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Original Article

Sequential Test Selection by Quantifying of the Reduction in Diagnostic Uncertainty for the Diagnosis of Proximal Caries

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ABSTRACT

Background: In order to determine the presence or absence of a certain disease, multiple diagnostic tests may be necessary. Performance of these tests can be sequentially evaluated.

Aims: The aim of the study is to determine the contribution of the test in each step, in reducing diagnostic uncertainty when multiple tests are sequentially used for the diagnosis.

Study Design: Diagnostic accuracy study

Methods: Radiographs of seventy-three patients of the Department of Dento-Maxillofacial Radiology of Hacettepe University Faculty of Dentistry were assessed. Panoramic (PAN), full mouth intraoral (FM), and bitewing (BW) radiographs were used for the diagnosis of proximal caries in the maxillary and mandibular molar regions. Diagnostic performance of radiography was sequentially evaluated by using the reduction in diagnostic uncertainty.

Results: FM provided maximum diagnostic information for ruling in potential in the maxillary and mandibular molar regions in the first step. FM provided more diagnostic information than BW radiographs for ruling in the mandibular region in the second step. In the mandibular region, BW radiographs provided more diagnostic information than FM for ruling out in the first step.

Conclusion: The presented method in this study provides the clinicians with a solution for the decision of the sequential selection of diagnostic tests for the correct diagnosis of the presence or absence of a certain disease.

Key Words: Test sequence, reduction in uncertainty, proximal caries, radiographic methods

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Introduction

Diagnostic tests are used to confirm the presence or absence of the disease in the diagnostic process. When disease status and test results are binary, there are two basic measures of accuracy of the diagnostic test: true positive rate (TPR, sensitivity) and true negative rate (TNR, specificity). Few diagnostic tests are both highly sensitive and highly specific (1). In this case, using only one diagnostic test can be insufficient for accurate diagnosis and clinicians may have to use several diagnostic tests for the diagnosis of certain diseases (2). When multiple diagnostic tests are used and each of the diagnostic tests is sequentially applied, some diagnostic performance indices should be used for determination of the diagnostic test to be selected in each step. The information theoretical approach enables physicians to evaluate the performance of sequential medical testing procedures. Uncertainty is a fundamental concept in information theory. Diagnostic tests help to reduce the diagnostic uncertainty about the presence or absence of a certain disease. Diagnostic uncertainty can be measured by using the basic concept of information theory (3-5). When multiple diagnostic tests are applied for the diagnosis, Horton suggested a stepwise method for evaluating the performance of each test in the sequential procedure by using information theory (6). According to the Horton method, when true disease status and diagnostic test have binary outcomes, the performance of each sequential test can be evaluated by using two different types of reductions in the diagnostic uncertainty. One reduction is provided by the positive test result and the other by the negative test result.

The aim of this study is to introduce Horton's method and to evaluate the performance of three different radiograph types, panoramic (PAN), full mouth (FM) and bitewing (BW), in the diagnosis of proximal caries in different dental regions. Accordingly, the discriminatory power of the radiographs will be investigated for both ruling in and ruling out potentials by using Horton's method (6, 7).

Performance of FM will be compared to sequentially used PAN and BW for the diagnosis of proximal caries in the maxillary and mandibular posterior regions.

Material and Methods

Diagnostic tests reduce uncertainty about the diagnosis. The uncertainty related to the disease under consideration before the diagnostic test is applied is referred to as "pre-test

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uncertainty" and after the test results are obtained, the uncertainty is referred to as "post-test uncertainty". While pre-test uncertainty depends on pre-test probability or prevalence (Pr), post-test uncertainty depends on post-test probabilities. The difference between post-test uncertainty and pre-test uncertainty gives the reduction in the diagnostic uncertainty or diagnostic information (6, 7). When true disease status (D+ and D-) and test results (T+ and T-) are binary, two different pre-test uncertainties and two different post-test uncertainties can be obtained. If the base of the logarithm is 2, then the uncertainty is measured in bits.

Pre-test uncertainties can be obtained by the following the equations.

(1) Pre-test uncertainty for disease $I_+^{/} = \log_2 \mathrm{Pr}$

(2) Pre-test uncertainty for non disease $I_-^{/} = \log_2 (1 - \mathrm{Pr})$

The post-test probabilities, positive predictive value (PPV) and negative predictive value (NPV) can be calculated according to the Bayes Theorem and used for evaluating the performances of the diagnostic tests in the medical literature. Predictive values depend on TPR, TNR, False Positive Rate (FPR), False Negative Rate (FNR) and pre-test disease probability or Pr.

Post-test uncertainties, based on PPV and NPV, can be obtained by the following the equations:

(3) Post-test uncertainty for disease

$$I_+^{//} = \log_2 \frac{TPR \times \mathrm{Pr}}{TPR \times \mathrm{Pr} + FPR(1 - \mathrm{Pr})}$$

(4) Post-test uncertainty for non disease

$$I_-^{//} = \log_2 \frac{TNR \times (1 - \mathrm{Pr})}{TNR \times (1 - \mathrm{Pr}) + FNR \times \mathrm{Pr}}$$

Two different types of reductions in the diagnostic uncertainty can be obtained and calculated using Equation (5) and (6)

(5) $$\Delta I_+ = \log_2 \frac{TPR}{TPR \times \mathrm{Pr} + FPR(1 - \mathrm{Pr})} bits$$

(6) $$\Delta I_- = \log_2 \frac{TNR}{TNR \times (1 - \mathrm{Pr}) + FNR \times \mathrm{Pr}} bits$$

The first reduction, ΔI_+, is obtained by taking the difference between post-test uncertainty (Equation 3), and pre-test uncertainty (Equation 1). ΔI_+ gives the diagnostic information provided by the positive test result. The second reduction, ΔI_-, which is defined as the difference between Equation (4) and Equation (2) gives the reduction in diagnostic uncertainty or diagnostic information provided by a negative test result.

When multiple diagnostic tests are used for the diagnosis of the presence or absence of a certain disease, sequential reduction in the diagnostic uncertainty or incremental diagnostic information can be calculated for each sequential step. The first step begins with calculating the initial uncertainty which depends on pre-test disease probability. The diagnostic information, ΔI_+, is calculated when the first test is used in the first step. When another sequential diagnostic test is applied in the next step, the PPV of the previous test is taken as the pre-test disease probability and pre-test uncertainty is calculated. ΔI_+ is re-calculated to take into account the characteristics of the new test which is used in this step. Total reduction in diagnostic uncertainty or total incremental information is obtained by the summing all ΔI_+ values provided by each sequential test. This value can be used for evaluating the ruling in the potential of the sequential test. These steps can be applied for the ruling out potential also. In this case, initial uncertainty and reduction in diagnostic uncertainty for non-disease can be calculated by Equation (2) and Equation (6), respectively. The sum of ΔI_- values is used to evaluate the ruling out potential of the sequential test.

In this study, initial pre-test disease probability was taken as 0.5 for proximal caries for maxillary and mandibular regions. Accordingly, initial uncertainty was -1 bit. Reduction in diagnostic uncertainty was obtained for each sequential step. The performance of each sequential step is shown by the graphs which help to easily interpret diagnostic information.

The performance of three different radiograph types, PAN, FM and BW, was sequentially evaluated by the method introduced in this study. Radiographs of seventy-three patients from the Department of Dento-Maxillofacial Radiology of Hacettepe University Faculty of Dentistry were assessed for the diagnosis of proximal caries between the years 2002 to 2003. Radiographs were taken by the same investigator (N.A.) to provide internal consistency. The Planmeca 2002 CC Proline (Helsinki, Finland) panoramic X-ray machine was used in this study, equipped with Kodak Lanex Medium intensifying screens and Kodak T-Mat G PAN film (Eastman Kodak Co., Rochester, NY, USA). The kilovoltage peak was varied according to patient's jaw size in order to maintain consistent radiographic density. FM series were taken with Planmeca Prostyle Intra (Helsinki, Finland) intraoral dental radiography unit. Double-packet Kodak Ektaspeed dental X-ray films (Eastman Kodak Co., Rochester, NY, USA) were used for intraoral radiographs. The dental X-ray unit was operated at 63 kVp, 8 mA, with a varied exposure time to maintain consistent film density. Intraoral films were processed in Dürr X-25 (Dürr-Dental Co., Bietigheim-Bissingen, Germany) and PAN films processed in a Velopex Extra-X automatic processor (Medivance Instruments Limited, UK) according to the manufacturer's recommendations. Radiographs were evaluated under standardised viewing conditions (low ambient lighting, masked viewbox, using magnifying glasses, an absence of distraction and a comfortable position for the observer).

Three different radiographic readings were recorded: PAN, FM and BW. Lesions were detected by three observers simultaneously (Ö.K., H.K., L.B.Ç.) using three radiograph types, and were accepted in the study as "true disease status". Clinical experience of the observers was 27 years, 34 years and 12 years, respectively. Radiographs on which the three experienced observers could not reach a consensus concerning the diagnosis were excluded from this study.

Table 1. Frequencies, TPR and TNR of the Radiographs for Proximal Caries in the Maxillary and Mandibular Molar Region

Dental Regions	Radiograph Types								
	PAN			FM			BW		
	n	TPR	TNR	n	TPR	TNR	n	TPR	TNR
Maxillary Molar	391	0.62	0.87	391	0.84	0.96	363	0.85	0.88
Mandibular Molar	334	0.62	0.92	334	0.90	0.99	310	0.94	0.87

TPR: True positive rate; TNR: True negative rate; PAN: Panoramic; FM: Full mouth intraoral; BW: Bitewing

Table 2. Ruling in potential of the diagnostic alternatives for maxillary and mandibular molar regions

Region	Diagnostic Alternatives (Test Sequence)	Reduction in Uncertainty (bits)	
		1st Step	2nd Step
Maxillary Molar	1 (1.PAN) (2.FM)	0.7312	**0.2543**
	2 (1.PAN) (2.BW)	0.7312	0.2249
	3 (1.FM)	**0.9260**	
	4 (1.BW) (2.PAN)	0.8156	0.1405
Mandibular Molar	1 (1.PAN) (2.FM)	0.8319	0.1536
	2 (1.PAN) (2.BW)	0.8319	0.1390
	3 (1.FM)	**0.9855**	
	4 (1.BW) (2.PAN)	0.8156	**0.1553**

PAN: Panoramic; FM: Full mouth intraoral; BW: Bitewing

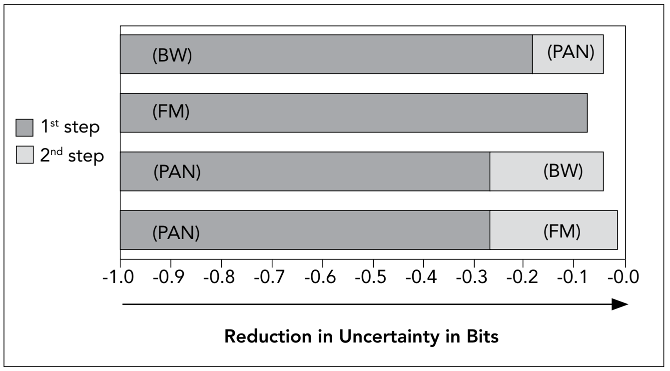

Figure 1. Ruling in potential of the diagnostic alternatives for maxillary molar region

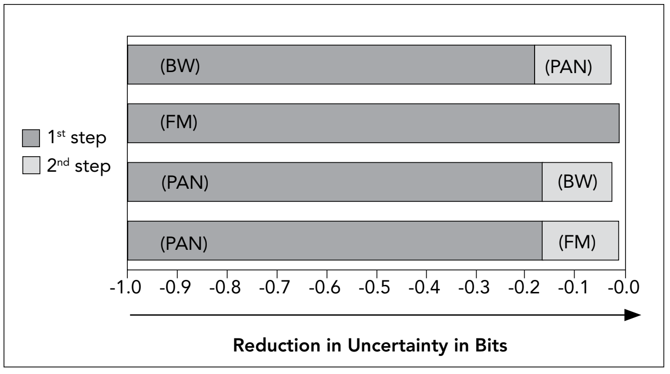

Figure 2. Ruling in potential of the diagnostic alternatives for mandibular molar region

Results

Number of teeth (n), TPR and TNR of radiographs for each dental region are presented in Table 1.

Four different diagnostic alternatives were evaluated for ruling in and ruling out proximal caries in both maxillary and mandibular molar regions. The reduction in diagnostic uncertainty for ruling in for each step and for both regions is shown in Table 2. When FM was used (diagnostic alternative 3), the amount of initial uncertainty, -1, was reduced as much as 0.926 for the maxillary molar region. FM provided a greater reduction in diagnostic uncertainty than other radiographs in the first step for the presence of proximal caries in both regions. When PAN was previously used, minimum reduction in uncertainty was obtained when compared with FM or BW for both regions. FM provided more information (diagnostic alternative 1) than BW (diagnostic alternative 2) in the second step for both regions. Regardless of which one (PAN and BW) was used first, diagnostic alternative 1 and diagnostic alternative 4 provided the same total cumulative reduction in uncertainty for the two regions. These results are shown in Figures 1 and 2 for the maxillary and mandibular molar regions, respectively.

Each step of the reduction in uncertainty for the ruling out potential of the diagnosis of the proximal caries for both molar regions is shown in Table 3. Using FM in the first step is the best strategy in both regions for diagnosing the absence of proximal caries. When only PAN was used in the first step, it provided minimum diagnostic information for the diagnosis of the absence of caries in both regions. When PAN was previously used, FM and BW gave the same diagnostic information for the maxillary region but FM provided more diagnostic information than BW in the mandibular molar region for ruling out in the second step. When BW and PAN were used sequentially, diagnostic alternative 4 gave the maximum total reduction in diagnostic uncertainty for two regions, as shown in Table 3. These results are shown in Figures 3 and 4 for maxillary and mandibular molar regions, respectively.

Table 3. Ruling out potential of the diagnostic alternatives for maxillary and mandibular molar regions

Region	Diagnostic Alternatives (Test Sequence)	Reduction in Uncertainty (bits)	
		1st Step	2nd Step
Maxillary Molar	1 (1.PAN) (2.FM)	0.4854	0.4099
	2 (1.PAN) (2.BW)	0.4854	0.4099
	3 (1.FM)	**0.7824**	
	4 (1.BW) (2.PAN)	0.7655	0.1298
Mandibular Molar	1 (1.PAN) (2.FM)	0.5012	0.4399
	2 (1.PAN) (2.BW)	0.5012	**0.4549**
	3 (1.FM)	0.8612	
	4 (1.BW) (2.PAN)	**0.9038**	0.0523

PAN: Panoramic; FM: Full mouth intraoral; BW: Bitewing

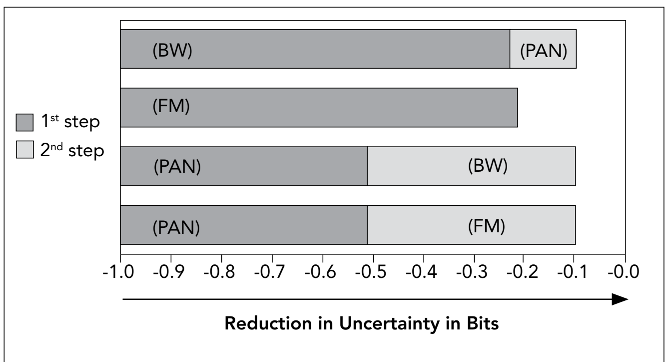

Figure 3. Ruling out potential of the diagnostic alternatives for maxillary molar region

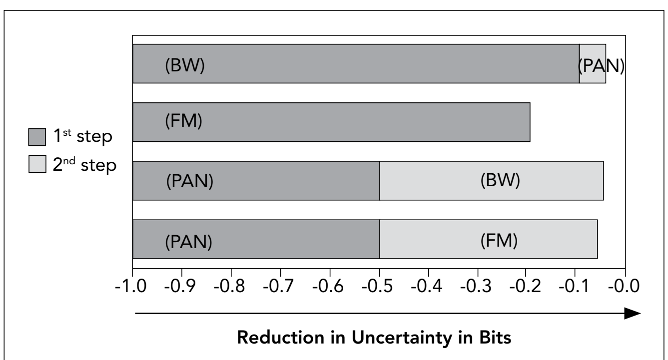

Figure 4. Ruling out potential of the diagnostic alternatives for mandibular molar region

Discussion

Diagnostic tests assist in making clinical judgments for the presence or absence of a certain disease. Using only one diagnostic test can be insufficient and another test may become necessary for an accurate diagnosis. If the initial decision about the presence or absence of disease is not clear when using only one test, multiple tests could be used to ensure an accurate diagnosis. Performing sequential diagnostic tests depends on minimising risk, patient discomfort, and the cost of testing whilst maximising diagnostic capability (8). Clinicians also need to use statistical tools for test selection in the determination of the optimum diagnostic test in each step. The performance of sequential tests can also be evaluated by several methods. Horton suggested the guideline based on uncertainty in the sequential test selection for diagnostic accuracy (6). Meanwhile, graphs are helpful tools in cases of diagnostic uncertainty for evaluating the performance of the test. The graphical method can provide useful information for comparing the performance of each of the sequential steps and alternative diagnostic sequences. This method also enables clinicians to evaluate two aspects, ruling in and ruling out potential of the sequential diagnostic test. The properties of the method present an advantage for interpreting the performance of different diagnostic alternatives which consist of multiple tests.

In this study, we evaluated the performance of sequentially used PAN, FM or BW for the diagnosis of proximal caries in two different regions using Horton's method. Radiography is a valuable supplement to a thorough clinical examination of teeth for detecting caries. Because the development of caries causes demineralisation of hard tissues, lesions are seen as radiolucent zones during radiographic examination. PAN, intraoral FM and BW radiographs are frequently used, either alone or in various combinations, in order to achieve a final diagnosis. BW radiography is the most useful radiological examination for detecting caries (9), intraoral FM radiographs are used for comprehensive radiographic examination, and PAN radiography is a radiographic technique that produces a single image of facial structures including both the maxillary and mandibular arches and their supporting structures. PAN radiographs are particularly useful in providing an overview of oral hard tissues, foreign bodies, cysts, tumours and other conditions within the jaw (10). However, PAN radiography has been used for the routine screening of patients at various institutions and private clinics (11). This preference may be based on the low radiation dose, simplicity of the application, lesser time requirements and the fact that it is more comfortable for patients as an extra-oral method.

In PAN machines using direct current technology, the tissue-absorbed dose is decreased by 25% when compared to the units that use alternating current. It is suggested that patient exposure in PAN radiographs obtained by the Planmeca 2002 CC Proline approximates the dose of a single periapical film (12). In addition, development of faster film and screen combinations has led to better radiographic quality. Despite improvements in techniques, PAN radiographs still do not depict caries in the posterior regions as clearly as intraoral radiographs. However, PAN radiographs might lead to the evaluation of a suspected area with supplemental BW radiography (13).

In this study, the radiographic diagnosis of proximal caries for only the maxillary and mandibular posterior regions was evaluated. Because proximal caries in the maxillary and mandibular anterior regions were usually detected during the clinical examination, these regions were not tested. In addition, diagnostic accuracy of the anterior region on panoramic radiographs is lower than that of intraoral radiographs (14). If necessary, periapical radiographs are preferred for these regions.

A number of investigations have compared conventional intraoral radiography with PAN radiography for the diagnosis of caries (15-20). However, in this study, the ability of radiographic techniques to reveal both the presence and absence of caries was measured. When Figures 1 and 2 were examined, it was noted that PAN radiography alone was insufficient for the diagnosis of both carious lesions and intact surfaces. This result may be explained by the fact that the detail of PAN radiography is inferior to intraoral radiography. FM radiography in the diagnosis of both maxillary and mandibular caries was superior to using other two techniques alone. BW radiography alone provided information about intact surfaces in the maxillary posterior region, but was almost the same as FM radiographs. BW radiography alone is the most successful test for the detection of intact surfaces in the mandibular posterior region. If PAN radiography is used instead of FM, it should be in conjunction with BW radiographs.

In the study, we evaluated the performance of the diagnostic tests which are used in Dento-Maxillofacial Radiology. Several statistical decision-making tools can assist clinicians in diagnosis management. Information theory enables us to evaluate different aspects of the diagnostic test performance. When disease status and test results are binary, evaluation of the reduction in diagnostic uncertainty in terms of both ruling in and ruling out potential when diagnostic tests are sequentially selected. Accordingly, three different radiograph types, PAN, FM and BW, were sequentially evaluated for the diagnosis of both the presence and absence of proximal caries in the maxillary and mandibular posterior regions. The performance of FM was compared to sequentially used PAN and BW for the diagnosis of proximal caries in both regions. The presented method in this study provides the clinicians with a relatively easy solution for the decision of the sequential selection of radiography types for the correct diagnosis of the presence or absence of proximal caries.

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