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Research

Visual scan behavior of new and experienced clinicians assessing panoramic radiographs

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ABSTRACT

Objective: The aim of this study was to examine and compare the visual scan behavior of clinicians with different levels of experience during assessment of panoramic radiographs.

Methods: The visual scan paths of 20 dentists, 10 with 5 years of clinical experience or less (new clinicians) and 10 with more than 5 years of clinical experience (experienced clinicians), were recorded as they assessed five panoramic radiographs. Differences between groups were tested for statistical significance, and associations between level of clinical experience, viewing time, completeness, and detection of abnormality were computed.

Results: Experienced clinicians were significantly quicker ($P < 0.001$) and, more often than new clinicians, had a discernible scanning pattern. New clinicians often had no pattern to radiograph assessment, but they scanned the radiographs significantly more completely ($P < 0.001$), and their gaze scan paths entered more areas of abnormality. There were significant positive correlations between viewing time and completeness ($P < 0.001$), and between viewing time and detection of abnormality ($P = 0.042$) but not between level of clinical experience and detection of abnormality ($P = 0.054$).

Conclusions: Experienced clinicians have a faster and more systematic approach to panoramic radiograph assessment but tend to be less complete than new clinicians.

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1. Introduction

A panoramic radiograph (PAN) is an important component of a patient's dental record. Its broad coverage makes a PAN useful in the evaluation of dental development and developmental anomalies, location of third molars, temporomandibular joint morphology, trauma, and pathology [1]. Traditionally, dental schools have educated students extensively in panoramic radiographic anatomy, but not all of them teach a systematic method of radiographic image assessment. This is remarkable, as establishing an assessment method early in one's career would seemingly increase the efficiency of radiographic image assessment. This, in turn, may result in earlier recognition of abnormality or pathology, a higher standard of clinical care, and better treatment outcomes.

It appears that an efficient method of radiographic image assessment is often developed with clinical experience. More

experienced clinicians have been shown to be faster and more accurate at radiographic image assessment than less experienced clinicians [2–5]. Their broad knowledge base, particularly knowledge of the normal, built up by viewing large numbers of radiographs, enables them to quickly compare a radiograph with a mental representation of a typical normal image, which allows for rapid identification of abnormalities and more accurate and time-efficient interpretation [6]. For instance, in mammogram interpretation studies, the most experienced observers had the fastest search times in the detection and confirmation of breast masses, whereas inexperienced observers were less efficient and their search was often distracted by image artifacts that captured their visual attention [5,7]. Although they scanned far less image area and spent less time on image assessment, experienced observers noticed more pathology and had fewer false positive findings than inexperienced observers [8].

Although PANs differ significantly from mammograms in their complexity and coverage of the patient's regional anatomy, it is conceivable that with their assessment, too, a relationship exists between level of clinical experience and image assessment efficiency. Until now, no studies have addressed the visual sampling

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strategies of clinicians assessing PANs, and it is unknown whether any consistent method of image assessment is developed with clinical experience, or if a consistent method can improve the detection of abnormalities. Therefore, we aimed to examine and compare the PAN assessment methods of dentists with different levels of clinical experience. We hypothesized that more experienced dentists would have a quicker and more systematic approach to image assessment.

2. Methods and materials

The study protocol had Institutional Review Board approval (University of Minnesota, 0906P67401). Informed consent for eye-position recording was obtained from all participants. Patient informed consent for the use of anonymized radiographs was not required.

2.1. Observers

Twenty dentists participated as observers. None of them required corrective lenses. The observers were divided into two equal-sized groups: dentists with practice experience of 5 years or less (new clinicians) and dentists with practice experience of more than 5 years (experienced clinicians). The group of new clinicians consisted of four orthodontic residents, three orthodontists, one pediatric dental resident, one periodontal resident, and one general dentist. The group of experienced clinicians consisted of 10 orthodontists. All observers had received similar training in the assessment of PANs and used this type of radiograph on a regular basis in their clinical practice.

2.2. Panoramic radiographs

Five digital PANs, one showing a late mixed dentition and four showing early permanent dentitions, which had been taken as part of orthodontic diagnostic records on an orthopantomograph OP100D x-ray machine (Instrumentarium Dental, Tuusula, Finland), were used as a test set. Three of the PANs showed normal radiographic anatomy, whereas the fourth and the fifth PAN showed an inverted mesiodens near the apex of the maxillary left central incisor and apical root resorption of the mandibular incisors, respectively, as significant findings. Mesiodentes and apical external root resorption of incisors have been reported to be prevalent in 0.15% to 1.9% [9] and 8.2% to 15.0% [10,11] of the general population, respectively. All PANs were read by an oral radiologist before the study to ensure that no abnormality or pathology was overlooked.

Each PAN was digitally divided into eight areas of interest (AOIs) using dedicated software (Eye-Trac, Applied Science Laboratories, Bedford, MA). Additional AOIs corresponding to the mesiodens and the area of root resorption were created in the two PANs with significant findings. This image compartmentation (Fig. 1) was invisible to the observers and was used to correlate each observer's visual scan path to the AOIs. The PANs were displayed on a 19-inch computer monitor with landscape screen orientation at a resolution of 1280 × 1024 pixels (1908FPC, Dell, Round Rock, TX).

2.3. Viewing procedure and data collection

A desk-mounted eye-tracking machine (Eye-Trac 6000, Applied Science Laboratories) was used to monitor each observer's visual scan path during assessment of the PANs, as detailed below. During data collection with this type of machine, the observer's head is stabilized in a chin rest, which is considered ideal for viewing stationary objects [12]. The machine was placed in a room with

white walls, dim light, and no distractions in the observer's field of view.

The observers were asked to assess the PANs as they would for their patients and to indicate when they were finished with the assessment of each PAN. No information was given on the presence or absence of abnormalities or pathology to not influence the eye-movement pattern or reinforce the need for an extensive search [13]. The observers were informed that the study was not performed to test their diagnostic skills, their name would not be linked to any data, and each PAN would be displayed for 90 seconds unless they chose to end the assessment early. The display time was chosen on the basis of an initial trial, in which no PAN assessment took longer than 60 seconds. For the purpose of the present study, an extra 50% was added to this time span to not influence the participants to go through the radiographs more quickly than they would normally do.

Each observer viewed the PANs at an eye-to-monitor distance of 45 cm. Before the viewing procedure, the eye-tracking machine was calibrated for each observer using a nine-point calibration image [12]. The pretrial calibration patterns were used to determine proper alignment of the eye-movement pattern relative to the image. Each observer viewed a practice PAN to gain familiarity with the display, the recording procedure, and the time limit. During this practice run, the operator confirmed that the eye-tracking machine picked up the observer's eye position consistently.

Data collection began with the simultaneous display of a PAN on the monitor and the start of eye-position recording. The sequence in which the PANs were shown was randomized for each observer. Once the observers indicated that they were finished with their assessment, eye tracking was discontinued, and the recording was stopped. The process was repeated until each observer had viewed all PANs. For post-trial calibration, each observer was asked to look at various points on the last PAN displayed. The post-trial calibration patterns were used to check for head movement during data

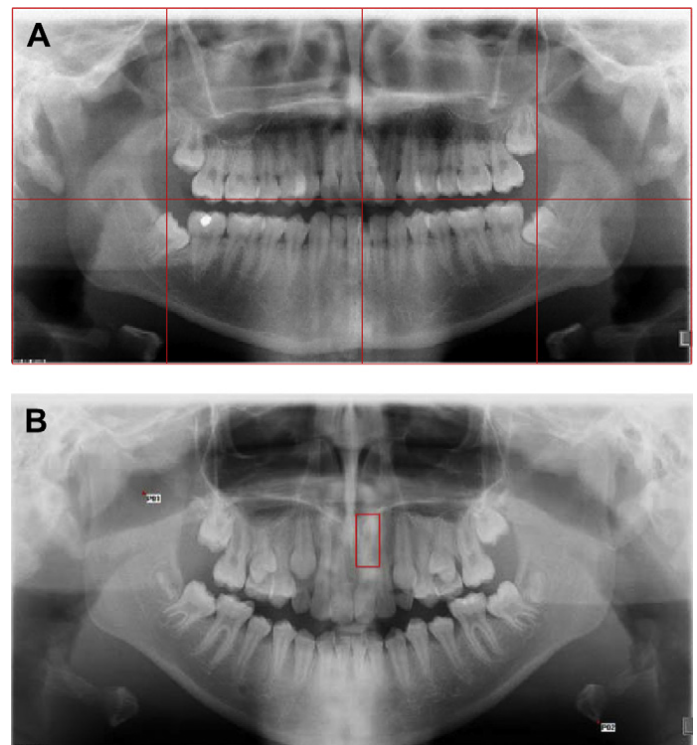


Fig. 1. Image compartmentation. (A) Panoramic radiograph (PAN) divided into eight areas of interest (AOIs). (B) Area of interest corresponding to the mesiodens as an example of the additional AOIs created in the PANs with significant findings.

collection and to assure that the eye-tracking machine accurately recorded the observer's eye positions. A single operator proctored the experiment.

Visual scanning consists of moving the axis of gaze over the image in a series of saccades interspersed with fixations landing on image features. Tracking the axis of gaze produces a pattern of successive fixations called a scan path [4]. Whereas saccades are too fast for information to be gathered, fixations represent the location of conscientious attention [14]. Therefore, the raw eye-movement data were grouped into fixations [12], with each fixation having both a duration and an x, y coordinate location representing a specific point on the image. The fixations were then applied to the AOs to allow comparison of the observers' scan paths. Each PAN was printed, with the scan path visualized as a series of dots indicating the center of the fixations connected by straight lines, and numerically coded to allow nonbiased evaluation. The scan paths were evaluated for viewing completeness (i.e., the scan path entering into all eight AOs), and detection of significant findings, namely, the scan path entering into the additional AOs corresponding to the mesiodens and the area of root resorption.

Each of the 100 scan paths was assigned to one of five visual scanning patterns: dental only, periphery to dental, dental to periphery, circular, or no pattern (Fig. 2). These patterns are characterized as follows: the pattern "dental only" is confined to the dentition; the pattern "periphery to dental" begins in the periphery (i.e., structures around the dentition) and finishes in the dentition; the pattern "dental to periphery" begins in the dentition and finishes in structures around the dentition; the pattern "circular" circles around the image, going back and forth between the dentition and the periphery; and "no pattern" described scan paths without discernible pattern. It was then determined whether

a discernible scanning pattern was used, and whether the use of a pattern depended on the level of clinical experience.

2.4. Statistical analysis

Mean values and standard deviations of the viewing time were calculated for each group of clinicians. Differences between groups were tested for statistical significance using a Mann-Whitney rank sum test after the data had been tested for normality (Kolmogorov-Smirnov test). Differences among PANs were tested for statistical significance using Kruskal-Wallis one-way ANOVA on ranks. Fisher's exact test was used to examine the significance of the associations between level of clinical experience and viewing completeness, level of clinical experience and detection of significant findings, and viewing completeness and detection of significant findings. Point biserial correlation coefficients were calculated to determine the correlations between viewing time and viewing completeness, and viewing time and detection of significant findings. Statistical analyses were performed using SigmaStat 3.5 (Systat Software, Point Richmond, CA) with $P < 0.05$ considered statistically significant.

3. Results and discussion

All PAN assessments were ended before the 90-second time limit. The viewing time (SD) per PAN was 39.7 (14.7) seconds in the group of new clinicians and 25.1 (13.5) seconds in the group of experienced clinicians. Although the difference between the groups was statistically significant ($P < 0.001$), the viewing times did not differ significantly among PANs ($P = 0.880$).

In the group of new clinicians, 88% of the PANs were viewed completely in that the scan path entered all eight AOs, whereas in

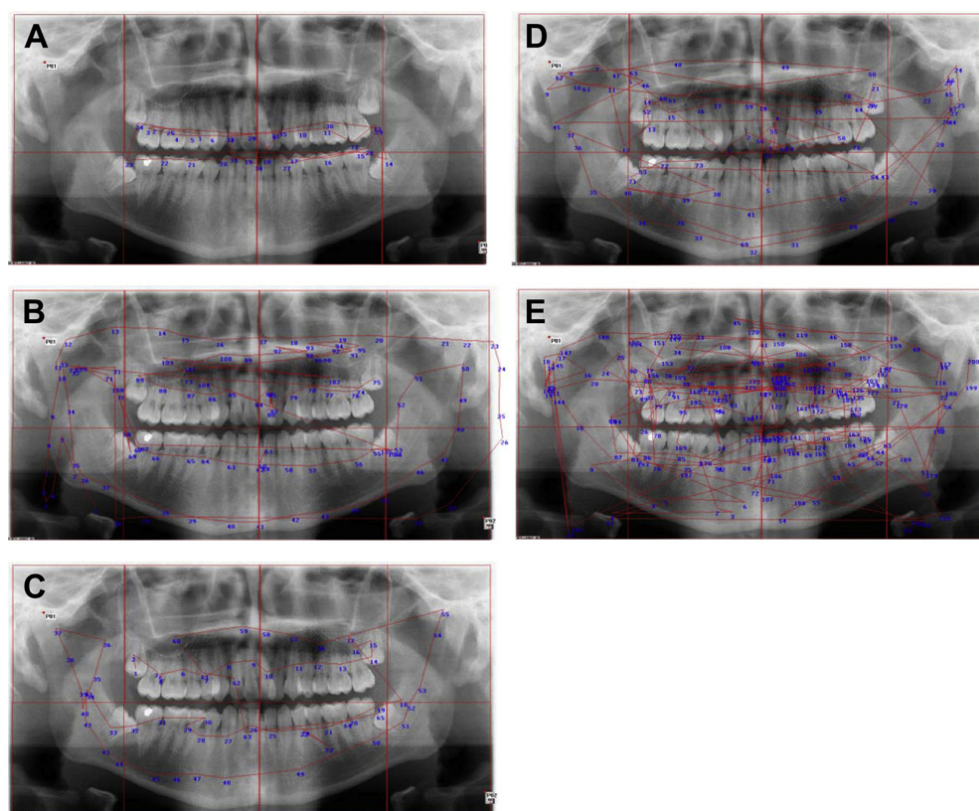


Fig. 2. Examples of the visual scanning patterns: (A) dental only, (B) periphery to dental, (C) dental to periphery, (D) circular, and (E) no pattern. The gaze scan paths are visualized as numbers indicating the center of the fixations connected by straight lines.

Table 1

Percentage of mesiodens and areas of root resorption detected by new and experienced clinicians, namely, scan paths entering into the additional areas of interest corresponding to the significant finding

Group	Mesiodens	Root resorption
New clinicians	90	30
Experienced clinicians	10	40

the group of experienced clinicians, only 48% of the PANs were viewed completely. Statistical testing revealed that the viewings of the new clinicians were significantly more complete than those of the experienced clinicians ($P < 0.001$).

In the group of new clinicians, 60% of the significant findings were detected in that the scan path entered into the additional AOIs corresponding to the mesiodens and the area of root resorption, whereas in the group of experienced clinicians, only 25% of the significant findings were detected. Details are shown in Table 1. There were no statistically significant associations between level of clinical experience and detection of significant findings ($P = 0.054$), or viewing completeness and detection of significant findings ($P = 0.471$).

Point biserial correlation coefficients (r_{pb}) indicated statistically significant positive correlations between viewing time and viewing completeness ($r_{pb} = 0.47$, $P < 0.001$), and viewing time and detection of significant findings ($r_{pb} = 0.31$, $P = 0.042$).

Experienced clinicians followed a discernible scanning pattern 92% of times, whereas new clinicians followed a pattern 62% of times. Table 2 shows the percentage of scan paths falling into the various scanning-pattern categories.

The present results support the hypothesis that experienced clinicians have a quicker and more systematic approach to PAN assessment than new clinicians. The significantly shorter viewing times for experienced clinicians are in accordance with image interpretation studies using chest x-ray films [3] and mammograms [5,7,8]. It is believed that experienced clinicians are more efficient at assessing these types of images because they use a holistic search approach [6]. The holistic approach, a global analysis of the visual input of the entire retinal image, is in contrast to the search-to-find method which involves scanning the image in a series of saccades, that is, jumping from point to point [6].

Efficiency combines the concepts of time use and quality, and with increasing experience, clinicians have been reported to miss fewer abnormalities. For instance, when searching mammograms for breast masses, experienced radiologists detected more pathology in a shorter time than less experienced radiology residents and technicians [5,8]. Although similar results were expected in the present study, the findings do not support these expectations. This may be the consequence of the observers' objective during image assessment. Whereas radiologists typically read x-ray films with the objective of assessing the imaged anatomical structures for normality or abnormality, dentists' objectives may be more diverse and may include aspects of treatment planning. In orthodontics, for instance, PANs are often taken midtreatment to evaluate root positions. When viewing a PAN, an experienced orthodontist may primarily focus on how to alter root positions to achieve an ideal

treatment result, and screening the image for abnormality may become secondary.

It must be noted that, for a small feature—normal or abnormal—to be detected, its image must be projected onto the fovea. However, covering a feature with foveal vision does not in itself guarantee detection [15]. As the observers in the present study were not tested on any findings, the fact that an observer's gaze scan path entered an AOI containing a significant finding does not exclude the possibility of a recognition error.

Similar to a mammogram interpretation study, in which inexperienced observers covered more image area than experienced observers [8], the PAN assessments of the new clinicians in the present study were more complete than those of the experienced clinicians. In addition, there was a significant positive correlation between viewing completeness and viewing time. It is reasonable to assume that the less experienced clinicians kept moving their gaze around the scene while they looked at the PANs, covering more image area with longer viewing times.

The present study also revealed a significant positive correlation between viewing time and detection of significant findings. From pulmonary nodule searches in chest x-ray films, it has been concluded that the probability that a vigilant observer will detect a nodule depends, among other factors, on the search duration [3,16]. However, there seems to be a limitation on the duration of discovery search [16]. The present results suggest that, for dentists assessing PANs, the duration becomes more limited with increasing experience. That may be attributed to a busier practice environment and shorter time available for radiograph assessment or to the higher self-confidence level of an experienced dentist compared with a less experienced dentist.

From the visual scan paths, it appears that all clinicians used a method similar to the search-to-find method when assessing PANs. There are several possible explanations for this observation. In a PAN, the entire image cannot be acquired in detail during one fixation. This causes the observer to move the eyes around the scene. Furthermore, a holistic search approach might not work for the detection of subtle abnormalities in complex x-ray films, such as PANs, where abnormality can be multifold and represent the presence, absence, or alteration of objects with various degrees of radiodensity. This idea is supported by the finding that obvious abnormalities in chest x-ray films are detected almost instantaneously by comparing the radiograph with a previously learned concept of normal whereas subtle abnormalities, in contrast, are found only through systematic search [3].

More often than new clinicians, experienced clinicians had a system to the way they assessed a PAN. This finding is consistent with the more systematic scanning patterns that have been reported for experienced observers when searching for bone fractures and pulmonary nodules [2,4]. These differences in scanning patterns have generally been attributed to changes in cognitive schema brought about by training and experience [2,17]. However, the present results suggest that the patterns are not uniform, and there is no consistent method of image assessment developed with clinical experience.

It seems that the use of a systematic scanning pattern is not critical for the detection of abnormality as long as all relevant areas are fixated and thus sampled. This assumption is corroborated by a study on pulmonary nodule search in chest x-ray films that found that most nodules could have been detected by random fixations [16]. The researchers concluded that, for covering nodules, systematic scanning is no more effective than random scanning [16]. In the present study, many of the new clinicians who entered the AOIs with the mesiodens and root resorption did so with scan paths that had no discernible pattern but many fixation points. In

Table 2

Percentage of scan paths falling into the various scanning pattern categories for new and experienced clinicians

Group	Dental only	Periphery to dental	Dental to periphery	Circular	No pattern
New clinicians	1	11	8	11	9
Experienced clinicians	7	9	15	15	4
Total	8	20	23	26	23

contrast, clinicians who used the pattern “dental only” tended to miss the significant findings as they did not fixate the relevant areas. An optimal image assessment strategy may, therefore, consist of scanning the entire x-ray film with closely spaced fixations. Such a strategy is not, in fact, observed and would require a relatively long time for completion [16].

While undoubtedly training and the knowledge of how normal and abnormal findings present are essential for the ability to detect abnormalities on PANs, it appears that several years of clinical experience are not. Experience may improve the effectiveness of scanning strategies for discovering known targets [7]; however, for unknown targets, individual observer characteristics and diagnostic attitude may have a stronger influence on accuracy than the length of clinical experience [5,18].

4. Conclusions

When assessing PANs, new clinicians spend longer time viewing, have more fixation points, and tend to be more complete than experienced clinicians, who more often have a systematic approach to image assessment but tend to be less complete. Clinicians are encouraged to utilize a scanning pattern that ensures complete coverage of the image and spend adequate search time to maximize detection of abnormalities.

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