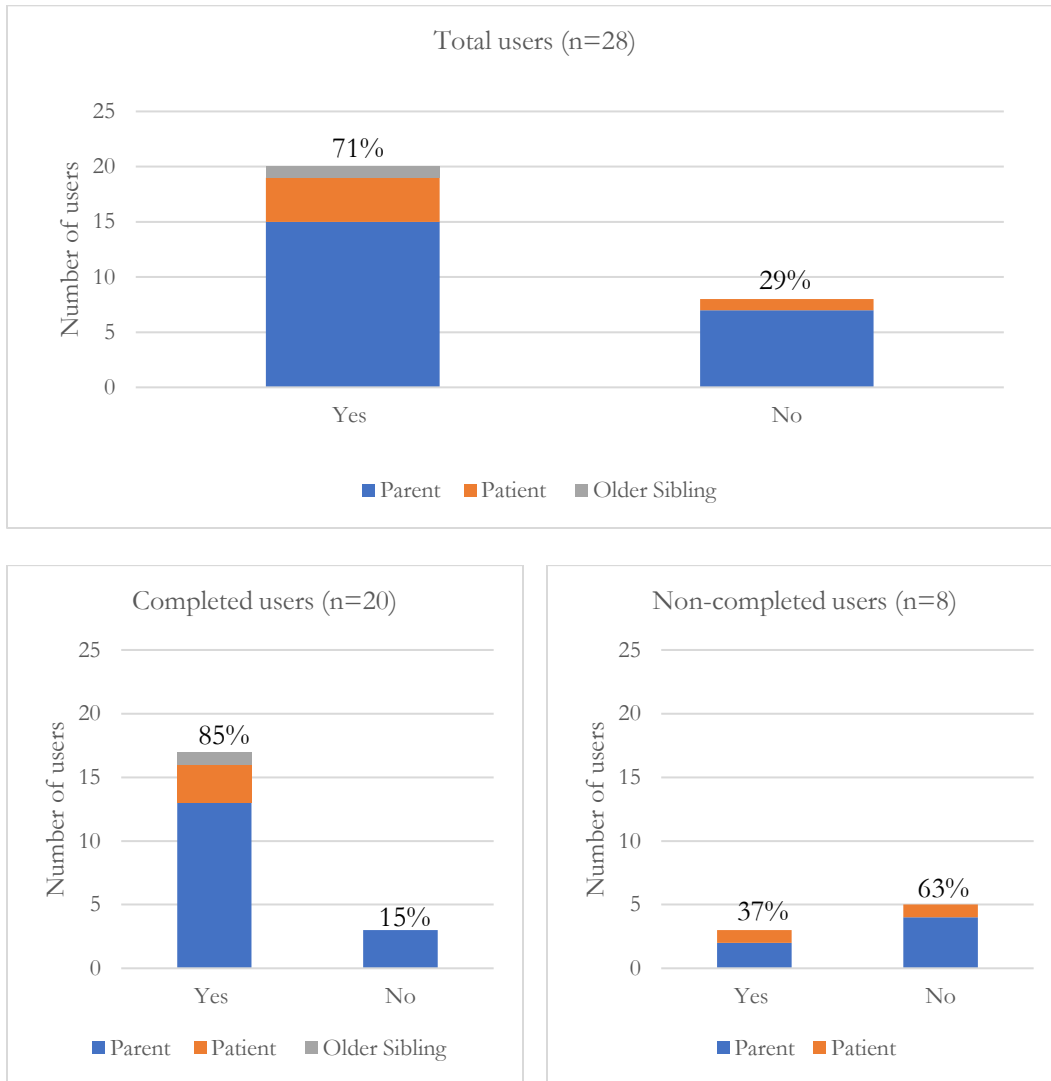


Figure 4: Results to the survey question: ‘Was the DM app easy to use?’ in total number of users (n=28/30), completed users (n=20) and non-completed users (n=8/10)

‘How long did it take you to capture the weekly photos/videos?’

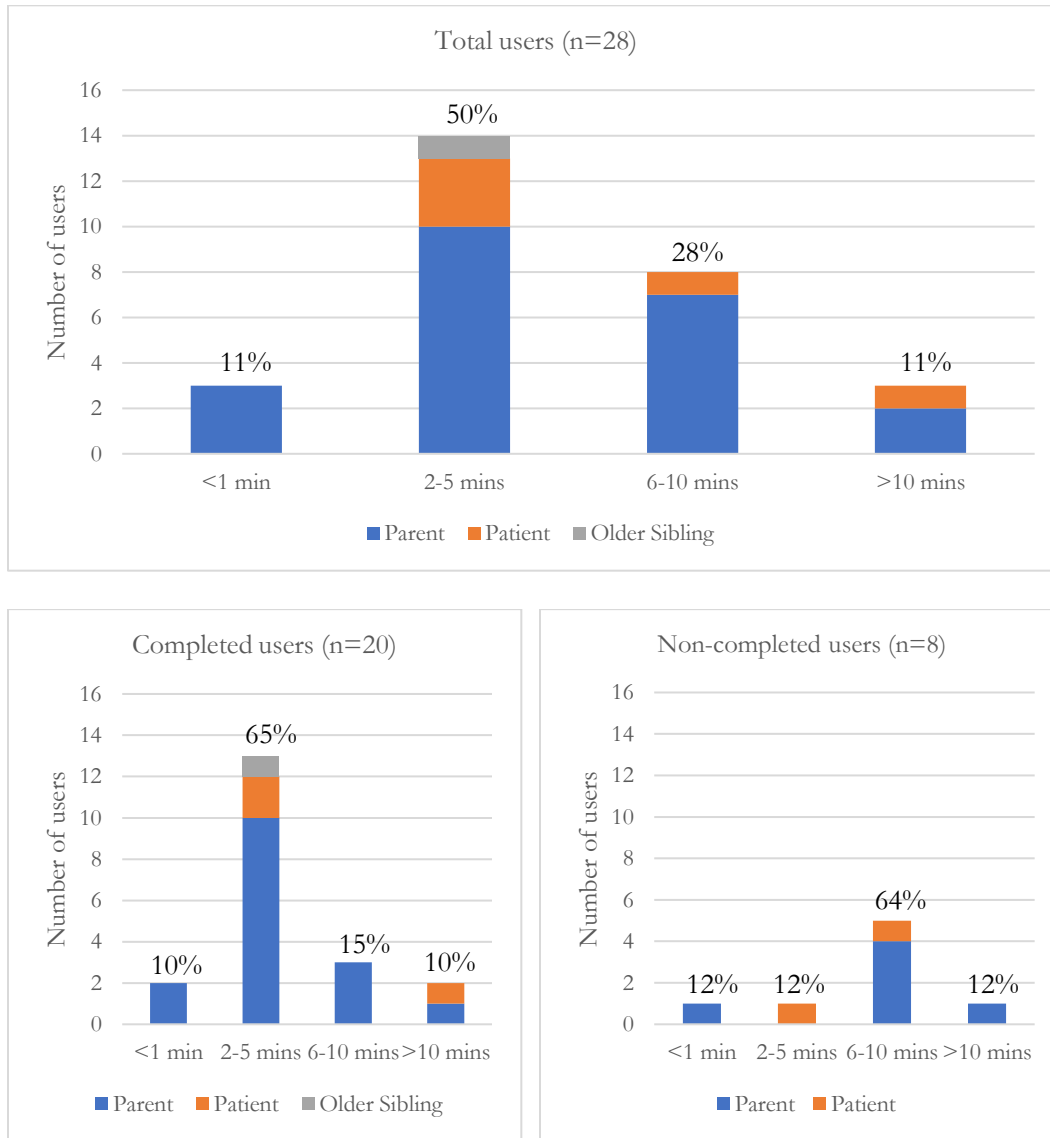


Figure 5: Results to the survey question: ‘How long did it take you to capture weekly photos/videos?’ in total number of users (n=28/30), completed users (n=20) and non-completed users (n=8/10)

‘Did the time of capturing weekly photos/videos improve over time?’

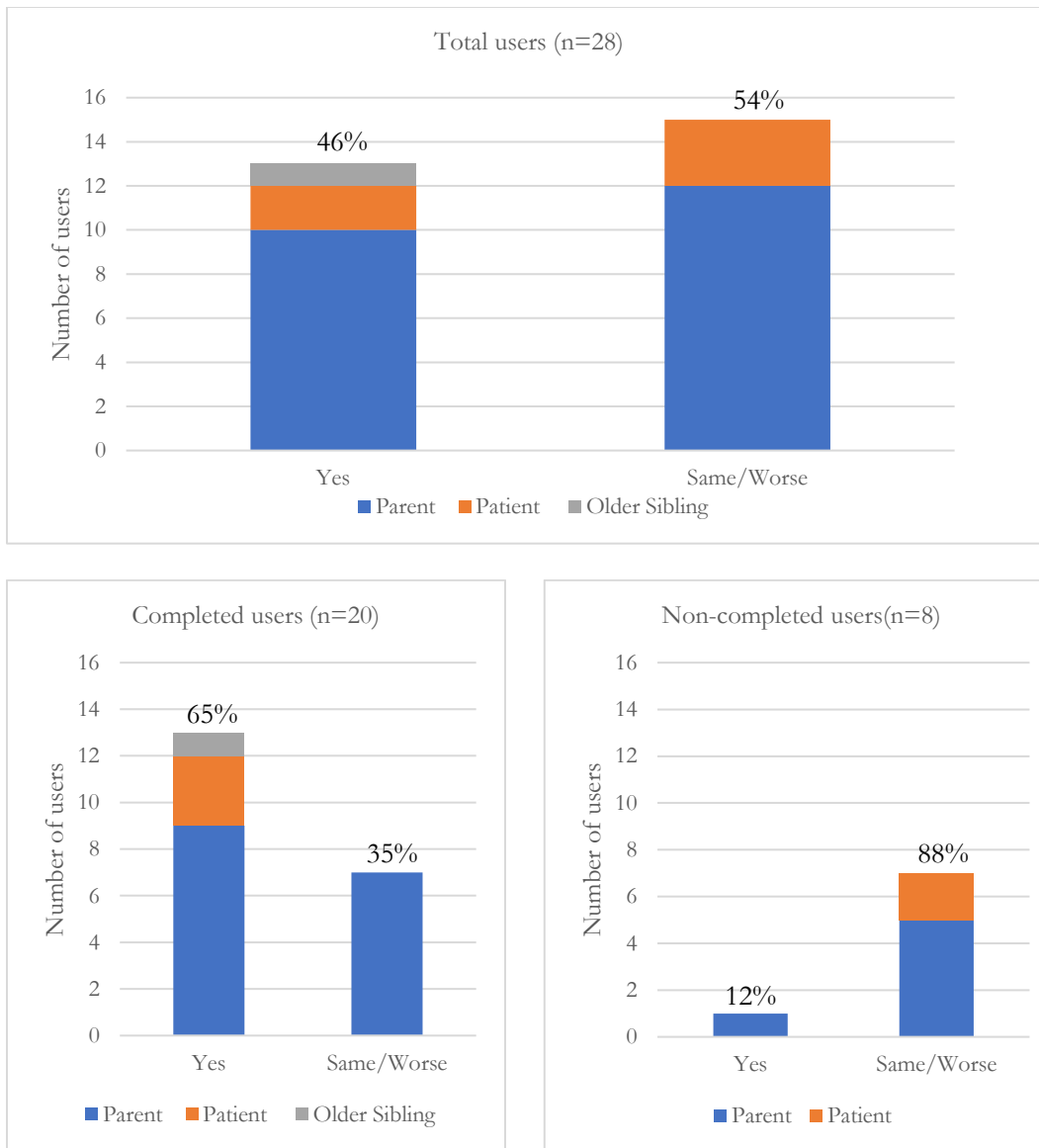


Figure 6: Results to the survey question: ‘Did the time of capturing weekly photos/videos improve over time?’ in total number of users (n=28/30), completed users (n=20) and non-completed users (n=8/10)

‘Did the ease of capturing weekly photos/videos improve over time?’

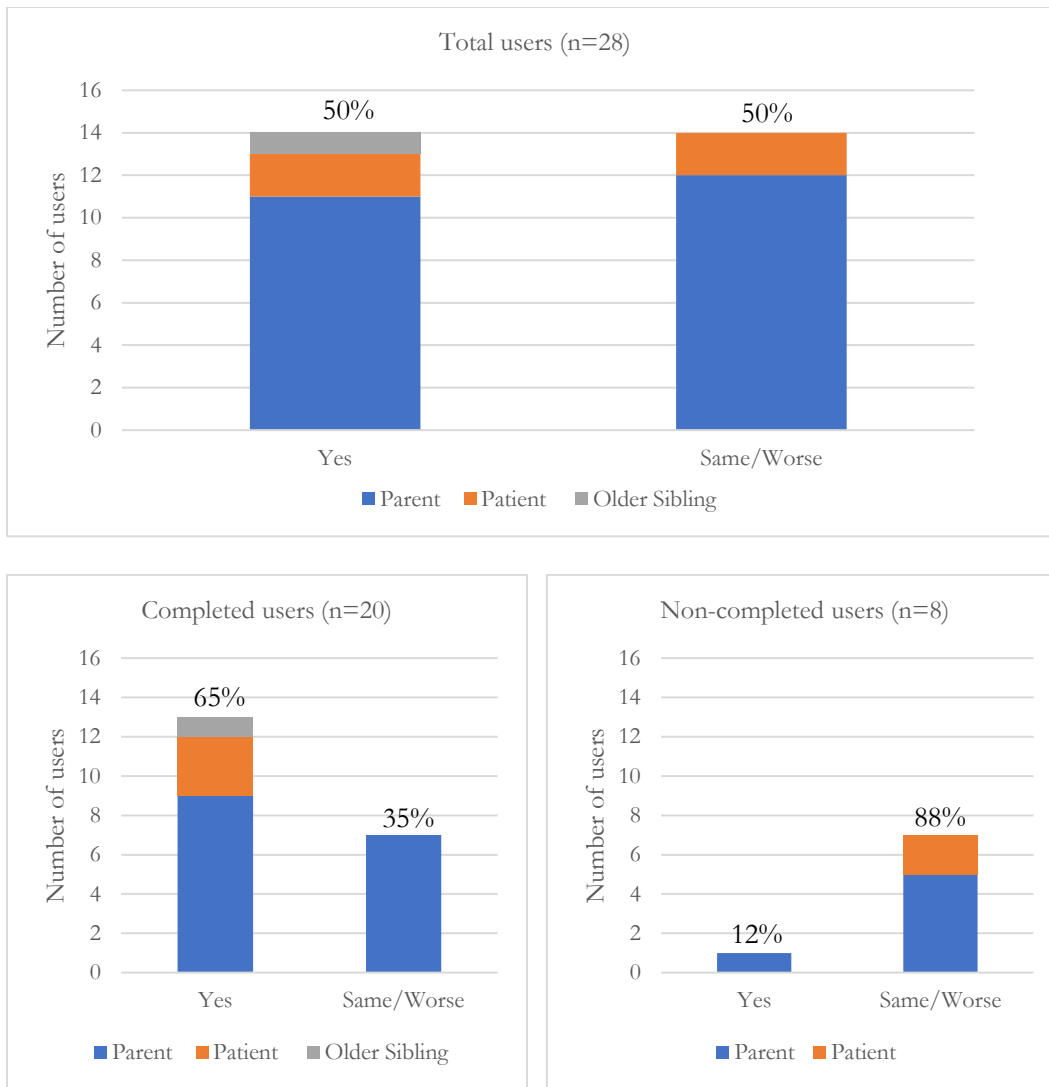


Figure 7: Results to the survey question: ‘Did the ease of capturing weekly photos/videos improve over time?’ in total number of users (n=28/30), completed users (n=20) and non-completed users (n=8/10)

‘How do you compare using the DM app versus coming in for regular checks during RPE?’

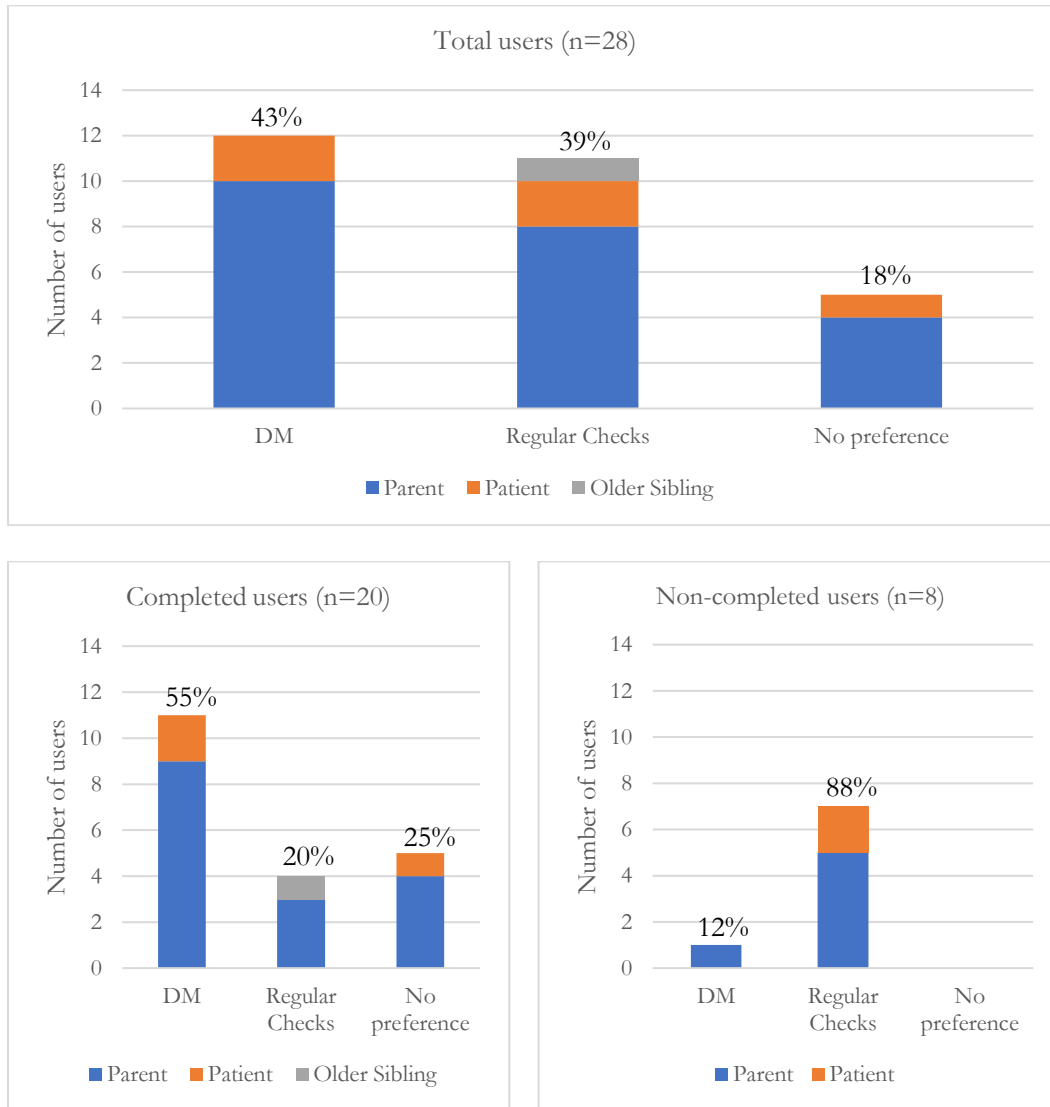


Figure 8: Results to the survey question: ‘How do you compare using the DM app versus coming in for regular checks during RPE?’ in total number of users (n=28/30), completed users (n=20) and non-completed users (n=8/10)

F. Tooth movement during rapid palatal expansion

Figures 9-14 (a-b) show trends in linear (mesial/distal, buccal/lingual, extrusion/intrusion), angular (buccal/lingual, mesial/distal) and rotational (mesial/distal) tooth movements identified by the DM software of the maxillary first molars and the mandibular first molars during RPE. Only patients with no fixed appliances were evaluated for the tooth movement evaluation in the mandibular arch (n=12). Two patients were excluded from this group due to one patient having a mandibular lingual holding arch in place and another patient losing both mandibular primary second molars during RPE treatment. Maxillary first molar crowns were observed in general to translate distal and buccal, extrude, tip buccal and mesial and rotate distal whereas the untreated mandibular first molar crowns were observed in general to translate distal and buccal, intrude, tip buccal and distal and rotate to the distal during RPE. Changes noted in the mandibular first molars were much smaller in comparison to the maxillary first molars.

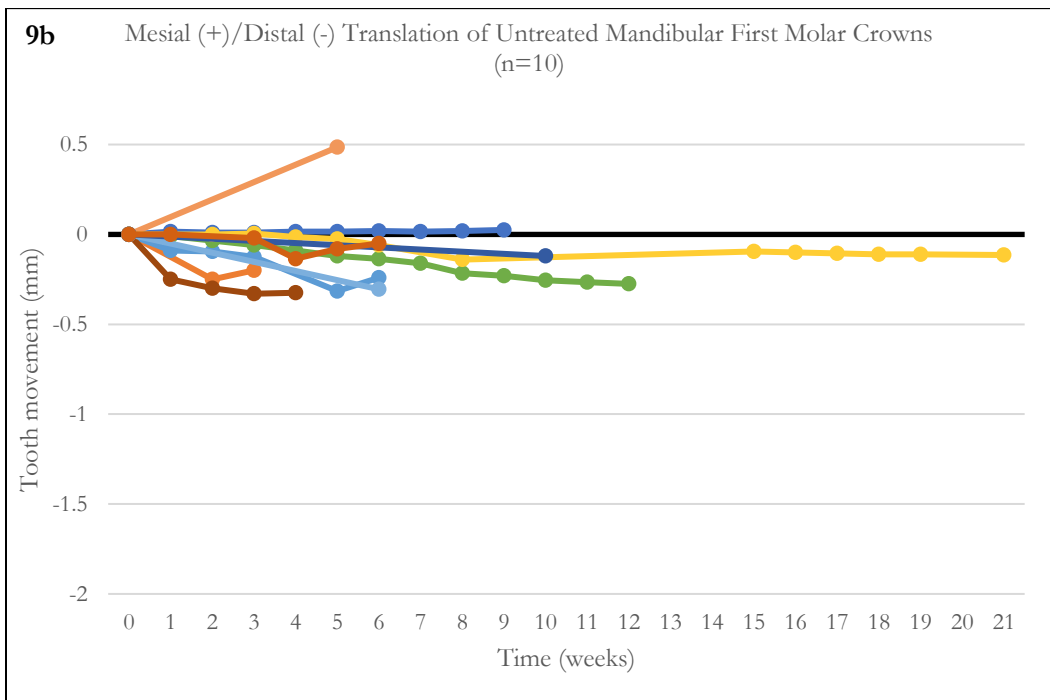
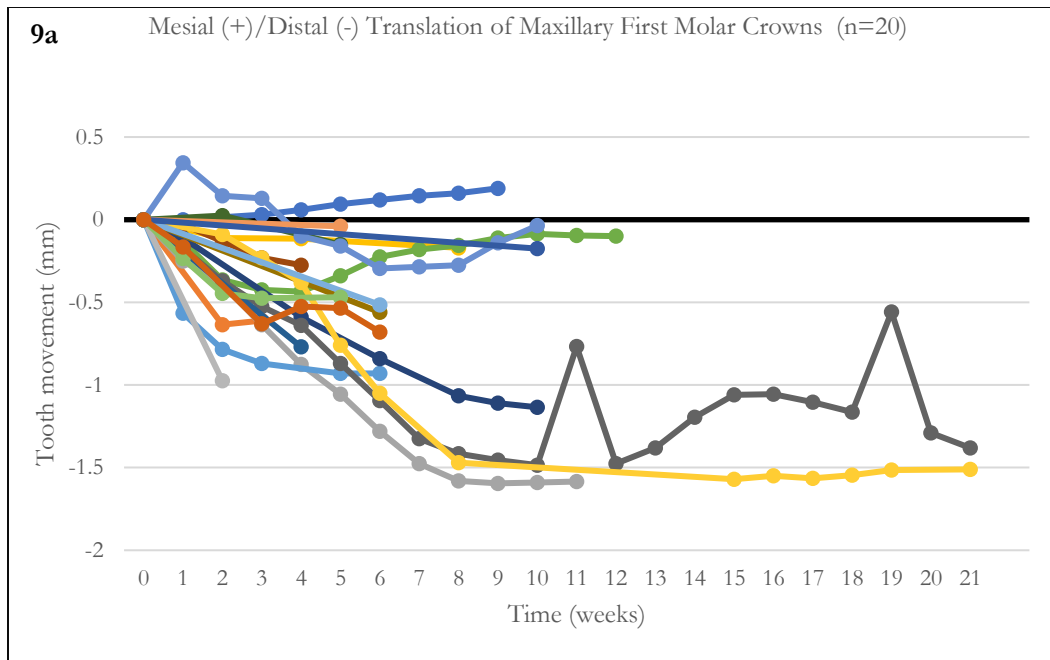


Figure 9: Mesial (+)/Distal (-) translation observed for maxillary first molar crowns (a) and untreated mandibular first molar crowns (b)

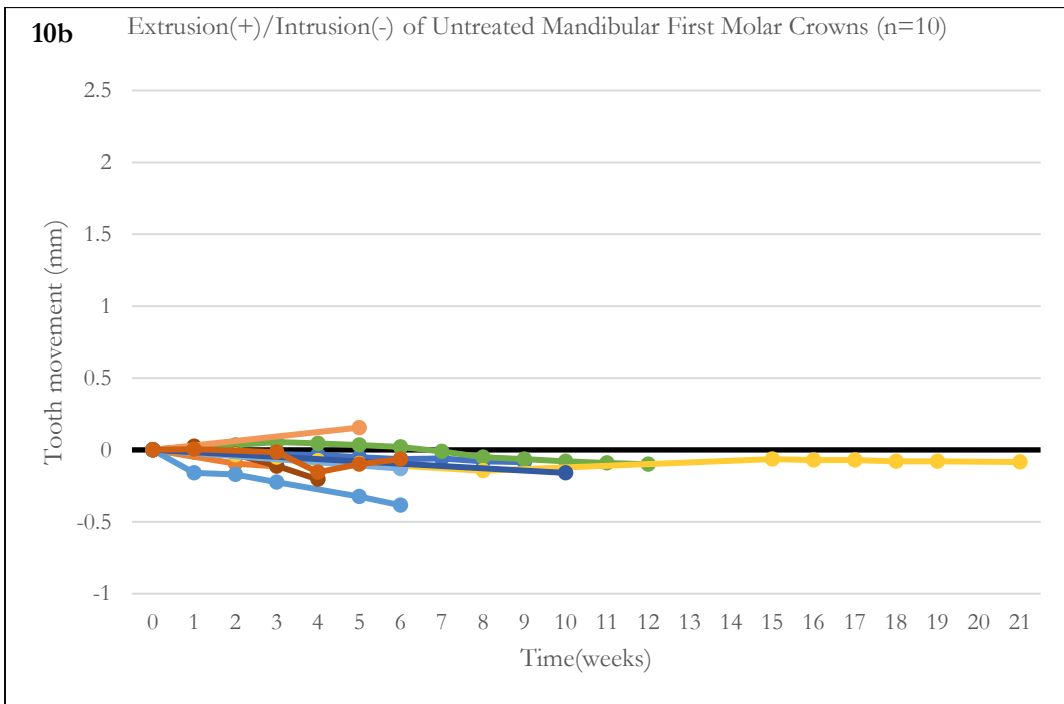
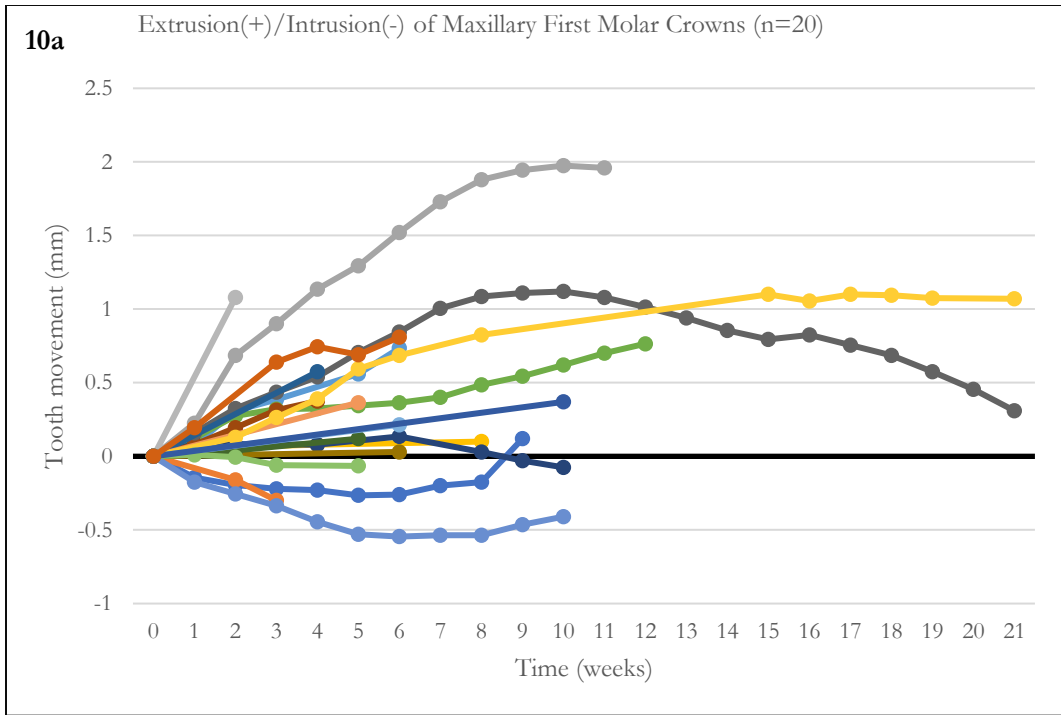


Figure 10: Extrusion (+)/Intrusion (-) observed for maxillary first molar crowns (a) and untreated mandibular first molar crowns(b)

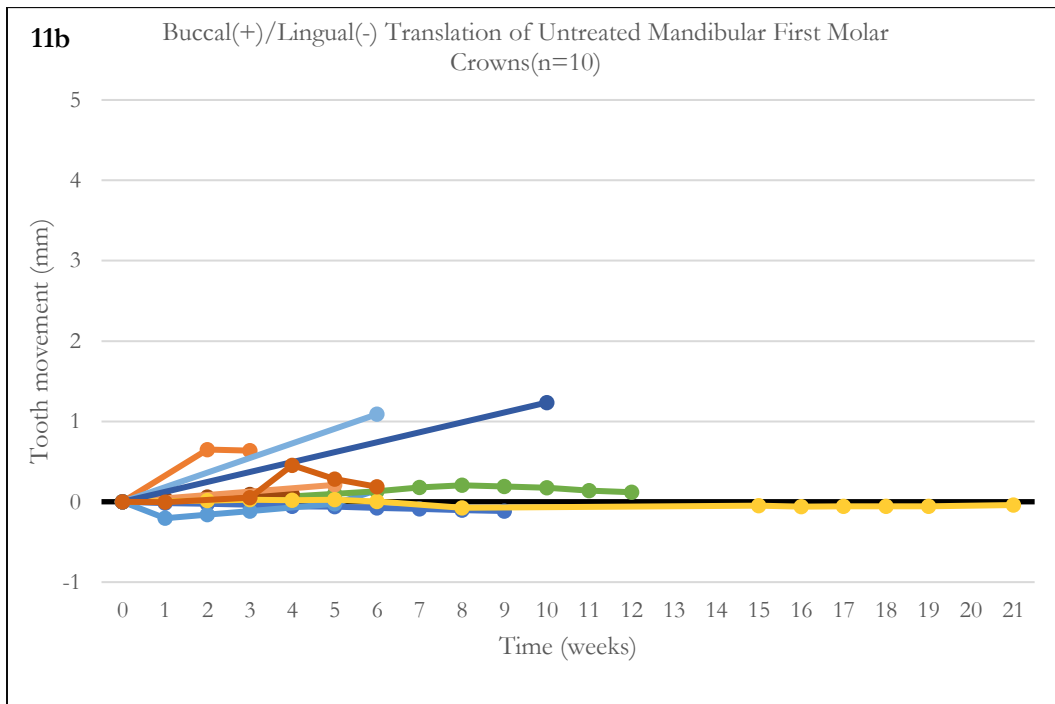
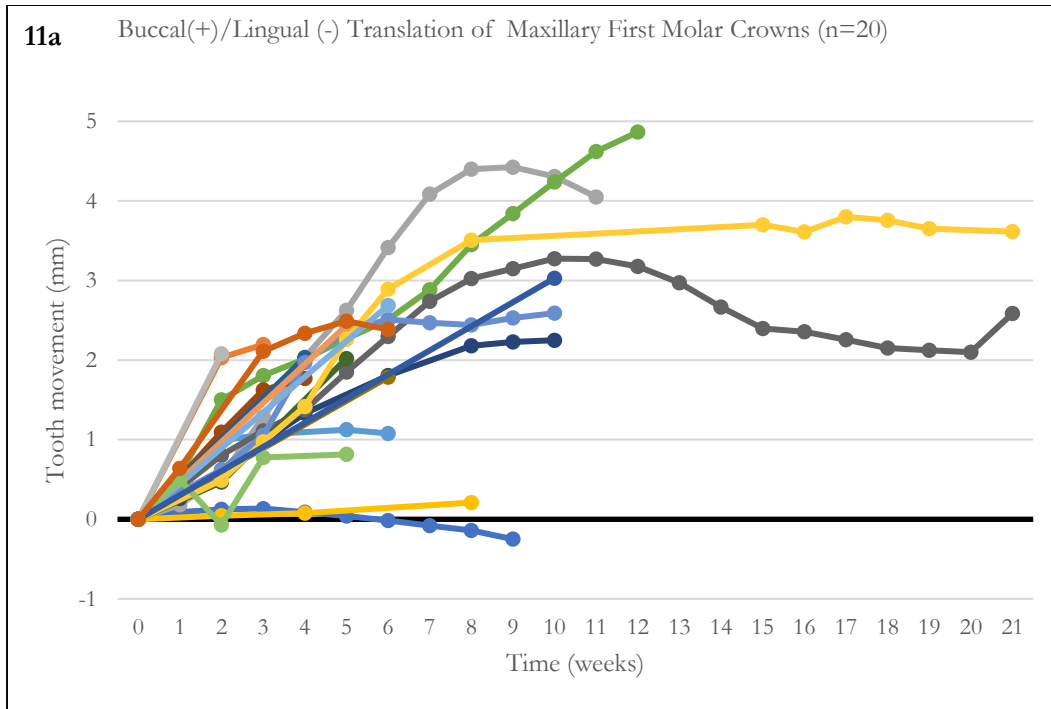


Figure 11: Buccal (+)/Lingual (-) translation observed for maxillary first molar crowns (a) and untreated mandibular first molar crowns(b)

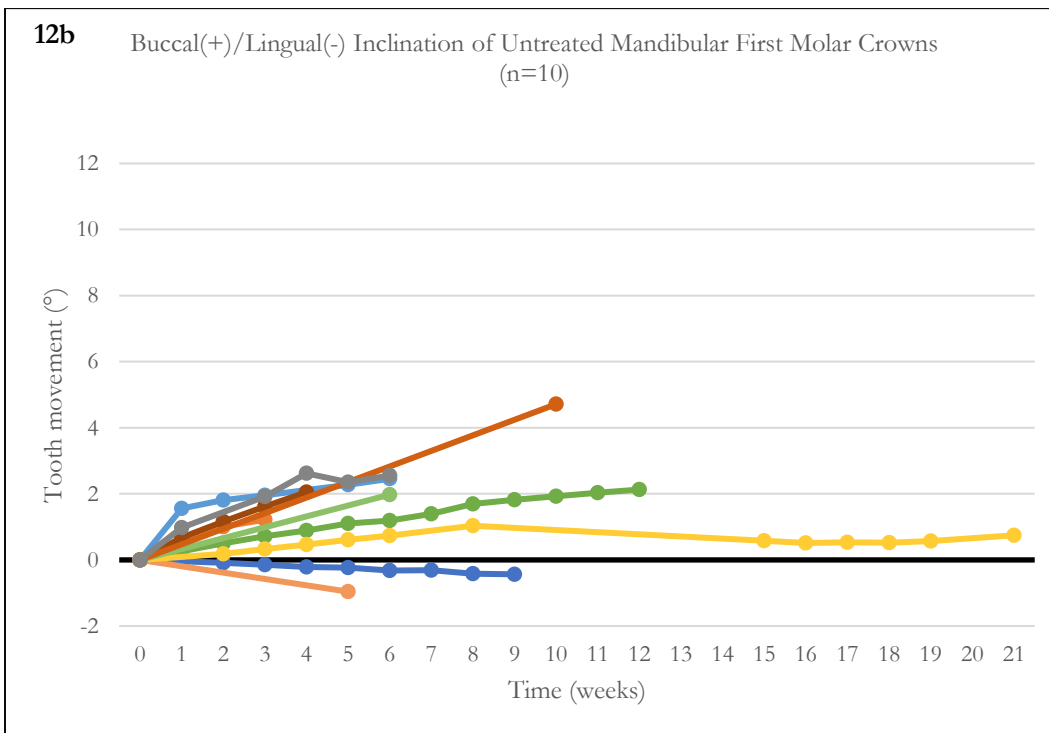
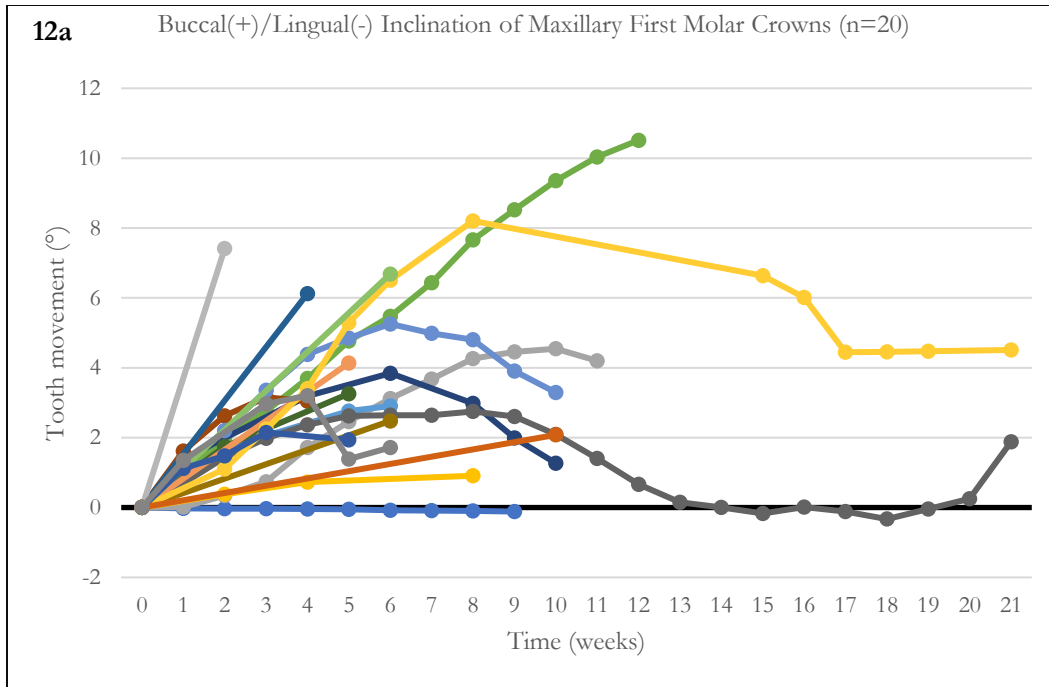


Figure 12: Buccal (+)/Lingual (-) inclination observed for maxillary first molar crowns (a) and untreated mandibular first molar crowns(b)

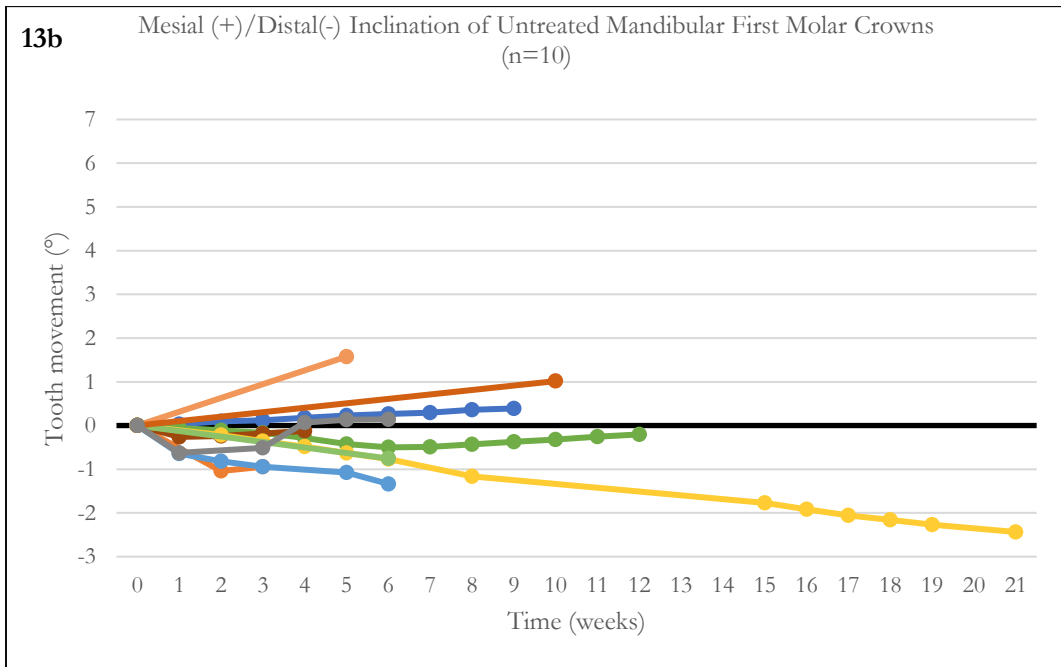
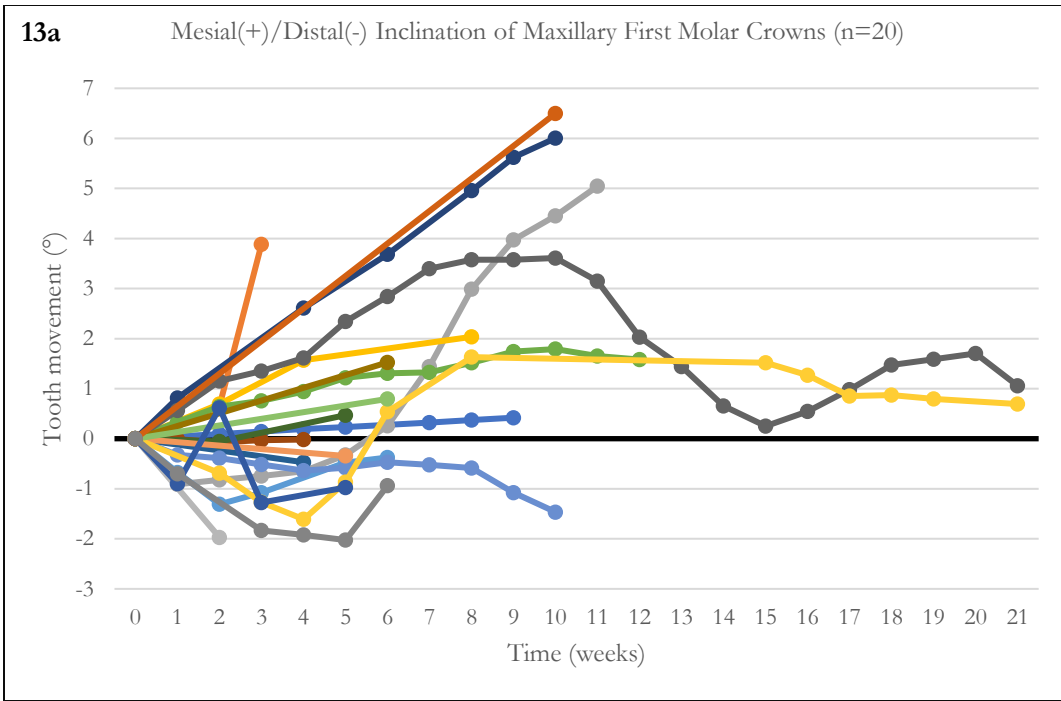


Figure 13: Mesial (+)/Distal (-) inclination observed for maxillary first molar crowns (a) and untreated mandibular first molar crowns(b)

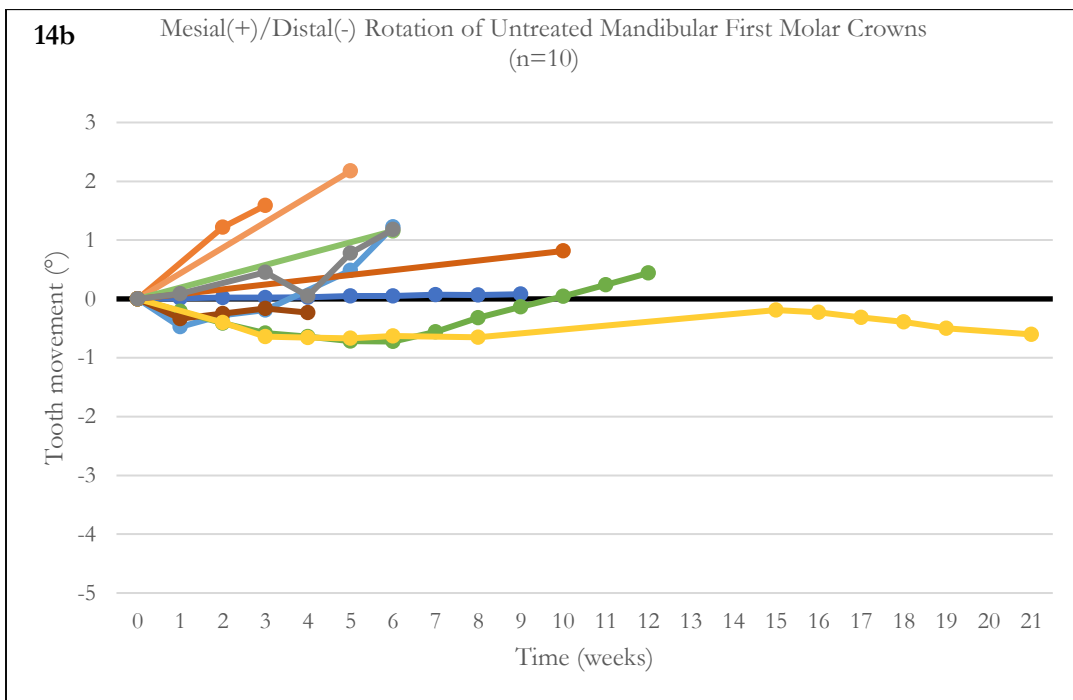
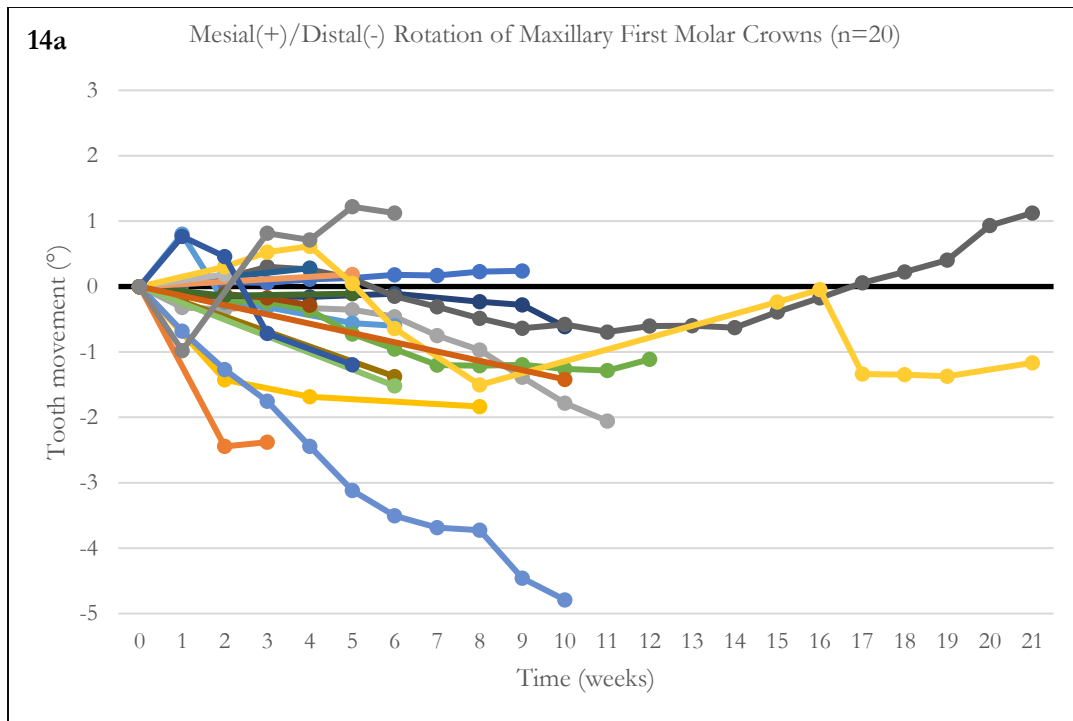


Figure 14: Mesial (+)/Distal (-) rotation observed for maxillary first molar crowns (a) and untreated mandibular first molar crowns(b)

DISCUSSION

Remote treatment monitoring has the potential to revolutionize the patient-doctor relationship and influence all aspects of patient care in orthodontics. 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 out 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 exam and digital model. There was a larger variation in the measurements between intraoral and DM compared to the digital model and DM (Figure 3) 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 to 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 to a digital model.

There are three unpublished studies that have similar results to this study. One study found no significant difference in intercanine and intermolar width and arch depth measurements made by DM compared to measurements made on the plaster models¹⁸. Two in-vitro studies compared the reliability of 3D digital models generated by DM in video mode and photo mode with 3D digital models generated by the iTero[®] Element[™] intraoral scanner and found that there was no clinically significant difference between the 3D digital models generated by iTero[®] Element[™] intraoral scanner and those generated by DM in video and photo mode^{19,20}.

While 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 5 (out 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 didn't 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 didn't 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 the DM app use. Another participant indicated that the lack of "immediate" feedback on the need to re-take poor quality DM scan was a source of frustration. Most of the negative remarks (specifically stated by ten 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 2-10 minutes to capture the weekly scans. Only about half of all the users found the ease and time of capturing photos/videos improve over time. Less 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 3 who works 60 hours/week and with my son living in 2 households, it (the DM app) wasn't 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”¹⁰. 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 exams)”¹⁰. An important consideration is that the average age of patients in the reported study¹⁰ was higher (mean age of 24 years) than this study. Overall, many factors seem to play a role in the success and preference for the use the DM app by the users.

The DM software utilizes digital photogrammetric system to describe and quantify tooth movement occurring during treatment. An unpublished study¹² investigated the reliability and accuracy of dental movements (linear and angular) tracked with DM against 3M[™] (True Definition Scanner) and found no statistical difference for movements tracked between the reference scanner and DM software for all linear measurements (mesial/distal translation, extrusion/intrusion, buccal/lingual translation). However, statistically significant differences were found for movements tracked between reference scanner and DM software for all angular measurements (buccal/lingual inclination, mesial/distal inclination, mesial/distal rotation) as well as for all linear and angular measurements of molars as compared to central incisors and canines; but these differences were considered to be clinically insignificant¹².

In this study, the maxillary first molar crowns were observed in general to translate distal and buccal, extrude, tip buccal and mesial and rotate distal whereas the mandibular first molar crowns were observed to translate distal and buccal, intrude, tip buccal and distal and rotate to the distal during RPE. Studies show that tooth-borne expanders result in buccal movement, buccal tipping and extrusion of maxillary molars as confirmed in this study²¹⁻²⁵. Many studies support spontaneous changes occurring in the mandibular arch leading to increase in intermolar width after palatal expansion^{15,26,27}. This increase in intermolar width in

the mandibular arch has shown to be maintained long term after expansion^{26,27}. It has been theorized that the increase in mandibular molar width may be due to changes in occlusal forces and the balance between tongue and buccal musculature resulting from expansion of the maxillary arch¹³ leading to “decompensation” or uprighting of the lower posterior teeth²⁸. The intrusion of mandibular first molars observed in this study may be due to compensatory changes resulting from the extrusion of the maxillary first molars. The observed distal translation and rotation of the maxillary first molars and mesial rotation of the mandibular first molars may explain the improvement in Class II molar correction reported by some studies²⁹⁻³¹ after palatal expansion although other studies report this effect as unpredictable and unsupported due to lack of controlled studies^{32,33}. This study did not quantify changes in molar classification after RPE and therefore cannot verify the accuracy of this observation. This study only included subjects with no appliances or changes in the mandibular arch (ex: loss of mandibular primary second molars) during expansion to minimize the effect of changes that naturally occur during transitional stage of dentition. The movements observed in the mandibular first molars may also be influenced by other factors such as presence or lack of crowding, degree of buccal/lingual inclination of molars before expansion which was not accounted for in this study.

Limitations and future research

This study had a limited sample size due to 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 exams. 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.

This study did not control for proficiency of participants with photography or comfort level with technology. There were variations in the presence and type of fixed appliances in addition to Hyrax[®] during RPE treatment which limited the number of subjects that could be analyzed for the descriptive data for tooth movement. Future study could limit to Hyrax[®]-only patients to assess tooth movement occurring not only at the first molars but also in the rest of the dentition during RPE treatment.

Since this study has shown that DM can accurately identify achievement of treatment goals during RPE treatment, future studies can assess the use of this technology during pre-treatment phase as a screening tool to evaluate the need for interceptive treatment, readiness for comprehensive treatment and during post treatment retention phase to evaluate any relapse. Remote treatment monitoring is applicable for patients undergoing clear aligner therapy as the mechanics and treatment are already incorporated into the aligners. Therefore, a future study assessing the use of DM to monitor frequency of aligner changes and track tooth movement occurring during clear aligner therapy would be beneficial.

CONCLUSION

- I. DM can remotely identify the correction of posterior crossbite.
- II. There was no significant difference in intermolar width measurements obtained with DM, digital model or intraoral exam.
- III. Although, half of the participants (47%) were unsuccessful in using the DM app independently, most participants (71%) found the DM app “easy” to use.
- IV. 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.

- V. During RPE treatment, maxillary first molar crowns were observed in general to translate distal and buccal, extrude, tip buccal and mesial and rotate distal whereas mandibular first molar crowns were observed in general to translate distal and buccal, intrude, tip buccal and distal and rotate mesial. Further studies need to be conducted to confirm these findings.

DISCLOSURE

The license for accessing the DM software and the tools (ex: cheek retractors) needed for the study were provided by DM. None of the authors listed are affiliated with this company or have received any compensations (financial or otherwise) from DM. DM did not have any role in the conception or design of this study.

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APPENDIX I

Qualitative Comments from the Patient Acceptance Survey

Positive

- “Everything was simple and straightforward”^{1*} - Patient
- “First time is always hard, but it got easier after that”¹ - Patient
- “Self-explanatory and user-friendly app”² - Parent
- “I see how it’s more useful in helping with school attendance, so we don’t miss too much school”² - Parent
- “Easy and well explained steps to take pictures”³ - Parent
- “The videos were helpful”⁵ - Parent
- “Great experience”⁵ - Parent
- “I wasn't sure how to take the videos, but the sample videos and messages always told me what to do correctly”⁷ – Parent
- “It’s very easy and convenient. Just follow the sample videos and pay attention to the notifications, so you know if the videos went through or not. If you need a redo, they'll message what needs to be done”⁷ - Parent
- “Easy and fast to take pictures - plus it shows you where to take the pictures”⁸ – Patient
- “It was really easy and fast to use. It gave directions and reminders when I needed to take pictures. Also, it uploads the pictures automatically after I am done, and I don't have to do anything”⁸ – Patient
- “After the first time, it was quick”⁹ – Parent
- “The app and messages worked well”⁹ – Parent
- “The software was excellent at leading through the instructions”¹¹ – Parent
- “It took 2-5 mins when my kid did it”¹³- Parent
- “It was pretty straightforward to use”¹⁴ – Parent
- “We had to do 15 turns on the expander the first round to get the space needed. We came in for expansion check appointment for them to tell us that we needed to do 8 more turns! Having the scan could have saved us lost school time and work”¹⁴ – Parent
- “It was as easy as taking a picture with your phone”¹⁵ - Parent
- “The routine seemed to get easier”¹⁵ – Parent
- “It (ease of capturing photos/videos) improved. You tend to find a simpler way of doing things”¹⁵ – Parent
- “I think this app catches much more than its intended purpose. It can give a clear view of something the patient might be doing wrong or not efficient enough and can be corrected through the app with suggestions and/or tips covering the entire area of dental hygiene and reduce the amount of counter measures that need to be done when the patient does finally come in”¹⁵ – Parent
- “I would prefer to use the DM app instead of coming in for regular checkups. Being in school, we are limited on time”¹⁵ – Parent

Negative

- “As convenient as the app is, for a single-mother of 3 who works 60 hours/week and with my son living in 2 households, it wasn't necessarily as convenient as it’s intended to be”² - Parent
- “The app is very well explanatory, but it takes practice to get better in taking pictures”³ - Parent
- “At times it (the time of capturing photos/videos) got worse”⁴ - Parent
- “The patient got tired of doing it. It was hard to get the green to show up. The delay in the results made it hard to go back and get new images”⁴ - Parent
- “Somehow you need to make it so that results are immediate. Getting the green was hard. Also, you need to be able to skip over the demo videos after the first couple of times”⁴ - Parent
- “The app was easy, but the problem is the availability of the phone - my phone has limited capacity” - Parent
- “Straight forward directions but making videos acceptable by the app was tricky”⁶ - Parent
- “This app is great, but it required more time than I had at the time”⁶ - Parent
- “The time of taking photos didn’t improve. I didn't continue using it for long enough”⁶ – Parent
- “It (time of capturing photos/videos) depends on her mood”⁷ - Parent
- “It (ease of capturing photos/videos) depends on her mood”⁷ - Parent

“It was not easy. We had to repeat taking the pictures a few times” - Parent

“I would forget to take it” – Patient

“The time lapse view of changes did not always work”⁹ – Parent

“I would have enjoyed the progress picture feature if it was working consistently but after a few weeks of it not updating, I stopped trying to see the progress pictures”⁹ – Parent

“Work on the notification system for Android” - Patient

“It took a while for her to get used to doing the videos. It took a fair amount of practice” - Parent

“The app sucks. Every time it said that I took the pictures wrong, but it seemed like I was following instructions. It’s very annoying”¹⁰ – Parent

“It (time of capturing photos/videos) didn’t improve. I kept getting follow up texts”¹⁰ - Parent

“If paying, I would want my child to be seen in person by the doctor”¹⁰ – Parent

“There was a problem with my phone's camera- it was “jumping” its focus”¹¹ - Parent

“It (time of capturing photos/videos) didn’t improve. If my phone worked properly, I would answer yes”¹¹ - Parent

“I think the study is a very good one, but it depends on the condition and performance of parent's camera”¹¹ - Parent

“Camera was slow & laggy compared to regular camera app. There were no opportunities to view photos myself and accept or reject before I submitted”¹² – Parent

“It (time of capturing photos/videos) improved -mostly thanks to giving up. The lack of immediate feedback made improvement unlikely. It's like trying to hit a target without being able to see and adopt after each attempt. If you only get an email a couple days later saying, “a little to the left”, you're never going to get better”¹² - Parent

“It was simple for younger people but when I did this it was crap”¹³ -Parent

“I think it's great if it works for you. I was a little lost so some ‘Help for Dummies’ would be nice. Younger people know how to do this without a problem. I was lost since I am not a very ‘tech’ person in my day-to-day life. I do see the good in it”¹³ - Parent

“It was hard to put the thing (cheek retractor) on” - Patient

“It was hard to get the pictures right” – Patient

“It seemed however we did it, all the scans came back as having to be redone”¹⁴ – Parent

“If it had worked for us and not failing on every scan, I could see how awesome this app could be”¹⁴ - Parent

“It was hard to get clear shots and to keep my daughter from moving because then the app wouldn't read it”¹⁶ – Parent

“I think if the motion detector was more lenient it would be easier to capture but it wants specific angles that sometimes you can't get. It is also hard for my daughter to turn and pull on both cheeks to do the full scan. It frustrated me and didn't make me want to use it every week. Thank you for letting us try it. Sorry it wasn't completed.”¹⁶ – Parent

“I want to help with the research, but my daughter did not want to have the cheek retractor in her mouth. It really hurt her”¹⁷ – Parent

“I only took it once”¹⁷ – Parent

“The cheek retractor really hurt her, and she didn't want to put that in her mouth. Also, it was hard to get the pictures right”¹⁷ – Parent

*Each number corresponds to responses from the same participant