Using an Eye-tracker to Measure Panoramic Interpretation Efficiency between Experienced and Inexperienced Clinicians

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<u>Dedication</u>

To my beautiful wife,

Dr. Leslie Hollevoet

For her unbelievable love and support over these busy years.
For her dedication to being the greatest mother a daughter could have.
For being the wonderful woman you are.

Abstract

Introduction: Panoramic images are an important part of a patient's dental and orthodontic record. They provide broad coverage and are a valuable screening tool for potential abnormalities and normal dental development. Dental students learn much about panoramic image anatomy during dental school but are not usually taught a systematic method of image interpretation. The use of an eye-tracker will allow visualization and statistical analysis of interpretation method to find differences between newer and experienced clinicians. Information gathered can be used to recommend an interpretation method to newer clinicians as they begin their dental career.

Methods and Materials: Two groups of clinicians were created: ten clinicians with more than five years clinical experience (experienced clinicians) and ten clinicians with five years or less experience (newer clinicians). Five panoramic images, three which contained no significant findings and two which had significant findings, were used in the study. An eye-tracker and the eye-tracking software were used to record and evaluate the interpretation methods to find differences between the groups.

Results: Newer clinician's interpretation path entered more areas of pathology or abnormality in portions of the image other than the dentition. Areas of abnormality or pathology within the dentition were entered equally by the interpretations paths of both groups. Newer clinicians had longer interpretation times and their interpretations included more fixation points and covered more image area. Experienced clinicians were quicker with interpretation and showed more of an interpretation pattern.

Conclusions: Newer clinicians are more complete (interpret the entire image), have more fixation points and spend longer time interpreting. Newer clinicians often had no pattern to interpretation, but had interpretation paths which entered areas of pathology or abnormality due to completeness of interpretation. Experienced clinicians showed much more pattern (systematic approach) to interpretation, but were less complete. In both groups, interpretations times were significantly longer when the entire image was interpreted.

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Introduction

Panoramic images are a main component of a patient's dental and orthodontic record. They serve as baselines prior to orthodontic treatment and as guides for mid-treatment decision making. Much can be visualized on a panoramic film: condyles, sinuses, dentition, mandible, nasal bones, maxilla and pathology/abnormalities that may lie in any of these areas.

Panoramic images provide broad coverage making them a useful screening tool. A clinician can use them to evaluate trauma, disease, hard tissue lesions, location of third molars, mixed dentition tooth development and developmental anomalies.[1] Panoramic images are one of the best screening images for evaluation of the tempormandibular joints (TMJ) and they provide visualization of both TMJs on the same image. Because they provide a tomographic type of view of the TMJ, they allow good assessment of the bony anatomy of the articulating surfaces of the condyle and glenoid fossa as well as a good view of the coronoid processes.[2] Panoramic images do not provide fine detail which limits their diagnostic ability, but they can assist in determining the need for other types of imaging.[1]

Information gathered undoubtedly guides treatment planning for patients. Because panoramic films offer much information about patients, it is important to use them to fullest advantage. Dental school teaches panoramic image anatomy but not necessarily a method of interpretation. Method often comes with clinical experience rather than dental school education.

With image interpretation, it is important to use a systematic approach and have a complete understanding of the appearances of normal anatomic structures on the image. Recognition of anatomic structures on a panoramic image can be challenging due to complex facial anatomy, superimposition of structures, changes in projection, and patient movement/positioning problems. It is important to become fluent in identifying the presence and condition of anatomic structures; as absence of normal structure may be the most important panoramic finding.[1]

Establishing an interpretation method early in one's career would seemingly increase efficiency of panoramic image interpretation. This leads to better treatment for the patient as pathology or other significant findings may be realized earlier before a problem manifests into something more obvious radiographically. The use of an eye-tracker would allow visualization and comparison of panoramic interpretation methods among clinicians.

Eye-tracking technology has many applications; which include academics, marketing, neuroscience, flight simulation and other military scenarios.[3] The use of eye-tracking technology in medicine and dentistry allows the ability for better teaching methods and better patient care.

Eye-tracking technology takes advantage of eye anatomy. As light enters the pupil, a portion of light is reflected back out the same path of entrance. Because the path light enters the eye and the path the eye takes when observing an object seldom coincide, the pupil usually appears black. The converse is true if both lie on the same path, which cause the pupil to illuminate. Eye-tracking machines use near-infra red (IR) light to take advantage of this. The light is in line with the path of subject observation allowing the camera to pick up the bright pupil when recording eye movement.[3] (Figure 1)

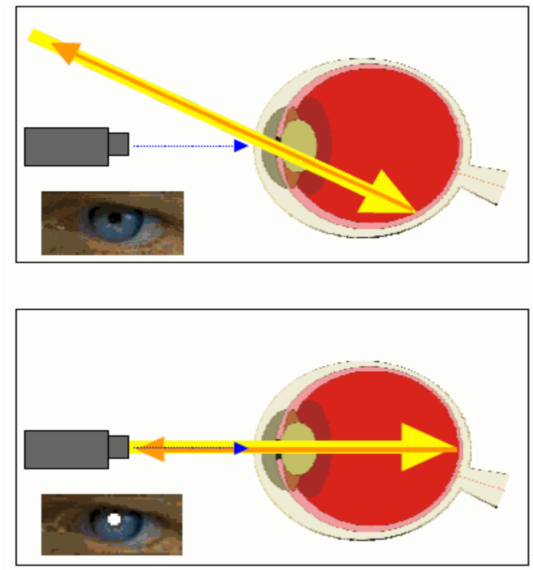

Figure 1-When light source (IR) and camera angle are coincident, pupil appears illuminated

Another advantageous property used by eye-tracking machines relates to the reflectivity of the cornea. When the IR light passes through the mostly transparent cornea, a small portion of the light is reflected back toward the camera and IR light source. The reflection will therefore be visible somewhere on the eye; depending where the camera and IR light are in relation to the eye during eye-tracking. An important point is that this reflection remains in the same place, regardless of where or how the eye turns. Note in Figure 2 the image is in focus but is black and white in color. The lack of detail actually increases an eye-trackers performance by taking away other structures that could interfere with a good reading.[3]

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Figure 2 – ideal pupil illumination and corneal reflection

The two properties mentioned above allow the eye-tracker to efficiently track a viewer's eye movement. When the viewer's eye moves, the pupil moves with it. This allows the eye-tracker to track the center of the viewer's eye. Conversely, as the eye moves the corneal reflection stays in the same place. The fixed reflection provides an "anchor" point for the eye in relation to the camera. Combining these two properties allow for recording the angle of the eye with respect to the stimuli.[3]

Once a focused and properly lit image of the viewer's eye is attained, the eye-tracker discriminates between the pupil and corneal reflection using crosshairs. There will be a white crosshair just to the right of the pupil and a black crosshair just to the right of the corneal reflection. (Figure 3) Consistent views of crosshairs allow the researcher to assure the eye-tracker is tracking the viewer's eye correctly. During eye-tracking, the camera takes pictures 60 times a second and the system determines the position of the pupil and corneal reflection based on the pictures. The system uses the pictures and draws vectors between the crosshairs to determine gaze location and direction.[3]

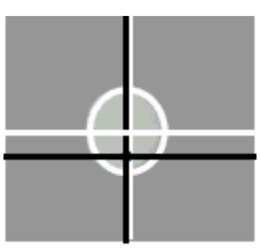
Figure 3 – crosshairs visualized by researcher

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Literature Review

The literature supports the fact that experienced clinicians are more proficient at radiographic interpretation. The advantage of having seen many films during practice allows a mental representation of what is normal. A radiographic abnormality amongst normal structure seems all the more obvious to a trained clinician. What the experienced clinician sees is transferred to his or her brain allowing fast comparison to what normal typically looks like. This allows for accurate and time efficient interpretation.

Eye-tracking has been used extensively in medical radiology.[4-8] It displays eye movements in a series of jumps, called saccades, along with the pauses between saccades, termed fixations.[4] The data is displayed in two dimensions on a computer screen which shows location and duration of fixations. These fixations occur in groups, often termed clusters, which indicate where an observer's attention is directed.[4] The Medical Image Perception Society (MIPS) was organized in 1997 to encourage research and improve education in image perception. Some aims of the MIPS include a) understanding how knowledge or expertise affects the recognition and detection of abnormalities and b) determining how observers find discrete abnormalities in noise-limited images. According to Krupinski et al , eye-tracking can expand our understanding of how knowledge gained from training and supplemented by experience influences diagnostic performance.[5]

It is assumed that experienced clinicians are faster and more efficient compared to residents in regards to radiograph interpretation. Both groups have knowledge in their areas of training, but the experienced group has implemented the knowledge through practice. Does practicing help develop a more systematic method of interpretation or allow for quicker recognition of normal and abnormal structures alike?

In a mammogram interpretation study by Nodine et al, those observers with more experience had the fastest search times when noting breast pathology. Inexperienced observers were less efficient due to more attention paid to potential masses as well as actual pathology.[6] The lack of experience did not allow the observers to quickly determine what was normal and what was pathological. The experienced observers may also have a more efficient search method. Kundel and La Follette compared eye-scanning paths of first-year medical residents to experienced radiologists, who found targets faster in interpretation. The residents had localized central patterns where the radiologists displayed circumferential patterns.[7] Searching in a circumferential pattern does not mean that experienced observers keyed in on numerous areas, as this would take some time due to the numerous possible areas that pathology may reside. The pattern allows for a global visualization of the image so something out of the ordinary can be found.[6] Experience has given observers the knowledge of how normal findings present, so an anomaly becomes quickly apparent.

Nodine and Kundel [4] have proposed a model of visual search that divides interpretation into three pieces. First, observers globally visualize the image for overall pattern recognition. The observer relies on knowledge of anatomy and abnormalities along with what they expect to find in the presented image. Kundel et al [8] found that experienced observers are more efficient in mammogram interpretation because of a rapid global recognition process followed by a holistic search approach, which is similar to the recognition of familiar faces.[9,10] This method leads to detection of breast cancers in less than one second of viewing.[8] The holistic method is in contrast to the search-to-find method, which involves scanning the image in a series of saccades (jumping from point to point). The observer relies on previous global analysis to determine where to direct the first saccade.[8] Once an experienced observer finds an abnormality via the holistic method, more subtle abnormalities are sought using the search-to-find method and knowledge from the initial global visualization.[11]

Nodine and Kundel's [4] second part of the visual search model pertains to focal attention to specific image detail. Observers use central vision to examine potentially abnormal sites. Eye-tracking shows fixation clusters associated with sites of viewer interest, meaning sites of potential pathology or abnormality.[4]

The third part of the visual search model leads from the focal search of specific sites to a decision between abnormality and negative finding. If the observer decides no site of interest is pathological, the film will be thought of as within normal limits. Conversely, the observer may decide on an area being pathological. The decisions can be divided into true-negatives (associated with fewest fixations), true-positives (associated with most fixations), and false-negatives (moderate amount of fixations).[4] The decision portion of the visual search method is where observer error is most likely to occur.[12] The error is a result of an observer deeming an abnormal area normal (a false-negative).

An observer's findings report will indicate any abnormal/pathological findings discovered during an interpretation. When a film is deemed free of pathology, it is considered to be within normal limits. In both situations, there are potential sites were the decision process between pathology and normal finding may have been difficult. If the final decision is no pathology, it is unlikely to show up on the observer's report. In the event that a wrong decision was made, the pathology may be allowed to progress to a more advanced stage. One can go back to the original film and see in hind-sight that indeed there was pathology, but it was missed initially (a false-negative). Eye-tracking can be useful for prevention of such situations. During interpretation, the false-negative receives numerous fixations from the observer. An eye-tracking report can provide areas that received the most fixations (increased dwell time), which would allow for reevaluation by the observer as well as other observers. This feedback could theoretically reduce the amount of missed pathology in early stages.[4] According to Kundel et al [13], when radiologists receive feedback indicating areas of increased dwell, they are 16% more likely to notice the abnormality upon reevaluation.

One may think experienced observers detect more pathology because more time is spent thoroughly interpreting all aspects of the radiograph. Krupinski [14] found the contrary; with experienced observers ending interpretation significantly earlier than inexperienced observers. In the shorter time duration, experienced observers noticed more pathology and had fewer false-positives.[14] Christianson et al supported this, finding that 60% of all radiographic findings vital to patient care were discovered in the first 15 seconds of interpretation.[15] Further, Krupinski [14] found that experienced observers scanned far less image area compared to inexperienced observers, whether the images contained pathology or not. Both groups of observers covered more area in lesion films. [14]

Hypothesis

Hypothesis: Compared with newer clinicians, experienced clinicians will miss fewer “areas of interest” and have a more systematic approach to the analysis of panoramic radiographs.

Specific Aims

-Use an ASL Eye-Trac 6000 to record panoramic interpretations of experienced and inexperienced dentists and orthodontists.

-Use collected data to differentiate interpretation method between the two groups.

-Use the results to recommend a method of interpretation to assist younger clinicians to be more efficient and systematic when viewing panoramic films.

Materials and Methods

An Applied Science Laboratories Eye-Trac 6000 eye-tracking machine was used for data collection. The machine is an entry-level eye-tracker from Applied Science Laboratories.[3] The machine, as pictured in Figure 4, is desk mounted so the observer’s head is in a stabilized position during data collection. This is ideal for the current study as stationary objects were used for observer interpretations.

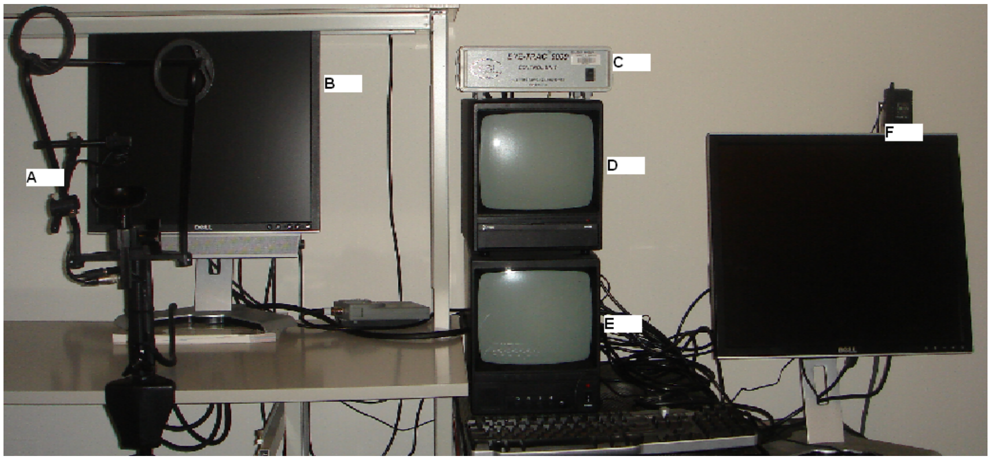

Figure 4 –ASL Eye-Trac 6000 used in study. **A**-chin rest with camera and near IR light source for viewers. **B**-monitor which displayed panoramic radiographs for viewers. **C**-control unit for data recording and analysis. **D**-monitor for researcher which displays same image shown in monitor B. During data collection a crosshair is displayed indicating where viewer is looking on the image. **E**-monitor with image of viewer's eye which is recorded by camera shown in A. The white and black crosshairs discussed above are displayed over the black and white image of the eye indicating the pupil and corneal reflection. **F**-additional monitor used by researcher to open eye-tracker software used for viewer calibration, data collection and data analysis.

Twenty subjects were recruited to participate in this eye-tracking study. All subjects were asked to volunteer in a panoramic film (PAN) interpretation study using an eye-tracker that would "observe how they interpret a panoramic film." The study design and recruitment of subjects was approved by the Institutional Review Board at the University of Minnesota. None of 20 subjects required corrective lenses to view panoramic images on the computer monitor (about 18 inches away). Corrective lenses can have a negative effect on eye-tracking as they create additional reflection. All subjects have graduated from dental school; and some are currently pursuing specialty degrees. Two groups were defined as follows: Group 1-ten dentists in practice for more than five years; Group 2-ten dentists in practice for five years or less. Group 1 consisted of ten orthodontists in the Minneapolis/St. Paul, MN area. Group 2 consisted of four orthodontic residents at the University of Minnesota; three orthodontists in the

Minneapolis/St. Paul, MN area; one pediatric resident at the University of Minnesota; one periodontic resident at the University of Minnesota; and one general dentist from the Minneapolis/St. Paul, MN area.

Five PANs were used in the study. All images were interpreted by a dental radiologist at the University of Minnesota to ensure no pathology or abnormality was overlooked when choosing PANs for the study. Three of the PANs represented anatomy and findings deemed within normal limits. (Figures 5-7) The fourth PAN had an inverted mesiodens near the apex of the upper left central incisor. (Figure 8) The fifth PAN had root resorption on the upper and lower incisors. (Figure 9)

Fig. 5 – considered within normal limits although upper left second premolar erupted out of ideal position.

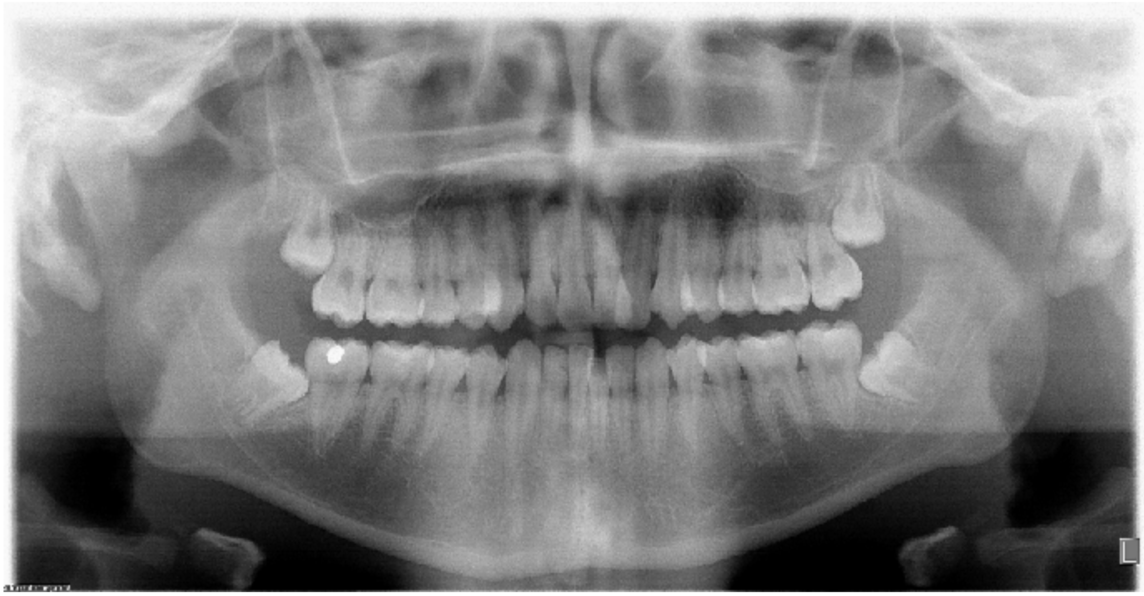

Fig. 6 – considered within normal limits.

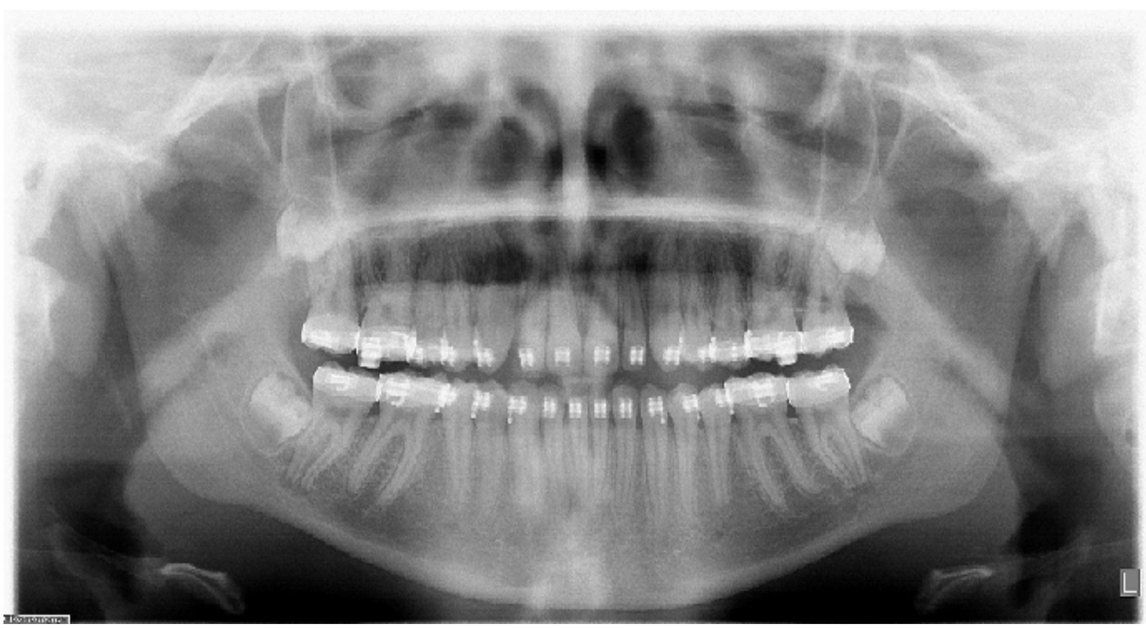

Fig. 7 – Considered within normal limits.

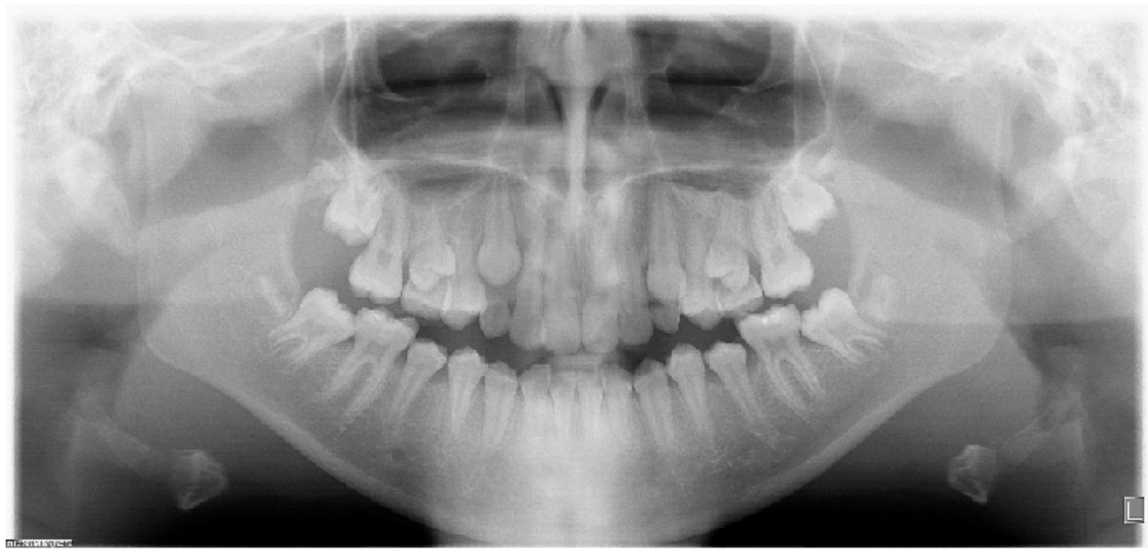

Fig. 8 – Inverted mesiodens near apex of upper left central incisor.

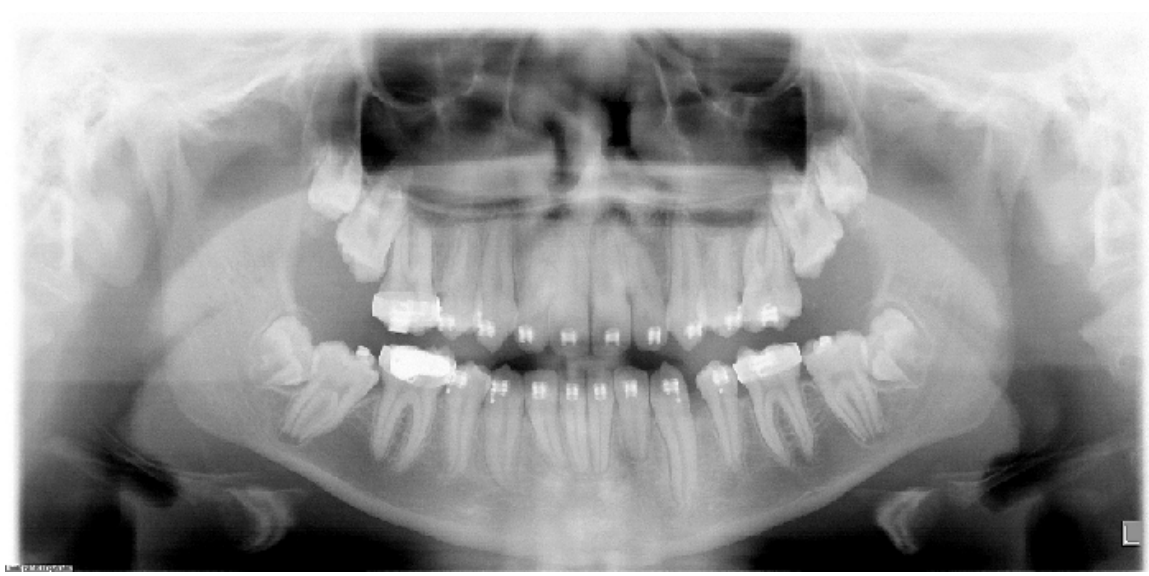

Fig. 9 – root resorption on upper and lower incisors.

Each PAN was manipulated using the Eye-Trac software.[3] The PANs were divided into eight quadrants (areas of interest or AOIs); which created boundaries between anatomical areas. (Figure 10) The eight areas consisted of the condyles (2), the sinuses and maxillary dentition (2), the lower borders of the mandible (2), a portion of the maxillary crowns and the mandibular dentition(2).

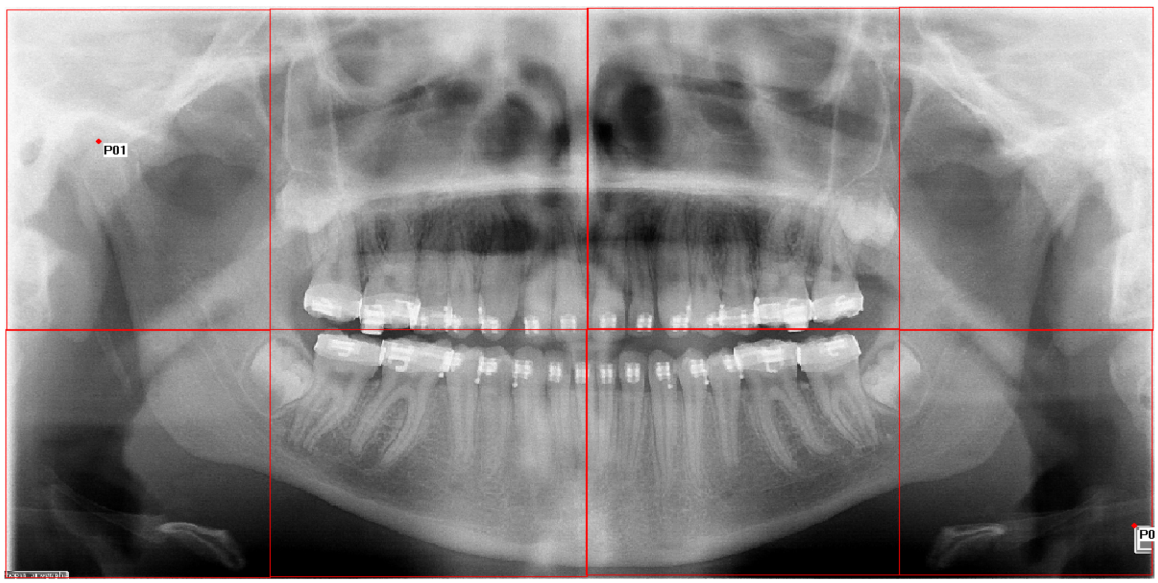

Fig. 10 – PAN divided into eight anatomical quadrants (areas of interest, AOIs) using Fixplot software from Applied Science Laboratories. Top row are AOIs 1-4 and bottom row are AOIs 5-8 (from left to right).

The eight AOIs were defined in the software, but observers could not see them and were unaware of their presence in the study. The software's statistical package can correlate each subject's scan path to these eight AOIs.

In addition to the eight AOIs, two of the PANs with significant findings had additional AOIs, as seen in Figure 11. These AOIs were created using ASL software.[3] Again, subjects were unaware of these AOIs. Incorporating such AOIs into the software allowed subject scan paths to be correlated with discovery of significant findings.

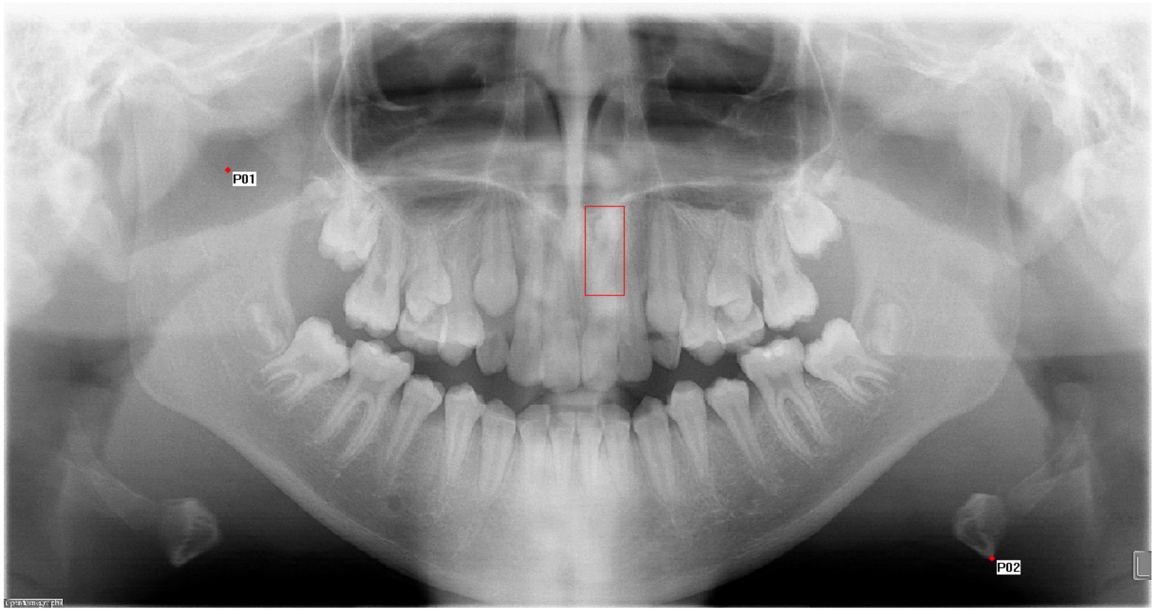

Fig. 11 – PAN with an AOI representing a significant finding (mesiodens). Made using Fixplot software from Applied Science Laboratories.

The AOIs were saved into the analysis software, Eyenal[3], and data collection then began. The eye-tracker was placed in a room with white walls, dim light and no distractions in the subject's field of view. (Figure 4) Prior to data collection, each subject was given the same written instructions:

> You will interpret five panoramic films as you would in your practice. The study is not a test but rather a study to observe your eye movements as you interpret radiographs. Your name will not be linked to data and you will not be tested on any type of findings. So be comfortable and interpret the five films as you would for your patients.
>
> You will first sit down at the eye-tracking machine and I will calibrate it your eye. I will then show you a test film and allow you to interpret for 1.5 minutes to give you a feel for how the study works. Following the test film, you will observe five films with a 1.5 minute time limit per film. You do not need to use the entire 1.5 minutes if you so choose. Following the last film, you will be free to leave with no follow-up. Please ask any questions prior to the study if you wish. Thank you for your participation.

After each subject read the instructions they were free to ask questions for any clarification. If no questions were asked, data collection began. Any questions asked were answered without disclosing any more information than was given in the written instructions.

Prior to showing the PANs, each subject had their eye calibrated to allow for accurate eye-tracking. The calibration screen used can be seen in Figure 12. Subjects were asked to look at each of the nine points and the calibration was saved. Each subject was then asked to view each point again to assure calibration was reproducible. If not, calibration was repeated and checked until correct.

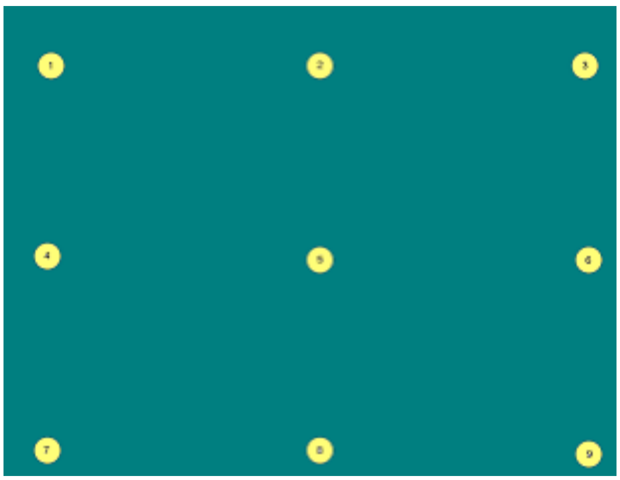

Figure 12- ASL nine point calibration image.

Once calibrated, each subject was presented with a “test PAN” to allow he or she to become comfortable with the viewing conditions and the 1.5 minute time limit. During the test PAN interpretation, the researcher assured the eye-tracker was picking up the subject’s eye consistently. This was done by assuring the white cross-hair remained fixed with the pupil reflection and the black cross-hair remained fixed with the corneal reflection. (Figure 3)

Once each was subject familiar with the process, data collection began. Prior to presenting each image, the display monitor was covered with an opaque sheet of paper to ensure the subject would not begin interpreting prior to recording. To start the recording, the image was loaded onto the monitor, the paper removed and the subject was asked to begin. Once finished, the recording was stopped and the paper replaced so interpretation of the next image could begin. The process was repeated until each subject viewed all five PANs. Once recording of the last PAN ceased, each subject was asked to look at various points on the last PAN displayed to again assure the eye-tracker was accurately recording eye movement. Following this, each subject was free to leave.

The sequence of PAN presentation for each subject was varied to eliminate any subject fatigue or concentration factors. Also, time was limited to about ten seconds between PAN presentations to keep each subject's participation time held to a minimum.

Once all data had been collected, the Eyenal[3] software was used to condense the raw data. Initial data consists of a multitude of segments representing each time the camera started and stopped recording. These segments consist of many of rapid, voluntary eye movements (saccades) which occur when a viewer moves from one point of interest to another. Additionally, the raw data consists of many involuntary eye movements termed microsaccades. The Eyenal[3] software separates saccades and microsaccades from "fixations", which refers to the subject's point of gaze. The software then applies the extracted fixations to the predetermined AOIs discussed above. This allows comparison of subject scan paths to various AOIs. Finally, the data is condensed further to "dwell" files. The dwell analysis counts all consecutive fixations within an AOI and condenses them into one dwell file. Once the subject leaves an AOI, a new dwell file begins in the next AOI. The condensed data was then exported to Microsoft Excel for statistical analysis.

In addition to using data collected by Eyenal, each film interpreted was printed on paper using Fixplot[3] so the scan path could be visualized. There were twenty subjects who each interpreted five films, yielding a total of 100 films. Each film was numerically coded to a master list of clinicians to allow non-biased observation by the author (D.H.). The films were grouped into one of five interpretation patterns (dental only, perimeter to dental, dental to perimeter, circular or no pattern) and checked for interpretation completeness; which means interpreting all eight AOIs (quadrants). The groupings were done twice to ensure accurate results.

Statistical Analysis

Statistics in this study were determined to be significant if below a p-value of 0.05. Two sample t-tests were done to determine significant differences between the means of samples being compared. To test independence between clinician experience and AOIs entered, Fisher exact tests (a version of the chi-squared test) were used.

Results

Data was used to compare interpretation variables between experienced and newer clinicians. Tables 1 and 2 give a global comparison between groups. For example, AOI #3 in Table 1 shows newer clinicians looked in that area 339 total times. Additionally, they stayed in that AOI for an average of 1.25 seconds each time they entered it and a total time of 423.20 seconds. When comparing Table 1 with Table 2, it can be seen that newer clinicians entered each of the AOIs more frequently and spent more total time in each of the AOIs. Experienced clinicians spent less total time, but did

AOI Name	# of times entering AOI	Mean seconds each time AOI entered	Total seconds spent in AOI
1	180	0.79	141.38
2	379	1.16	437.78
3	339	1.25	423.20
4	142	0.80	113.40
5	119	0.46	54.57
6	279	0.88	244.58
7	277	1.04	289.42
8	163	0.48	78.01

Table 1 – times spent in each AOI for newer clinician group

spend longer average times each time they entered one of the AOIs. Both groups spent the majority of time in AOIs 2,3,6 and 7; those of which contain the dentition.

AOI Name	# of times entering AOI	Mean seconds each time AOI entered	Total seconds spent in AOI
1	111	1.13	125.37
2	237	1.31	309.52
3	215	1.48	317.65
4	103	0.99	102.18
5	55	0.66	36.36
6	183	1.14	207.71
7	207	0.97	200.63
8	110	0.65	71.50

Table 2 – times spent in each AOI for experienced clinician group.

Table 3 shows the results for one of the images containing an additional AOI other than the eight quadrants; which includes an inverted mesiodens in the maxillary anterior region. The table shows how experienced clinicians viewed the image compared to newer clinicians. Table 3 shows that newer clinicians entered the AOI containing the mesiodens a total of 17 times compared to experienced clinicians who entered the AOI two times.

Group	# of times entering mesiodens AOI	Mean seconds each time AOI entered	Total seconds spent in AOI
Newer Clinicians	17	0.43	7.26
Experienced Clinicians	2	2.07	4.13

Table 3 – Interpretation of film with mesiodens AOI.

Next, time spent interpreting was compared to whether the AOI containing the mesiodens was entered. These results can be seen in Table 4. It can be seen that clinicians who entered the mesiodens AOI spent an average of 40.50 seconds interpreting compared to 27.17 seconds for those who did not enter the AOI. The interpretation time differences were statistically significant with a p-value of 0.0377.

Entered mesiodens AOI	# Clinicians	Mean seconds spent interpreting	Minimum seconds interpreting	Maximum seconds interpreting	Standard Deviation
Not found	10	27.17	12.10	56.97	13.18
Found	10	40.50	21.22	63.68	13.40

Table 4 – finding mesiodens versus interpretation time.

Table 5 compares experienced versus newer clinicians in regard to entering the AOI containing the mesiodens. Only one experienced clinician entered the AOI containing the mesiodens whereas nine newer clinicians entered it. A version of the chi square test designed for small sample sizes (the Fisher exact test) was used and resulted in a p-value of .0011, meaning the difference between groups was statistically significant.

	Newer Clinicians	Experienced Clinicians	Total
AOI not entered	1	9	10
AOI entered	9	1	10
Total	10	10	20

Table 5 – comparing experienced and newer clinicians with entering AOI containing the mesiodens.

Of all the clinicians who interpreted the image with the mesiodens, newer clinicians spent an average interpretation time of 41.28 seconds compared to 26.40 seconds for experienced clinicians. At the 0.05 level this was statistically significant (using a two sample t-test) with a p-value of 0.0183.

Table 6 shows the comparison between interpretation completeness and interpretation time in regard to the image with the mesiodens. 15 clinicians entered all eight AOIs (quadrants 1-8) and spent an average of 37.46 seconds interpreting. The five who did not enter all eight AOIs spent an average of 22.97 seconds. The difference between groups was statistically significant at the 0.05 level with a p-value of 0.0044.

All 8 AOIs entered	# of clinicians	Mean seconds interpreting film	Minimum seconds interpreting film	Maximum seconds interpreting film	Standard deviation
No	5	22.97	15.63	28.29	4.82
Yes	15	37.46	12.10	63.68	15.09

Table 6 – Interpretation completeness versus time spent interpreting.

The second image containing AOIs other than the eight quadrants included upper and lower incisor root resorption (Figure 10). Tables 7 and 8 show how experienced clinicians interpreted the image compared to newer clinicians. Results between groups were very similar; unlike those seen in the film with the mesiodens (Table 3).

Group	# times entering lower root resorption AOI	Mean seconds each time AOI entered	Total seconds spent in AOI
Newer Clinicians	3	0.53	1.59
Experienced Clinicians	4	0.45	1.79

Table 7 – interpretation of film with root resorption (showing lower root resorption).

Group	# times entering upper root resorption AOI	Mean seconds each time AOI entered	Total seconds spent in AOI
Newer Clinicians	1	0.17	0.17
Experienced Clinicians	1	0.08	0.08

Table 8 – interpretation of film with root resorption (showing upper root resorption).

Next was a comparison of clinicians who entered the lower root resorption AOI versus those who did not. Table 9 shows that seven clinicians entered the root resorption AOI and 13 did not. For those who entered the AOI, average interpretation time was 34.90 seconds. The clinicians who did not enter the resorption AOI spent an average of 28.52 seconds. A two sample t-test to compare the two means yielded a p-value of 0.3782, showing there was not a statistically significant difference between the two groups.

Entered lower root resorption AOI	# of clinicians	Mean seconds spent interpreting	Minimum seconds spent interpreting	Maximum seconds spent interpreting	Standard Deviation
No	13	28.52	9.13	65.26	16.53
Yes	7	34.90	14.63	50.65	11.62

Table 9 – finding lower root resorption versus interpretation time.

Three newer clinicians entered the lower root resorption AOI and four experienced clinicians entered it. The Fisher exact test was used to test independence between experience and resorption found, with the null hypothesis that the two variables are independent. The p-value of the test was 0.6594, which provides no evidence to reject the null hypothesis.

For the upper root resorption, only two of the twenty clinicians entered the upper root resorption AOI. Table 10 shows those who entered it interpreted for an average of 32.47 seconds while those who did not enter the resorption AOI spent an average of 30.56 seconds interpreting the x-ray.

Entered upper root resorption AOI	# of clinicians	Mean seconds spent interpreting	Minimum seconds spent interpreting	Maximum seconds spent interpreting	Standard Deviation
No	18	30.56	9.13	65.26	14.82
Yes	2	32.47	16.12	48.81	23.12

Table 10 – finding upper root resorption versus interpretation time.

Looking at interpretation times on the image with upper and lower root resorption, experienced clinicians spent an average interpretation time of 23.63 seconds compared to 37.63 seconds for newer clinicians. The difference between groups was significant at the .05 level, with a p-value of 0.0295.

Looking again at the image with upper and lower root resorption, completeness of interpretation was compared to time spent interpreting. For this image, 15 clinicians entered all eight AOIs (quadrants), spending an average of 35.53 seconds interpreting. Five clinicians did not enter all eight AOIs and spent an average of 16.43 seconds interpreting. This comparison can be seen in Table 11. The result of a two sample t-test (with unequal variances) for this relationship was statistically significant with a p-value of 0.0008.

All 8 AOIs entered	# of clinicians	Mean seconds spent interpreting	Minimum seconds spent interpreting	Maximum seconds spent interpreting	Standard Deviation
No	5	16.43	9.13	26.81	6.43
Yes	15	35.53	16.12	65.26	14.00

Table 11 – interpretation completeness versus time spent interpreting.

Overall, clinicians spent an average time of 32.32 seconds interpreting an x-ray, with a minimum of 9.13 seconds, a maximum of 71.92 seconds and a standard deviation of 15.76. Of all 100 interpretations, there were 67 instances where the clinician entered all eight AOIs (quadrants) during the interpretation. The average interpretation time for this group was 37.46 seconds, compared to 21.64 seconds for clinicians who did not enter all eight AOIs; as can be seen in Table 12. Whether or not an image had additional AOIs (as two did), had no real effect on interpretation times. Images with additional AOIs had an average of 32.37 seconds of interpretation time compared to 32.16 seconds for those without.

Entered all 8 AOIs	# of interpretations	Means seconds spent interpreting	Minimum seconds spent interpreting	Maximum seconds spent interpreting	Standard Deviation
No	33	21.64	9.13	60.38	12.09
Yes	67	37.46	12.44	71.92	14.75

Table 12 – interpretation completeness versus time spent interpreting.

The following results were acquired through analysis of printed copies of each of the 100 interpretations; an example of such can be seen in Figure 13. First, each interpretation was looked at to see if the interpretation included looking at the condyles. Two groups were created; those where interpretation included looking at both condyles and those where interpretation included looking at one or no condyles. Determination of a clinician looking at a condyle or not was done by observing whether or not there was a fixation point associated with the condyle. The example in Figure 13 shows a clinician fixating on both condyles. Figure 14 shows a clinician that did not fixate on either condyle. Of the 100 interpretations, 68 included the subject looking at both condyles, whereas 32 included interpretations including one or no condyles. Looking further, of the 32 interpretations that missed one or both condyles 19 were from experienced clinicians.

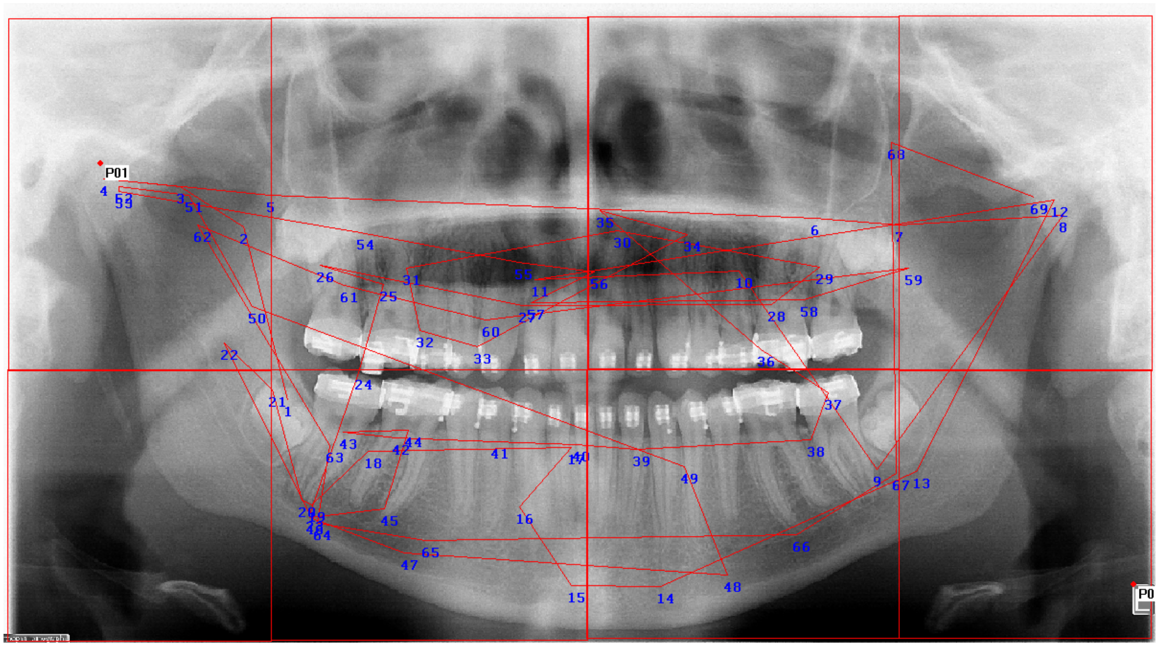

Figure 13 – interpretation that includes observation of both condyles.

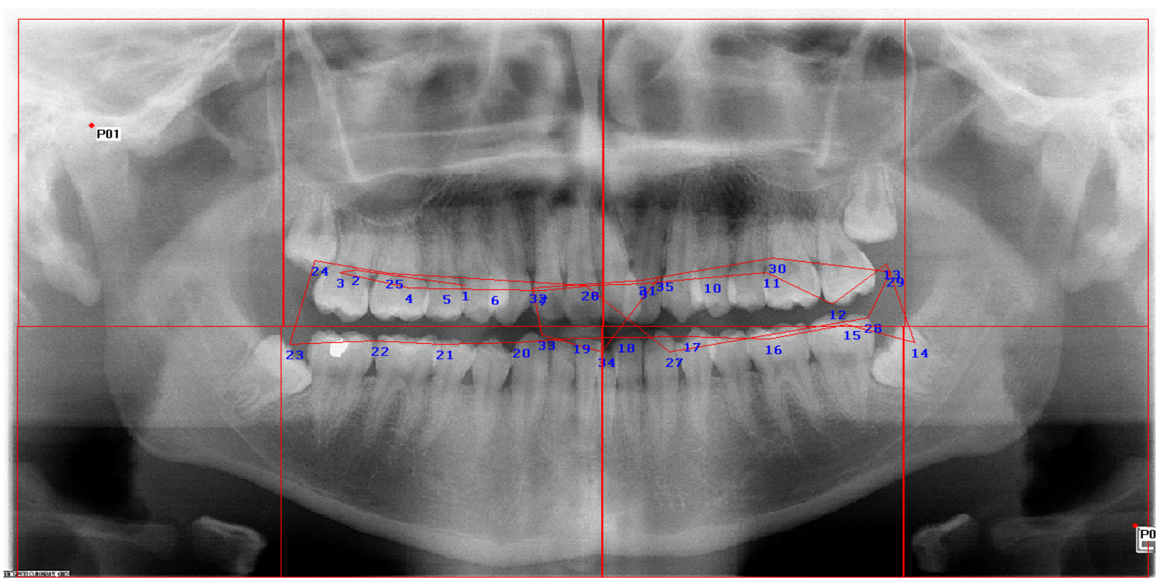

Figure 14 – interpretation that includes observation of no condyles. Interpretation "dental only".

Next, each of the 100 interpretations was grouped according to the pattern of interpretation. Five pattern classifications were created. First was "dental only" (Figure 14) which consisted of an interpretation confined to the dental area of the x-ray only.

Second was “perimeter to dental” (Figure 15) meaning the interpretation began in structures around the dentition first and finished in the dental area. Third (Figure 16) was interpretations going from “dental to perimeter”. Fourth (Figure 17) consisted of “circular” patterns that circled around the image in a visible pattern going back and forth between dental and perimeter. Fifth (Figure 18) was limited to interpretations where “no pattern” could be discerned. Each fixation point has a number so the scan path can be visualized easily. Table 13 shows the number of clinicians in each group along with the numbers of experienced and newer clinicians in each group. Experienced clinicians had a pattern to interpretation 46/50 times, whereas newer clinicians had a pattern 31/50 times.

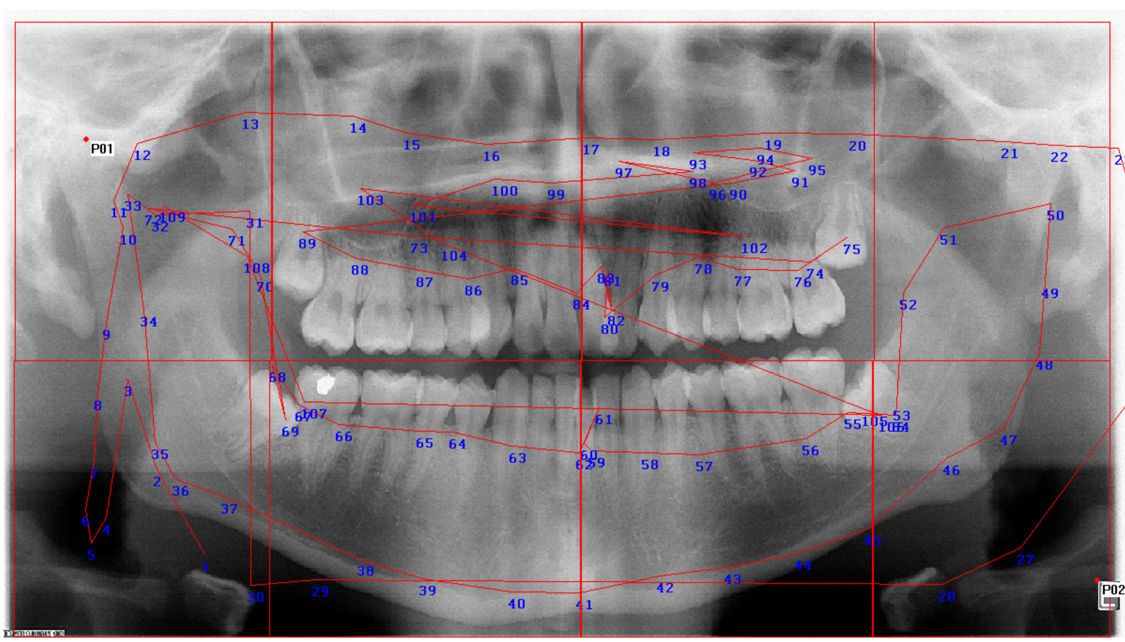

Figure 15 – Interpretation “perimeter to dental”.

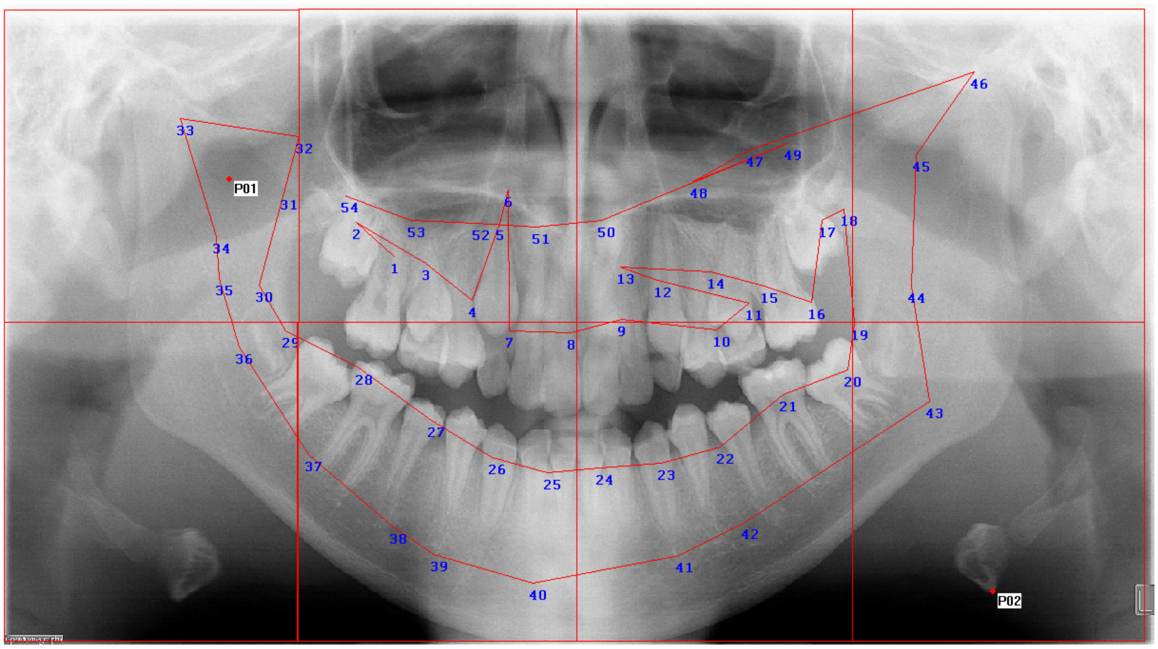

Figure 16 – Interpretation “dental to perimeter”.

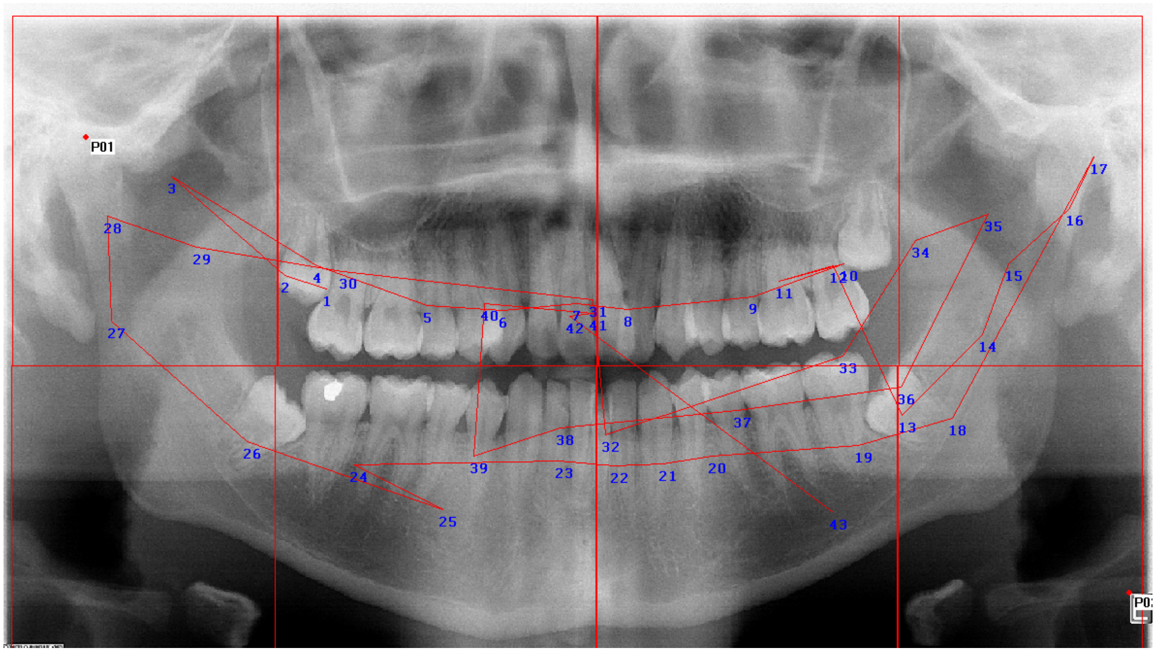

Figure 17 – Interpretation “circular”.

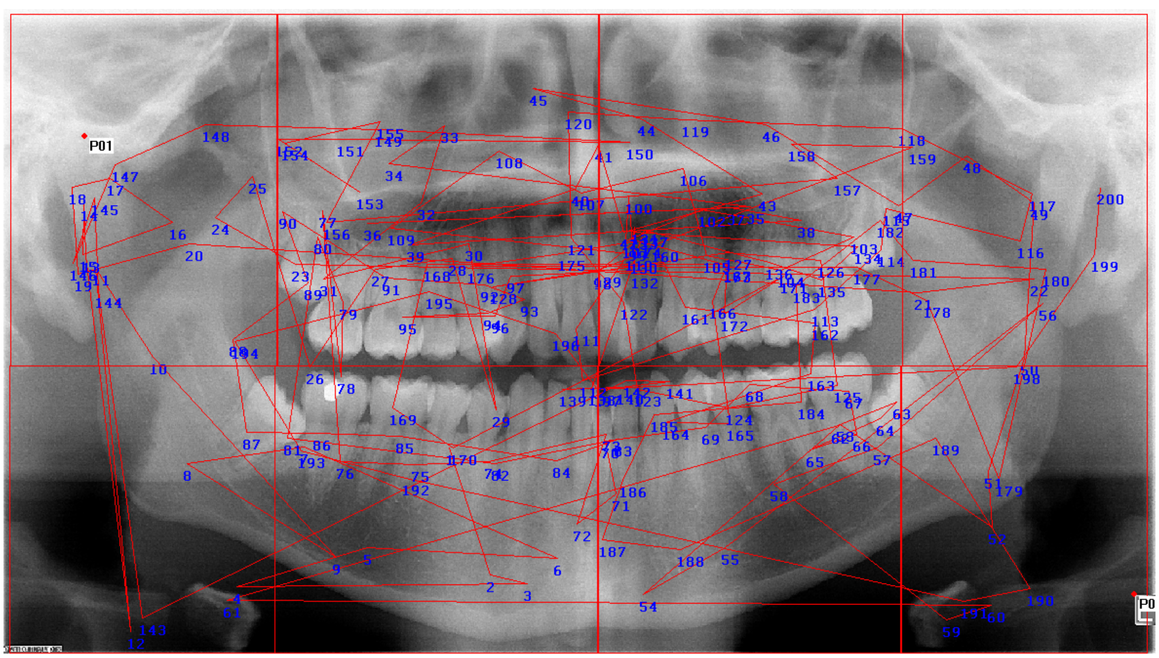

Figure 18 – interpretation “no pattern”.

Pattern	Experienced Clinicians	Newer Clinicians	Total
Dental	7	1	8
Perimeter to dental	9	11	20
Dental to perimeter	15	8	23
Circular	15	11	26
No pattern	4	19	23

Table 13 – Interpretation pattern type among experienced and newer clinicians.

Next, interpretations of the mesiodens and resorption films were evaluated to see which pattern group they should be placed in. These results can be viewed in Table 14. Of the 20 interpretations where the mesiodens or root resorption was found, 12 interpretations had a pattern compared to eight interpretations with no discernable pattern. Also, it important to note the majority of interpretations began in AOI #1 (upper left when looking at film) of all x-rays; regardless of pattern type.

Pattern	Mesiodens	Lower root resorption	Upper root resorption
Dental	1		
Perimeter to dental	3	1	
Dental to perimeter	2	1	
Circular	1	2	1
No pattern	3	4	1

Table 14 – patterns of individual clinicians who found significant AOIs.

Discussion

Krupinski [14] and Nodine et al [6] both noted previously that experienced clinicians spend less time interpreting x-rays. Findings in this study follow the same trend as noted in Tables 1 and 2, with experienced clinicians spending less total time in each of the eight quadrants. Experienced clinicians spent longer average times in each quadrant, but entered each quadrant on fewer occasions. Newer clinicians have not seen enough "normal" x-rays to quickly rule out pathology, which likely accounts for longer interpretation times and the reexamination of quadrants. The first piece of Nodine and Kundel's model of visual search explains how observers first globally search an image for overall pattern recognition.[4] An observer relies on previous knowledge of what is normal and what is not; which implies experience to be a key ingredient to an efficient global search. Newer clinicians lack the previous experience; requiring them to spend more time "searching" for abnormalities that may be present.

With experience one would predict a clinician to miss fewer abnormalities or variations of normal when viewing an image. Krupinski [14] found experienced clinicians noticed more pathology in a shorter duration of time compared with newer clinicians. Although similar results were expected with panoramic interpretation; the current study veered from these predictions. Table 3 shows newer clinicians entered the mesiodens AOI 17 times compared to two times for experienced clinicians. Table 5 shows how this equated to nine newer clinicians and one experienced clinician entering the mesiodens AOI (some clinicians looked at it more than one time), which was statistically significant. Tables 7 and 8 show the two groups entered the root resorption AOI equally in the image containing maxillary and mandibular incisor resorption. Finding reasons for this difference in results is difficult. It needs to be understood that just because newer clinicians entered the AOIs, such as the mesiodens, doesn't mean they "knew they saw it." Seeing something and mentally processing the fact there's something of significance to be seen are two different situations. For example, look at Figure 19.[16] What can be seen; a type of design or hidden message? Just because one looks at this image, or a radiograph for that matter, doesn't mean one always sees what is there. This being said, the study cannot account for who processed what was fixated on but only that is was looked at. Further study, perhaps with the use of post-interpretation questionnaires, need to be done to compare AOIs seen with what was mentally processed.

Figure 19 – the word "LIFT" written in an illusionary way.

Another factor to consider is experience itself. As a radiologist, you are expected to interpret x-rays and seek out all that is bad or abnormal. In orthodontics panoramic images are typically not taken for pathological detection, but rather to evaluate root position/condition so treatment can be altered accordingly. An experienced radiologist will likely become more and more proficient at detecting abnormalities as years go by. In orthodontics, an experienced clinician becomes more proficient at evaluating root positions and how they need to be altered for treatment finishing. Perhaps the proficiency experience provides in some areas may also detract from others. An experienced orthodontist may become so focused on how to continue treatment by looking at tooth anatomy and root angulations that screening for pathology becomes and afterthought.

This would support the fact newer clinicians found more pathology unassociated with the dentition, whereas results were similar with root resorption detection.

The results of this study are interesting in regard to interpretation completeness (entering all eight quadrants) and time spent interpreting. Tables 6, 11 and 12 show that clinicians who entered all eight quadrants spent significantly longer time interpreting than clinicians who did not enter at all quadrants. It can be stressed here that although efficiency is important, completeness is of equal importance. Being efficient means not wasting time or energy getting to a desired endpoint; but keep in mind that taking the extra time to be complete is not inefficient.

Table 4 compared time spent interpreting to whether or not the AOI with the mesiodens was entered. Those clinicians who entered the AOI spent significantly longer time interpreting compared to those who did not enter it. This finding directs importance to the results in Tables 6, 11 and 12 in that taking enough time to interpret images is important; as here it resulted in finding abnormality.

Each interpretation was printed on paper and evaluated by the principal investigator (D.H.). Though seemingly subjective to have one examiner classify the interpretations; the process was relatively straightforward and the findings are interesting. The effect of orthodontics on the tempormandibular joint is a point of controversy and the results of the study seem to show this. Of the 100 interpretations, 68 interpretations included looking at both condyles. Of the 32 that did not look at both, 19 were from experienced clinicians. None of the 19 experienced clinicians who did not look at both condyles routinely mount patient study casts or routinely place emphasis on TMJs when treatment planning. This example shows how treatment style may lend to interpretation style. This being said, it is important to observe both TMJs as the bony anatomy of the articulating surfaces of the condyle and glenoid fossa can be visualized on a panoramic image.[2]

Defining and grouping interpretation patterns and comparing them with the results discussed above would help with finding an efficient pattern. Table 13 shows that of the 50 interpretations by experienced clinicians, 46 showed patterns that could be placed into one of the four groups. There were fewer newer clinicians showing a distinct pattern, with 19 having no discernable pattern. These findings are in agreement with those of Kundel and Lafollette[7], where they found experienced radiologists to have circumferential patterns of interpretation. The fact experienced clinicians show more pattern to interpretation leads one to think they would find more abnormalities; which was not the case as noted in previous discussion. Though most experienced clinicians had a pattern of interpretation, they were not necessarily complete. Many of the experienced interpretations did not include entering all quadrants, seven included only dentition and most included fewer fixation points compared to newer clinicians. Krupinski[14] also found that experienced observers scanned far less image area compared to inexperienced observers; but in contrast to the current study, experienced observers found more pathology.

Many of the newer clinicians who entered the AOI with the mesiodens and root resorption did so with interpretations that had no pattern, but did have many fixations points. Table 14 shows that of the 20 interpretations where these AOIs were found, twelve had a pattern to interpretation. It seems that newer clinicians found most AOIs through completeness, but with no real pattern. Experienced clinicians often were not complete, but showed pattern to interpretation. Adding the completeness of newer clinicians with the interpretation pattern of experienced clinicians would likely yield a more efficient interpretation method.

The hypothesis of this study predicted experienced clinicians would miss less AOIs and be more systematic in interpretation. The results of the study show that newer clinicians entered more of the abnormal AOIs; which contradicts the first part of the hypothesis. Experienced clinicians showed more pattern to interpretation, indicating a system to the way they interpret a panoramic image. This systematic approach to interpretation supports the second portion of the hypothesis.

Conclusions

Panoramic films are a great screening tool and a wealth of information can be found within them. A recommendation for better utilization is to develop an interpretation pattern and look at all portions of the x-ray; perhaps mentally dividing it into eight quadrants to assure it is interpreted completely. Once interpreted and areas of significance diagnosed and/or noted; switch gears and use it as a clinical tool in evaluating root positions, etc. The key is not to lose site of the big picture as a panoramic film may have a lot to offer. Clinicians are encouraged to use the results of this study to develop a method of interpretation to maximize efficiency not only sooner in practice, but for the road ahead.

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