EFFICACY OF LASER FLUORESCENCE IN DENTAL CARIES DIAGNOSIS:

A META-ANALYSIS

by

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ABSTRACT

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Introduction: The ability to accurately diagnose the presence or absence of dental caries is of the utmost importance since errors may lead to either performance of irreversible, but unnecessary, dental procedures, or failure to provide needed treatment. Conventional caries detection methods (visual/tactile/radiographic) rely on subjective judgment and are prone to misinterpretation. To improve accuracy, several adjunctive diagnostic instruments are available. Of these, laser fluorescence has received the most attention. However, a majority of studies possess shortcomings in methodology that limit their value. As a result, the plethora of conflicting reports in the scientific literature renders it difficult for practitioners to make confident, informed decisions regarding the effectiveness of these instruments.

Objective: This meta-analysis sought to evaluate the effectiveness (sensitivity and specificity) of laser fluorescence, as compared to other diagnostic methods (visual/tactile examination; bitewing radiographs; fiber-optic transillumination) in the detection of dental caries.

Methods: A PubMed search of the relevant English language literature published between 1985 and April 2012 was conducted using variations of the following key terms: caries diagnostic methods, visual/tactile detection, FOTI, fiber optic transillumination, bitewing radiographs, laser fluorescence, and DIAGNOdent. This initial search identified 6,489 citations. Applying several inclusion and exclusion criteria followed by title and abstract reviews, and finally, full manuscript review yielded 28 publications. To facilitate comparisons among studies, we converted the sensitivity and specificity values of each diagnostic test to their standard scores, or normal deviate values (Z values). Mean (± standard deviation) D_z values were calculated for each diagnostic method and compared via a multivariate analysis of variance (MANOVA).

Results: MANOVA revealed no statistically significant differences in D_z values among any of the four diagnostic methods evaluated.

Conclusion: As compared to other methods, laser fluorescence appears to neither enhance nor hinder the accuracy of caries diagnostic decisions.

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CHAPTER 1: REVIEW OF LITERATURE

Modern management of dental caries relies upon diagnosis of the disease process and detection of pathologic changes (i.e. lesion formation) in their earliest stages (1). Bader, Shugars and Bonito described the diagnosis of dental caries as "an exhaustive search for evidence of demineralization on individual tooth surfaces" (2). The traditional methods that dentists, particularly in the U.S., use in the diagnosis of caries lesions involve visual and tactile examination combined with radiographic assessment. Explorers are used to probe accessible smooth and fissured surfaces and restoration margins, while radiographs are used to assess proximal surfaces. For many years, refinement of technique, rather than development of new technology, characterized these methods (3).

While perhaps a seemingly basic skill, the diagnosis of dental caries can be quite difficult, even for experienced clinicians. Differences among dentists in diagnostic decision-making are often considerable because our diagnostic methods "depend on subjective interpretation of subtle visual and tactile cues" (2). In a study analyzing the variation in dentists' clinical decisions for treatment, Bader and Shugars (4) discussed that the age of the practitioner, clinical experience, educational background, region of practice, and patient population all influence the decision-making process. The effects of these decisions are evident in the early stages of diagnosis of dental disease, as seen, for example, when one provider decides to monitor and remineralize a caries lesion, while another practitioner feels the best decision is to restore the lesion. In another study, Shugars and colleagues (5) studied the proportion of large restorations that were diagnosed as needing crowns among 100 practices in four regions of the United States.

Results revealed a threefold difference in this proportion across the different regions. Decisions for irreversible care should be based on what is best (in terms of function, economy, and longevity) for the patient, considering the 'do no harm' (6) concept. With all factors (e.g., differences in clinicians' diagnostic abilities, educational backgrounds, and clinical experience, as well as differences in opinion) considered, variations in diagnoses and treatment methods can be diverse within the dental community.

As seen in many aspects of our professional and personal lives, computerized and technical devices are on the rise and in demand. As related to dentistry, some of these devices are intended to aid the practitioner in caries detection by providing supplemental diagnostic information to reinforce clinical decisions and, ultimately, reduce or minimize the amount of human error. There is a definite need for improved accuracy in caries diagnosis; a possible solution may lie in the development and refinement of these diagnostic technologies. We see this occurring in the dental market today as more technological caries detection devices are available; however, we need to know if they offer consistent results.

Changing Epidemiology of Dental Caries

Caries diagnosis is further complicated by the epidemiologic changes in dental caries experience observed in recent decades. Several reports have confirmed that during the last three decades there has been a dramatic reduction in the prevalence, incidence, and severity of dental caries throughout most of the developed world (7-12). This trend is generally attributed to the widespread adoption of public water fluoridation programs and the use of fluoridated dentifrices (9, 13, 14). However, dental caries remains one of

the most prevalent diseases worldwide, with 91% of adults experiencing at least one caries lesion in their lifetimes (8, 15).

Bader and Brown (3) discussed how changes in caries experience (lower) and progression rate (slower) have affected the diagnosis and treatment of caries in several ways. As caries prevalence decreases, the likelihood of making a false-positive diagnosis increases. Because no diagnostic test is 100% accurate, all tests will result in some level of false-positive, as well as false-negative diagnoses (16). In the coming years, as fewer teeth have caries, false-positive diagnoses will likely account for an even greater proportion of all diagnoses made (3). Moreover, as the relative distribution of caries has changed, the occlusal surface, rather than the interproximal, has become the most affected site, accounting for over 80% of all caries lesions in both children and adults (17). Proximal surfaces present challenges to accurate diagnosis because of their limited access for visual inspection. Bitewing radiographs are essential in detecting lesions that are hidden from direct examination; however, even slight overlapping of interproximal areas may render radiographs ineffectual (16). Occlusal surfaces present their own unique diagnostic challenges due to their irregular anatomy, variable enamel thickness, and capacity for partial remineralization, which can mask underlying ”hidden caries” in dentin (18). Although radiographs are indispensible in caries diagnosis, they cannot accurately detect early enamel lesions (16). Moreover, radiographic films can be of limited value in the diagnosis of secondary caries because of the obscuring effect of the restorative material (19).

Because caries lesions progress at slower rates today, the astute clinician should consider the possibility of preventive, rather than restorative, therapy. Caries lesions can

be arrested and, in some cases, reversed (9). Slower progression rates provide enhanced opportunity for success in sealing at-risk occlusal surfaces and remineralizing incipient smooth surface lesions; therefore, monitoring at regular intervals over time can be crucial to determining disease activity and the need to restore (3). The availability of fluoride (through drinking water and over-the-counter dental products) has changed the behavior of caries lesions dramatically (20). In a study by Hopcraft and Morgan (21), patients with no lifetime exposure to fluoridated drinking water were twice as likely to have interproximal lesions compared to individuals with a lifetime exposure to fluoridated drinking water. Differentiation between progressing and arrested lesions is essential for appropriate treatment. Arrested lesions were once active carious sites which have become non-active and present the possibility of remineralization.

Progression of caries lesions, even at a slow rate, leads to morphologic changes (demineralization) in enamel, making diagnosis difficult. With these lesions, there is a substantial risk of damaging demineralized enamel surfaces when using an explorer for tactile examination. Depending on the sharpness of the explorer, depth and width of pits/fissures, and amount of tactile pressure used, affects the clinician's ability in diagnosing the presence of caries lesions (22). Ekstrand, Qvist, and Thylstrup (23) demonstrated the harmful effects on demineralized enamel that can occur while using an explorer in examining fissures. Similarly, van Dorp, Exterkate, and ten Cate (24) demonstrated that damage from an explorer on demineralized enamel can actually increase the growth of the caries lesion.

Accuracy of Diagnostic Tests

Any diagnostic test will produce one of four possible outcomes, only two of which are potentially correct. The accuracy of a diagnostic test is typically described in terms of four parameters: (1) sensitivity (Sn); (2) specificity (Sp); (3) positive predictive value (PPV); and (4) negative predictive value (NPV) (Table 1) (25).

Table 1. Diagnostic test characteristics and definitions (25).

Diagnostic Test Result	Actual Condition (Disease)	
	Positive	Negative
Positive	True Positive (A)	False Positive (B)
Negative	False Negative (C)	True Negative (D)

Sensitivity = A / (A + C) Positive Predictive Value = A / (A + B)

Specificity = D / (B + D) Negative Predictive Value = D / (C + D)

Sensitivity is the proportion of diseased persons in a screened population who are identified as such by the screening test; sensitivity represents a test's ability to correctly identify disease when it is present.

Specificity is the proportion of truly non-diseased persons in a screened population who are identified as such by the screening test; specificity represents a test's ability to correctly identify the absence of disease when it, indeed, is not present.

Positive predictive value is the probability that a person with a positive test result does have the disease.

Negative predictive value is the probability that a person with a negative test result truly does not have the disease.

Accuracy is the degree to which a measurement, or an estimate based on more than one measurement, represents the true value of the attribute being measured, i.e., "the proportion of all test results, both positive and negative, that are correct" (25). For a diagnostic test, accuracy is often defined as the combination or sum of sensitivity plus specificity.

Misdiagnosis – in either direction – results in undesirable consequences. A false positive diagnosis is a positive test result in a subject who, in fact, does not possess the attribute (e.g., disease) for which the test is conducted. A false negative diagnosis is a negative test result in a subject who actually possesses the attribute for which the test is conducted (25). For dental caries, a false-positive diagnosis may result in unnecessary irreversible restorative procedures because clinicians assume that active caries lesions are present when, indeed, they are not. A false negative diagnosis leads to untreated active decay and allows for progression of caries lesions.

Clinical Methods of Caries Diagnosis

The traditional method of caries diagnosis involves the use of visual and tactile examination, usually combined with radiographic images. Fracaro, Seow, McAllan, and Purdie (26) examined 481 children (ages 5-12 yrs) and 1,929 occlusal surfaces of first and second permanent molars. The study involved five clinicians and revealed that 96% of the teeth scored by clinicians as having caries matched the radiographic findings. However, the specificity was found to be 0.58, meaning the clinicians' diagnoses correctly identified only 58% of the caries-free surfaces. Hopcraft and Morgan (21) evaluated 973 Australian Army recruits using visual/tactile inspection and bitewing radiographs. In this study, the clinical diagnostic criteria for dental caries were visually

apparent cavitation, discoloration through enamel, or visual evidence of recurrent caries. Radiographic assessment evaluated the extent of radiolucency into the enamel and dentin. Twenty repeat blind examinations were conducted by each examiner on four occasions to measure intra-examiner reliability. Three examiners were used, and the results showed the use of bitewing radiographs identified more than 2/3 of the interproximal lesions that were missed compared to visual/tactile alone.

Valera and colleagues (27) examined 72 extracted permanent molars for extent of caries lesions. Inter-examiner reproducibility by visual inspection alone, which included two exams, was 0.61 and 0.53, while radiographic inspection resulted in a reproducibility of 0.22 and 0.32. Braga and colleagues (28) assessed the reliability of conventional diagnostic methods in detecting secondary caries. Fifty-four primary molars (extracted/exfoliated) were evaluated by two dental examiners using conventional methods. Inter-examiner agreement for visual examination in enamel and dentin was 0.71/0.88. The agreement for tactile was 0.86 (enamel)/0.69 (dentin) and for radiography among the examiners was 0.48/0.55, respectively. Both of the previously mentioned studies reveal that conventional diagnostic methods still result in inconsistent diagnoses by practitioners.

Lussi (29) demonstrated that many occlusal caries lesions (still in enamel) cannot be discovered by visualization and probing alone. In this study, 34 dentists (16 private practice dentists and 18 dentists employed at the University of Bern, School of Dental Medicine) evaluated the occlusal surfaces of 61 (54 molars, 7 premolars) extracted posterior teeth. After histologic preparation and evaluation of the specimens, the percentage of clinically correct treatment decisions was determined to be 73%. Mean

sensitivity and specificity were 62% and 84%, respectively; the dentists were more likely not to treat decayed teeth than to restore sound teeth.

Adjuncts for Caries Diagnosis

Illumination and magnification. Today, it is very common for providers to use illumination and magnification during examination and treatment. In a study conducted by Maggio, Villegas, and Blatz (30), preclinical dental students using magnification completed more preparations, worked more quickly per procedure, and used the computer-assisted evaluation (comparison of student's preparations to 'ideal' preparations) less frequently and for shorter periods. According to Friedman (31), appropriate visual enhancement should be considered for all dental professionals to make the practice of dentistry more precise and to reduce the risk of musculoskeletal injury.

Eichenberger and colleagues (32) discussed the higher visual acuity achieved while using magnification devices. In this study, dentists used loops ranging from a single lens loupe 2x, Galilean loupe 2.5x, and the Keplerian loupe 4.3x compared to unaided visual acuity. The Keplerian loupe obtained the highest visual acuity (measured with miniature E-optotype tests on a negatoscope) followed by the 2.5x loupes, 2.0x loupes, and single lens loupe; unaided vision provided the lowest acuity. Christensen (33) believed he achieved a higher level of quality in his dentistry when using magnification. However, there is little quantifiable objective evidence that illumination and magnification, individually or in combination, significantly improve clinicians' diagnostic accuracy.

Digital Radiography. Radiographic technology has improved with the advent of both high speed radiographic films and especially with the use of digital imaging,

reducing radiation doses and producing diagnostic films almost instantly. The immediate viewing of the image is a significant clinical advantage, along with the ability to change contrast (lighten or darken) and enlarge images. Digital radiography eliminates the need to maintain developer and fixer solutions and allows for storage of images on a computer database, thus making consultation with other practitioners more convenient (34).

The difficulty of precise caries detection is related to factors such as the complex anatomy of pits and fissures (35) and superimposition of structures in the radiographic evaluation (36). Moreover, radiographs underestimate the extent of demineralization and are unable to reveal the earliest stages of dental caries (37). Anbiaee and colleagues (38) reported that digital and conventional bitewing radiographs had similar diagnostic accuracy for the detection of recurrent caries. In this laboratory study, digital and conventional radiographs were made following placement of interproximal amalgam restorations and production of simulated secondary caries lesions. The overall accuracy, as determined by three expert observers, was 76% for digital and 75% for conventional radiography. However, because digital radiography required less ionizing radiation, the authors recommended this method of imaging for routine dental care. Similarly, Dias da Silva and colleagues (39) reported that digital radiography was as accurate as conventional radiography and visual inspection of primary teeth with occlusal caries when dentin is involved. Digital radiography revealed a sensitivity of 0.68 (into dentin) for both examiners, and a specificity of 0.90 and 1.0, respectively, for each examiner. Conventional radiography results were 0.74 (examiner 1) and 0.79 (examiner 2) for sensitivity and 0.87 (examiner 1)/0.94 (examiner 2) for specificity. Chong and colleagues (40) reported sensitivities of 0.81 and 0.90 for clinical examinations

conducted with conventional and digital radiography, respectively. In this study, 320 extracted premolars were examined using an explorer, followed by an examination using laser fluorescence. The teeth were then exposed using conventional and digital radiography. The gold standard of histological sectioning of the teeth was not performed in this study due to the large number of specimens. Rather, the authors used the Spearman rank correlation to assess how well the different diagnostic methods correlated to each other. The sensitivity of the clinical exam with conventional films was 0.81, while the specificity was determined to be 0.44. The visual-tactile exam with digital radiography resulted in a sensitivity of 0.90 and a specificity of 0.44. Laser fluorescence along with visual-tactile examination revealed a sensitivity and specificity of 0.89 and 0.56, respectively.

Technologic Aids in Caries Diagnosis

Fiber-optic Transillumination. Fiber-optic transillumination (FOTI) is a visual inspection technique that uses the light scattering properties of enamel to visualize density variations in tooth structure. When light is passed perpendicular to a suspected caries lesion, the light becomes scattered due to a change in density of the tooth structure (demineralized areas are not as dense); the resulting contrast is used to detect the caries lesion. Digitized fiber-optic transillumination (DI-FOTI) is similar to FOTI, but images are collected and transmitted to a computer monitor for evaluation (41). In a study by Cortes, Ellwood, and Ekstrand (42) involving 111 extracted permanent molars, FOTI accurately identified 50% of the sound sites and 66% of lesions into dentin. Hintze, Wenzel, Danielson, and Nyvad (43) found in an *in vivo* study involving 338 unrestored interproximal posterior surfaces, that using FOTI revealed a sensitivity ranging from 0.00

to 0.08 and a specificity of 0.99 to 1.00 among four clinicians. It was demonstrated that the lesions detected in enamel by FOTI were found to be in dentin on the bitewing radiographs. The authors concluded that due to its low sensitivity and positive predictive values, FOTI should be used as only a supplemental diagnostic tool for diagnosis of interproximal caries lesions. In contrast, Mitropoulos, whose *in vivo* study included 1,042 tooth surfaces and one examiner, concluded that FOTI significantly improved the detection of interproximal caries (44).

Electrical Conductance/Resistance. Electronic Caries Monitor (ECM) and Electrical Impedance Spectroscopy (EIS) are two methods that employ electrical measurements in diagnosing dental caries. ECM uses a single fixed frequency alternating current to measure bulk resistance of tooth structure, while EIS measures the dielectric properties of a medium (e.g., tooth structure) as a function of frequency. The main advantage of EIS over ECM is that since materials exhibit different electrical responses at different frequencies, EIS can help determine more accurately the various densities which demonstrate these differences. Several factors affect electrical measurements of teeth: the porosity of the tissues; the surface area of the electrical contact; the thickness of the tissues; the extent of hydration of tissues; and the temperature and concentration of the ions in the fluid within the tooth. As a tooth demineralizes, it becomes more porous. These porosities become filled with fluids (saliva) that contain ions, which leads to increased electrical conductivity (45). Longbottom (45) reported that ECM measurements, which apply to occlusal sites only, can vary according to the relative occlusal to interproximal smooth surface caries ratios for prevalence or incidence in patients. In an *in vitro* study, Lussi and colleagues (46) found that ECM had a specificity

range of 0.64 to 0.78 and a sensitivity range of 0.87 to 0.92. This study involved 11 dentists who recorded two different measurements (one with laser fluorescence and one with ECM) on 83 extracted molar teeth. When compared to laser fluorescence, ECM had lower diagnostic validity based on the sensitivity and specificity values (46). In contrast, Huysmans, Longbottom, and Pitts (47) found that electrical methods and bitewing radiography showed higher sensitivity and lower specificity than visual inspection, and that the overall diagnostic performance of electrical measurements was superior to visual inspection alone.

Laser Fluorescence. The presence of bacterial metabolites has been used as a marker, or surrogate, for caries, and a workable system using this technology is commercially available. Bacterial metabolites within caries lesions produce fluorescence that can be enhanced by laser light (48). DIAGNOdent (KaVo, Lake Zurich, IL) generates laser light with a wavelength of 655 nm. The laser light is absorbed by both organic and inorganic materials in the teeth, and re-emitted as fluorescence within the infrared range. In the presence of dental caries, fluorescence increases, and the change is registered as an increased digital number and indicated acoustically (49).

Numerous studies have evaluated the efficacy of laser fluorescence. Results have been equivocal. Bader, Shugars and Bonito (2) concluded that DIAGNOdent is more sensitive than traditional visual and tactile diagnostic methods; however, the increased likelihood of false positive diagnoses, compared with that of visual methods, limits its usefulness as a principal diagnostic tool. Similarly, Bamzahim and Angmar-Mansson (50) concluded that DIAGNOdent should be used only as an adjunct to conventional methods in determining the presence of secondary caries. In this study, restorative

materials produced little or no fluorescence, thus blocking potential caries readings by DIAGNOdent. Staining, often evident around restorations, resulted in higher DIAGNOdent readings, leading to more false positive readings. Apostolopoulou, Lagouvardos, Kavvadia, and Papagiannoulis (51) reported that laser fluorescence (DIAGNOdent) had better sensitivity (0.90) than specificity (0.36) for enamel lesions and better specificity (0.91) than sensitivity (0.36) for lesions into dentin. With this study, 24 extracted primary molars were examined by one clinician using direct and indirect visualization, radiographs, and laser fluorescence.

In another study, Bamzahim, Abdulaziz and Shi (52) evaluated the detection of secondary caries lesions around amalgam restorations using DIAGNOdent, visual, tactile, and conventional radiographic means. This study showed the sensitivity and specificity of DIAGNOdent and conventional radiography were 0.60/0.81 and 0.56/0.92 respectively, while sensitivity and specificity of visual inspection were 0.44 and 0.96. Of the 51 restored teeth used in this study, 29% had staining around the restoration margins. All of the teeth that resulted in a false positive diagnosis with DIAGNOdent had stained margins. The authors concluded that DIAGNOdent should be used only as an adjunct to conventional methods when detecting secondary caries around amalgam restorations. Diniz and colleagues (53) examined the influence of clear and opaque sealants on laser fluorescence (LF) caries detection success, and found that opaque sealants decreased fluorescence significantly in comparison to clear sealants. A possible explanation to this is that titanium dioxide (pigment) could absorb either the light emitted by the devices or the fluorescence emitted by the carious tissue (54).

In contrast, Lussi and Francescut (55) evaluated 95 deciduous teeth (extracted – *in vitro*) via visual inspection, visual inspection with magnification, visual inspection combined with light pressure probing, bitewing radiography, and laser fluorescence (DIAGNOdent). In comparison to conventional clinical methods, laser fluorescence showed a significantly greater ability to detect dentinal lesions in deciduous teeth. The authors concluded that DIAGNOdent could be used as an additional tool in the detection of occlusal caries in deciduous teeth, and its good reproducibility should enable the laser device to monitor the caries process over time.

Boston (56) performed an *in vitro* study using laser fluorescence to detect secondary caries lesions around resin composite restorations. Fifteen extracted teeth were examined using DIAGNOdent and then sectioned for histologic evaluation. The histologic incidence was 20% for enamel caries and 36.7% for dentin caries. With DIAGNOdent, the sensitivity and specificity were 0.67/0.79 and 0.73/0.84 for enamel and dentin lesions, respectively. The author concluded that DIAGNOdent may have potential for detecting secondary caries adjacent to resin composite restorations and that further research is needed with DIAGNOdent for its use around restorative materials.

Cortes and colleagues (42) performed a study that involved 111 extracted molar teeth and five diagnostic methods to include visual, FOTI, combined FOTI/visual, laser fluorescence (DIAGNOdent), and the Electrical Caries Monitor. DIAGNOdent showed a sensitivity of 0.72 and a specificity of 0.91, while the ECM had corresponding values of 0.90 and 0.83. Visual examination revealed sensitivity and specificity values of 0.96 and 0.57; FOTI of 0.96 and 0.74; and combined FOTI/visual values of 0.94 and 0.70. The authors believe that in a clinical setting it is inappropriate to apply cut-off values without

first considering the caries risk profile of the individual patient; therefore, they suggested that ECM and laser fluorescence can be useful in monitoring progression of lesions, but using these devices alone without clinical examination should be avoided. Lussi, Hibst and Paulus (57) advised that the decision to begin restorative treatment should not be based solely on laser fluorescence readings; the clinician must also consider the patient's case history, perceived caries activity, and the status of the surface (intact or cavitated), as well as fluoride and dietary status.

Laser Light and Heat. Light of various wavelengths has been used to penetrate tooth structure and cause enamel fluorescence, which can then be visualized and measured. The Canary Dental Caries Detection System (Quantum Dental Technologies; Toronto Canada) is a new (2010) device for the early detection and monitoring of caries lesions. According to the manufacturer's claims, this instrument can detect decay on smooth enamel surfaces, root surfaces, occlusal and interproximal surfaces, and around existing amalgam or resin composite restorations. The Canary System uses a low-power, pulsating laser light to scan teeth for the presence of dental caries. The laser light is absorbed by the tooth and two phenomena are observed: (1) the light is converted into luminescence, and (2) there is a release of heat (less than 1 degree Celsius). This heat will not harm the tooth, and simultaneous measurement of the reflected heat and light provides information on the presence and extent of teeth decay below the tooth surface. The Canary System is commercially available in Canada. Performance data are limited to the manufacturer's claims (58); there are currently no published independent laboratory or clinical evaluations of this system.

Summary

Caries diagnosis remains one of the most challenging aspects of clinical practice. Whether trying to interpret radiographs with superimposed structures or attempting to diagnose caries lesions in occlusal grooves with an explorer, there are errors that occur. When weighing the clinical implications of false-positive and false-negative diagnoses, one must consider the consequences of performing unnecessary dental procedures, as well as the potential harm of failing to treat active disease. When caries are left untreated, this allows for further progression of lesions and destruction of tooth structure. Conversely, treatment of teeth that do not need restorative intervention leads to a financial burden on patients, irreversible damage to teeth, and the likelihood of re-restoration in subsequent years.

Due to shortcomings in conventional caries detection methods (visual; tactile; radiographs), there is a need to find an adjunctive diagnostic aid that can give consistent results. There are several caries diagnostic aids commercially available. These systems attempt to improve diagnostic accuracy; however, numerous past studies using these devices reveal variable and inconsistent results; moreover, variations in study methodologies make comparisons from one study to another difficult. As a result, the current literature can be quite confusing. The ideal caries diagnostic system must provide consistently accurate performance in a variety of clinical situations, which may include permanent and deciduous teeth; occlusal, proximal, and smooth surfaces; primary and secondary caries; non-restored teeth, as well as those restored with a variety of metallic and non-metallic materials. High sensitivity and high specificity are absolute requirements. Of the various caries diagnostic systems available, laser fluorescence (e.g., DIAGNOdent) has received the most attention. However, a majority of studies possess

shortcomings in methodology that limit their value (2, 16). As a result, the plethora of contradictory reports in the scientific literature renders it difficult for practitioners to make confident, informed decisions regarding the effectiveness of these products. Therefore, the purpose of this study is to evaluate the past studies via meta-analysis to compare the traditional diagnostic methods of visual/tactile, radiographs, FOTI, and laser fluorescence to determine which methods, or combination of methods, produce the greatest accuracy in caries detection.

CHAPTER II: MATERIALS AND METHODS

We sought to answer the question, "What is the validity of laser fluorescence, as compared to other diagnostic methods, for detecting caries lesions in permanent teeth?" A PubMed search of the relevant English language literature published between June 1985 and April 2012 was conducted using variations of the following key terms: caries diagnostic methods, visual/tactile detection, FOTI, fiber optic transillumination, electrical conductance, bitewing radiographs, laser fluorescence, and DIAGNOdent (Table 2). This initial search identified 6,489 citations. Applying several inclusion and exclusion criteria (Table 3), we subjected the articles to title and abstract reviews, followed by full text review, to select a final number of 28 publications to be included in the meta-analysis.

Table 2. Initial literature search.

Key Word	**PubMed**
Caries diagnostic methods	3962
Laser fluorescence AND dentistry	427
Laser fluorescence AND caries	314
Laser fluorescence AND caries diagnosis	283
Visual and tactile detection of dental caries	24
visual AND caries diagnosis	432
tactile AND caries diagnosis	98
bitewing radiographs AND caries	461
bitewing radiographs AND caries detection	100
FOTI AND caries	36
electrical conductance AND caries	95
DIAGNOdent	199
DIAGNOdent AND visual detection	58
Total	**6,489**

Table 3. Inclusion and exclusion criteria.

Inclusion Criteria	Exclusion Criteria
In vivo and in vitro studies involving human teeth	Studies that used bovine or other non-human teeth
Sensitivity and specificity reported, or calculable from reported data	Sensitivity and specificity not reported, or not calculable
Gold standard of histological sectioning or access into tooth structure to verify presence of decay	Teeth not analyzed using histological sectioning or access into tooth structure to verify presence of decay
Permanent teeth	Primary teeth
Occlusal, interproximal, and smooth surfaces	Systematic Reviews, meta-analyses, or studies that discussed caries diagnostic methods but did not present any results
Primary caries lesions	Secondary (recurrent) caries lesions
Studies using laser fluorescence, bitewing radiographs, visual/tactile, or fiber optic transillumination in caries diagnosis	

Appendix A was constructed to present the studies included in our analysis. We recorded the following parameters for each study: 1) authors; 2) year of publication; 3) setting (*in vivo* or *in vitro*); 4) number of teeth or surfaces involved; 5) method of caries diagnosis; 6) number of examiners; 7) lesion prevalence (i.e., frequency); 8) sensitivity; and 9) specificity.

To facilitate comparisons among studies, we converted the sensitivity and specificity values of each diagnostic test to their standard scores, or normal deviate values (Z_{caries} and Z_{sound}, respectively) (Appendix B) using an online calculator (59). According to Walker and Watkins (59),

> "This *z-value* or *z score* expresses the divergence of the experimental result x [in our case the sensitivity and specificity] from the most probable result μ as a number of standard deviations σ. The larger the value of *Z*, the less probable the experimental result is due to chance…Since the mean value and standard deviation depend upon the number of trials in the experiment, comparison between experiments with differing number of

> trials is facilitated by standardizing the result: transforming it to a distribution with mean value zero and standard deviation of 1. A normally distributed experimental result x is thus standardized by subtracting the mean and dividing by the standard deviation of the experiment:"
>
> $$z = (x - \mu) / \sigma$$

Z_{caries} was then plotted against Z_{sound} (Figure 1; Appendix C). The upward-sloping diagonal line represents all diagnostic test outcomes resulting from chance alone (59). D_z represents the distance from a plotted point (i.e., Sn/Sp test result) to the diagonal line and "quantifies the performance above chance of the diagnostic test in a single value" (2). The D_z value was calculated using the following formula:

$$D_z = (Z_{caries} - Z_{sound}) / \sqrt{2}\,.$$

Mean (± standard deviation) D_z values were calculated for each diagnostic method. Mean values were compared via a two-way analysis of variance (ANOVA), with D_z as the dependent variable and the following independent variables: 1) diagnostic method (four levels – visual/tactile examination, radiographic examination, laser fluorescence, and fiberoptic transillumination); 2) type of surfaces (three levels – occlusal, proximal, and facial/lingual smooth surface). Statistical analyses were accomplished using Statistical Package for the Social Sciences (SPSS) Version 18 computer software (SPSS, Inc., Chicago, IL). All significance levels were set at $\alpha = 0.05$.

CHAPTER III: RESULTS

Results of the study are presented in Tables 6 through 9. Unweighted mean sensitivity and specificity values (Table 4) were calculated for each diagnostic method from the data obtained from the studies analyzed. Sensitivity values ranged from 0.361 for visual/tactile examination of proximal surfaces to 0.840 for fiber-optic transillumination of occlusal surfaces. Fiber-optic transillumination had the highest sensitivity values for occlusal surfaces. Laser fluorescence had the second highest mean sensitivity value for occlusal surfaces and highest value for proximal surfaces.

Table 4. Mean sensitivity and specificity values for laser fluorescence, visual/tactile examination, radiographs, and fiber-optic transillumination (FOTI).

Diagnostic Method	Sensitivity		Specificity	
	Surfaces		Surfaces	
	Occlusal	Proximal	Occlusal	Proximal
Laser Fluorescence	0.731	0.798	0.716	0.878
Visual/Tactile Examination	0.642	0.361	0.784	0.988
Radiographs	0.559	0.452	0.814	0.892
Fiber-optic Transillumination	0.840	0.424	0.843	0.910

Among the four diagnostic methods, the Specificity values ranged from 0.716 (laser fluorescence and occlusal surfaces) to 0.988 (visual/tactile examination of proximal surfaces) (Table 4). Visual/tactile examination had the highest specificity (0.988) for proximal surfaces, while having a value of 0.784 for the occlusal surface. Laser fluorescence, had values of 0.716 and 0.878 for the occlusal and proximal surfaces, respectively.

Statistical analysis (Table 5) revealed that the sensitivity of laser fluorescence (0.7415) was significantly higher than that of radiographs (0.4884), but statistically similar to fiber-optic transillumination and visual/tactile examination ($p = 0.188$). Likewise, there were no statistically significant differences in sensitivity among radiographs, fiber-optic transillumination, and visual/tactile examination. Similarly, there were no significant differences in specificity among any of the four diagnostic methods ($p = 0.321$).

Table 5. Statistical significance of sensitivity and specificity scores.*

Statistical Significance			
Method	Sensitivity		Specificity
Radiographs	0.4884		0.8560
Fiber Optic	0.6030	0.6030	0.8756
Visual/Tactile	0.6336	0.6336	0.8013
Laser Fluorescence		0.7415	0.7403
Significance	**0.433**	**0.188**	**0.321**

* Two-way ANOVA and Tukey HSD post hoc tests ($\alpha = 0.05$).

Table 8 presents the D_z values for the four diagnostic methods in coordination with the occlusal and proximal surfaces. As discussed earlier, D_z quantifies the performance above chance of the diagnostic test in a single value. When D_z values are plotted graphically (as in Figure 1, Apendix C), the higher the D_z value, the farther the plotted value is away from the diagonal line (representing chance), and the less likely the result is from chance. D_z values ranged from 1.208 (laser fluorescence on occlusal surfaces) to 1.887 (fiberoptic transillumination on proximal surfaces). For all surfaces combined, fiber-optic transillumination exhibited the highest D_z value (1.721), while

laser fluorescence had the lowest (1.365). However, there were no statistically significant differences in D_z values among the four diagnostic methods ($p = 0.930$).

Table 6. Mean D_z values for laser fluorescence, visual/tactile examination, radiographs, and fiber-optic transillumination (FOTI).

Diagnostic Method	Mean D_z		
	Surfaces		
	Occlusal	Proximal	All Surfaces Combined
Laser Fluorescence	1.208	1.523	1.256
Visual/Tactile Examination	1.468	1.841	1.516
Radiographs	1.635	1.212	1.476
Fiberoptic Transillumination	1.554	1.887	1.606

CHAPTER IV: DISCUSSION

This meta-analysis sought to evaluate the scientific evidence regarding the effectiveness of laser fluorescence, as compared to other caries diagnostic methods. In reviewing the extensive literature on this topic, there appeared to be a wide range of results (i.e., sensitivity and specificity values) with caries diagnostic aids that may easily lead to confusion regarding interpretation of their effectiveness.

Due to the vast number of studies that have been published, we chose to restrict this meta-analysis to studies that included only permanent teeth and primary decay, and that also used histologic sectioning as the ”gold standard” confirmation for the presence of caries. We did not include studies (of which we found three) that verified the presence of decay by first opening the pits/fissures, followed by visual/tactile inspection. As compared to histologic sectioning, the process of opening of pits/fissures introduces more human error. However, in Akarsu and Koprulu’s study (60), two examiners used visual inspection, bitewing radiographs, and laser fluorescence to verify the presence of decay. Agreement was needed before access was made into tooth structure to evaluate the extent of the decay. Similarly, with Chu, Lo, and You (61), two clinicians evaluated the patients via visual/tactile and radiographic examination. A third independent examiner evaluated the occlusal fissures using laser fluorescence, and there was a 10% random sampling of teeth on the same day to assess intra-examiner reliability. Patients were assumed to have fissure caries if the visual exam, radiographic exam, or DIAGNOdent had met study parameters (extent of decay into enamel or dentin/DIAGNOdent score of at least 20). Costa, de Paula, and Bezerra (22) used two examiners in the study, and for ethical reasons, opening of the fissures occurred only in cases when both examiners agreed on at

least one diagnostic method (visual, radiograph, and laser fluorescence) to the presence of dentin caries. I believe these three *in vivo* studies, with the standards they set for caries detection, were validated but we wanted to keep consistency in the diagnostic processes used in our analysis. However, I do believe that the ultimate standard in caries detection is still histologic sectioning, but this approach is not practical with *in vivo* studies.

Our literature search found five studies (28, 50, 62-64) that assessed the effectiveness of caries diagnostic methods for secondary caries and/or primary teeth. Although we did not include studies of secondary caries or primary teeth in this analysis, the literature suggests a variety of results. In a study involving primary teeth, Attrill and Ashley (64) found that sensitivities using laser fluorescence ranged from 0.77 to 0.80, while specificities were 0.82 to 0.85. Evaluating primary molars, Neuhaus and colleagues (62) reported sensitivity/specificity values of 0.68/0.84 with laser fluorescence, and 0.64/0.79 with bitewings radiographs. Braga and colleagues' (28) study of primary teeth and secondary decay revealed a sensitivity of 0.56 and specificity of 0.84 with laser fluorescence, while bitewing radiographs resulted in 0.48 (Sn) and 0.72 (Sp), and visual/tactile examinatoin had 0.75 (Sn) and 0.71 (Sp). However, I do believe it would be beneficial to compare the accuracy of various diagnostic aids with recurrent decay.

With the 28 studies selected for this analysis, there were variations with regard to the number of examiners and specimens (teeth) used within each. The sample sizes used within the 28 studies ranged from 25 up to 240 teeth. Those studies with 25 specimens [Baseren and Gokalp (65), Fung and colleagues (66)] had two and nine clinicians, respectively, to help compensate for the lower number of specimens. However, there

appear to be no differences in outcomes compared to the studies that presented more specimens. Differences in clinical experience and educational background can affect examiner decision-making (4). Among the studies we selected, none gave specific background information about the clinicians. Also, there were differences in the number of examiners, ranging from one clinician (42, 49, 26, 66-68) to as many as 34 (29). Studies utilizing multiple examiners may present a more realistic and representative range of the diagnostic devices; however, we did not exclude studies with only one examiner if the studies met our inclusion criteria.

We chose to perform the analysis by converting the sensitivity and specificity numbers to standard scores (Z_{caries} and Z_{sound}), followed by calculating a D_z value that represented the performance above chance of the diagnostic test in a single value. With this approach, we limited the strength of the individual studies since the number of teeth included in each study was negated. Also, the sensitivities and specificities were eventually combined to a single D_z value, thus losing the individuality of those numbers. However, I observe sensitivity and specificity values with equal value. With their clinical relevance, it is not ideal to either leave untreated decay or to restore a surface that has no caries present. Both result in negative consequences.

CHAPTER V: CONCLUSION

In regards to the caries diagnostic methods observed in this analysis, there were no significant differences in respect to sensitivity, specificity, or D_z values. Laser fluorescence had some of the highest values in regards to sensitivity, but rendered the lowest values with specificity. Laser fluorescence produced numbers that are comparable to the older and accepted diagnostic methods of visual/tactile and bitewing radiographs. In regards to clinical significance, laser fluorescence is a good adjunct to conventional caries diagnostic methods, but it is still lacking the consistency to be used on its own in the caries diagnostic process.

APPENDIX A

APPENDIX A

Literature and study parameters.

Authors	Year	Setting (in vitro)	Number of Teeth	Dx Method	Number of Examiners	Lesion Prevalence	Sensitivity	Specificity
Alwas-Danowska H and colleagues	2002	In vitro	49 molars	Observer #1 LF Visual	1	Histologic section	 0.93 (1998) 1.00 (1999) 0.40	 0.59 (1998) 0.50 (1999) .94
Alwas-Danowska H and colleagues	2002	In vitro	49 molars	Observer #2 LF Visual	1	Histologic section	 0.93 (1998) 0.93 (1999) 0.6	 0.53 (1998) 0.47 (1999) 0.88
Baseren N, Gokalp S	2003	In vitro	25 molars	LF	2	Histologic section	0.83	0.74
Boston D	2003	In vitro	150 teeth	Visual	1	Histologic section	0.45	0.68
Cortes D, Ellwood R, Ekstrand K	2002	In vitro	111 molars	Visual	1	Histologic section	Enamel 0.97 Dentin 0.78	Enamel 0.57 Dentin 0.83
Cortes D, Ellwood R, Ekstrand K	2002	In vitro	111 molars	FOTI	1	Histologic section	Enamel 0.96 Dentin 0.89	Enamel 0.74 Dentin 0.92
Cortes D, Ellwood R, Ekstrand K	2002	In vitro	111 molars	LF	1	Histologic section	Enamel 0.72 Dentin 0.93	Enamel 0.91 Dentin 0.72

Authors	Year	Setting (in vitro)	Number of Teeth	Dx Method	Number of Examiners	Lesion Prevalence	Sensitivity	Specificity
Cortes D, Ellwood R, Ekstrand K	2002	In vitro	111 molars	ECM	1	Histologic section	Enamel 0.90 Dentin 0.81	Enamel 0.83 Dentin 0.85
de Paula A and colleagues	2009	In vitro	26 molars – 64 occlusal sites	Visual	2	Histologic section	Enamel 0.63 Dentin 0.33	Enamel 1.0 Dentin 0.95
de Paula A and colleagues	2009	In vitro	26 molars – 64 occlusal sites	LF	2	Histologic section	Enamel 0.72 Dentin 0.42	Enamel 1.0 Dentin 0.65
Downer MC, O'Mullane D	1975	In vitro	109 teeth	Visual	1	Histologic exam	Pits and fissures 0.91 Smooth surface 0.94	Pits and fissures 0.81 Smooth surface 0.92
Downer MC, O'Mullane D	1975	In vitro	109 teeth	Visual and Tactile	1	Histologic exam	Pits and fissures 0.92 Smooth surface 0.93	Pits and fissures 0.85 Smooth surface 0.97
Downer MC	1989	In vitro	85 teeth	Visual	1	Histologic section	0.62	0.85
El-Housseiny and Jamjoum	2001	In vitro	46 perm teeth	LF	16	Histologic section	0.95	0.50
El-Housseiny and Jamjoum	2001	In vitro	46 perm teeth	Visual	15	Histologic section	0.66	0.63

Authors	Year	Setting (in vitro)	Number of Teeth	Dx Method	Number of Examiners	Lesion Prevalence	Sensitivity	Specificity
Fung L, Smales R, Ngo H, Mount G	2004	In vitro	25 teeth - occlusal	LF	9	Histologic section	0.65 0.69 0.54 0.63 0.19 0.56 0.77 0.50 0.75	0.88 0.89 0.92 0.96 0.97 0.82 0.78 0.71 0.86
Huysmans M and colleagues	1998	In vitro	107 extracted premolars and molars	BW	2	Histologic section	0.58	0.87
Huysmans M and colleagues	1998	In vitro	107 extracted premolars and molars	Visual	2	Histologic section	0.27	1.0
Huysmans M and colleagues	1998	In vitro	107 extracted premolars and molars	ECM – Airflow method ECM - surface	2	Histologic section	ECM airflow 0.58 ECM surface 0.76	ECM airflow 0.94 ECM surface 0.90
Jablonski-Momeni A and colleagues	2010	In vitro	100 teeth	LF	1 for solid teeth, 1 for teeth after sectioned	Histologic section	Enamel 0.82 Dentin 0.54	Enamel 0.48 Dentin 0.89
Kay and colleagues	1988	In vitro	30 teeth	Visual of occlusal surfaces	10	Histologic section	0.57	0.67

Authors	Year	Setting (in vitro)	Number of Teeth	Dx Method	Number of Examiners	Lesion Prevalence	Sensitivity	Specificity
Ketly C, Holt R	1993	In vitro	100 molars	BW for occlusal surfaces	2	Histologic section	0.67	0.92
Ketly C, Holt R	1993	In vitro	100 molars	Visual	2	Histologic section	0.31	0.98
Lussi A	1991	In vitro	61 teeth	Visual	34 dentists	Histologic section	0.65	0.83
Lussi A	1991	In vitro	61 teeth	Visual/ Tactile	34 dentists	Histologic section	0.61	0.87
Lussi A and colleagues	1999	In vitro	105 teeth – occlusal surfaces	ECM	11	Histologic section	0.90	0.71
Lussi A and colleagues	2006	In vitro	75 molars / 150 sites	LF	5	Histologic section	Enamel 0.88 Dentin 0.89	Enamel 0.92 Dentin 0.82
Lussi A and colleagues	2006	In vitro	75 molars / 150 sites	BW	5	Histologic section	Enamel 0.68 Dentin 0.45	Enamel 0.67 Dentin 0.89
Nytun R and colleagues	1992	In vitro	30 perm molars	BW	10	Histologic section	0.66	0.50
Nytun R and colleagues	1992	In vitro	30 perm molars	Visual	10	Histologic section	0.72	0.41
Peers A and colleagues	1993	In vitro	240 teeth	FOTI	1	Histologic section	0.67	0.97
Peers A and colleagues	1993	In vitro	240 teeth	Visual	1	Histologic section	0.38	0.99
Peers A and colleagues	1993	In vitro	240 teeth	BW	1	Histologic section	0.59	0.96

Authors	Year	Setting (in vitro)	Number of Teeth	Dx Method	Number of Examiners	Lesion Prevalence	Sensitivity	Specificity
Reis A and colleagues	2006	In vivo and in vitro	57 3rd molars	Visual	2	Intraorally then histologic evaluation following extraction	Enamel 0.75 Dentin 0.69	Enamel 0.55 Dentin 0.88
Reis A and colleagues	2006	In vitro	57 3rd molars	LF	2	Intraorally then histologic evaluation following extraction	Enamel 0.71 Dentin 0.78	Enamel 0.57 Dentin 0.63
Ricketts D and colleagues	1995	In vitro	48 molars	Visual	12	Histologic exam	0.49	0.90
Ricketts D and colleagues	1995	In vitro	48 molars	BW	12	Histologic exam	0.62	0.76
Rodrigues J and colleagues	2009	In vitro	148 teeth	Visual	2	Histologic section	Enamel 0.40 Dentin 0.88	Enamel .97 Dentin 0.46
Rodrigues J and colleagues	2009	In vitro	148 teeth	LF	2	Histologic section	Enamel 0.92 Dentin 0.82	Enamel 0.53 Dentin 0.28
Russel M and Pitts	1993	In vitro	240 sites	LF	3	Histologic section	0.26	0.90
Shi XQ and colleagues	2001	In vitro	40 teeth	QLF	1	Histologic section	0.94	1.0
Shi XQ and colleagues	2001	In vitro	40 teeth	LF	1	Histologic section	0.75	0.96
Valera F and colleagues	2008	In vitro	72 teeth occlusals	Visual	3	Histologic section	0.44	1.0
Valera F and colleagues	2008	In vitro	72 teeth occlusals	BW	3	Histologic section	0.12	0.98

Authors	Year	Setting (in vitro)	Number of Teeth	Dx Method	Number of Examiners	Lesion Prevalence	Sensitivity	Specificity
Valera F and colleagues	2008	In vitro	72 teeth	LF	3	Histologic section	0.33	1.0
Wenzel A and colleagues	2002	In vitro	190 teeth	Digital BW – 2 systems	4	Histologic section	Digital BW system 1 Enamel 0.27 Dentin 0.37 Digital BW system 2 Enamel 0.33 Dentin 0.41	Digital BW system 1 Enamel 0.95 Dentin 0.96 Digital BW new system 2 Enamel 0.94 Dentin 0.94
White and Yoon	2000	In vitro	80 teeth	BW	12	Histologic section	Enamel .4-.42 Dentin .61-.63 All lesions .52-.54	Enamel .75-.78 Dentin .91-.92 All lesions .75-.78

APPENDIX B

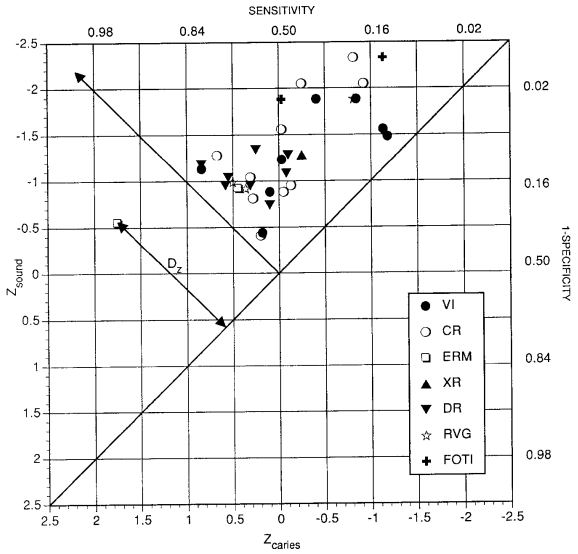
Calculation of standard score (*z*-score) values from Sensitivity/Specificity data.

Study Number	Method	Surface	Sn	Sp	1 - Sp	Z caries	Z Sound	Difference	D_Z
1	LF	Occl	0.95	0.52	0.48	1.645	-0.05	1.695	1.199
	Visual	Occl	0.51	0.91	0.09	0.025	-1.341	1.366	0.966
2	LF	Occl	0.83	0.74	0.26	0.954	-0.643	1.597	1.129
3	Visual	Occl	0.97	0.57	0.43	1.881	-0.176	2.057	1.454
	Visual	Occl	0.78	0.83	0.17	0.772	-0.954	1.726	1.220
	FOTI	Occl	0.96	0.74	0.26	1.751	-0.643	2.394	1.692
	FOTI	Occl	0.89	0.92	0.08	1.227	-1.405	2.632	1.861
	LF	Occl	0.72	0.91	0.09	0.583	-1.341	1.924	1.360
	LF	Occl	0.93	0.72	0.28	1.476	-0.583	2.059	1.455
	ECM	Occl	0.9	0.83	0.17	1.282	-0.954	2.236	1.581
	ECM	Occl	0.81	0.85	0.15	0.878	-1.036	1.914	1.353
4	Visual	Occl	0.63	1	0	0.332	-6	6.332	4.477
	Visual	Occl	0.33	0.95	0.05	0.439	-1.645	2.084	1.473
	LF	Occl	0.72	1	0	0.583	-6	6.583	4.654
	LF	Occl	0.42	0.65	0.35	0.202	-0.385	0.587	0.415
5	Visual	Occl	0.92	0.85	0.15	1.405	-1.036	2.441	1.726
	Visual	Smooth	0.93	0.97	0.03	1.476	-1.881	3.357	2.373
6	Visual	Occl	0.62	0.85	0.15	0.305	-1.036	1.341	0.948
7	LF	Occl	0.95	0.5	0.5	1.645		1.645	1.163
	Visual	Occl	0.66	0.63	0.37	0.412	-0.332	0.744	0.526
8	LF	Occl	0.59	0.87	0.13	0.228	-1.126	1.354	0.957
9	Dig Xray	Occl	0.58	0.87	0.13	0.202	-1.126	1.328	0.939
	Visual	Occl	0.27	1	0	0.613	-6	6.613	4.676
	ECM	Occl	0.58	0.94	0.06	0.202	-1.555	1.757	1.242
	ECM	Occl	0.76	0.9	0.1	0.706	-1.282	1.988	1.405
10	Visual	Occl	0.91	0.54	0.46	1.341	-0.1	1.441	1.018
	Visual	Occl	0.7	0.91	0.09	0.524	-1.341	1.865	1.318
	LF	Occl	0.82	0.48	0.52	0.915	0.05	0.865	0.611
	LF	Occl	0.54	0.89	0.11	0.1	-1.227	1.327	0.938
11	Visual	Occl	0.57	0.67	0.33	0.176	-0.439	0.615	0.434
12	Conv Xray	Occl	0.67	0.92	0.08	0.439	-1.405	1.844	1.303
	Conv Xray	Occl	0.93	0.89	0.11	1.476	-1.227	2.703	1.911
	Visual	Occl	0.31	0.98	0.02	0.496	-2.054	2.55	1.803
	Visual	Occl	0.45	1	0	0.126	-6	6.126	4.331
13	Visual	Occl	0.65	0.83	0.17	0.385	-0.954	1.339	0.946
	Vis/Tact	Occl	0.61	0.87	0.13	0.279	-1.126	1.405	0.993
14	LF	Occl	0.85	0.75	0.25	1.036	-0.674	1.71	1.209
	LF	Occl	0.8	0.83	0.17	0.842	-0.954	1.796	1.269
	ECM	Occl	0.9	0.71	0.29	1.282	-0.553	1.835	1.297
15	LF	Interprox	0.88	0.92	0.08	1.175	-1.405	2.58	1.824
	LF	Interprox	0.89	0.82	0.18	1.227	-0.915	2.142	1.514
	Conv Xray	Interprox	0.68	0.67	0.33	0.468	-0.439	0.907	0.641
	Conv Xray	Interprox	0.45	0.89	0.11	0.126	-1.227	1.353	0.956

16	Conv Xray	Occl	0.66	0.5	0.5	0.412		0.412	0.291
17	Visual	Occl	0.72	0.41	0.59	0.583	0.228	0.355	0.251
18	FOTI	Interprox	0.67	0.97	0.03	0.439	-1.881	2.32	1.640
	Visual	Interprox	0.38	0.99	0.01	0.305	-2.326	2.631	1.860
	Conv Xray	Interprox	0.59	0.96	0.04	0.228	-1.751	1.979	1.399
19	Visual	Occl	0.77	0.73	0.27	0.739	-0.613	1.352	0.956
	Visual	Occl	0.75	0.58	0.42	0.674	-0.202	0.876	0.619
	Visual	Occl	0.72	0.84	0.16	0.583	-0.994	1.577	1.115
	Visual	Occl	0.75	0.55	0.45	0.674	-0.126	0.8	0.565
	Visual	Occl	0.69	0.88	0.12	0.496	-1.175	1.671	1.181
	LF	Occl	0.8	0.43	0.57	0.842	0.176	0.666	0.470
	LF	Occl	0.75	0.52	0.48	0.674	-0.05	0.724	0.511
	LF	Occl	0.71	0.57	0.43	0.553	-0.176	0.729	0.515
	LF	Occl	0.78	0.63	0.37	0.772	-0.332	1.104	0.780
	LF	Occl	0.72	0.73	0.27	0.583	-0.613	1.196	0.845
20	Visual	Occl	0.49	0.9	0.1	0.025	-1.282	1.307	0.924
	Conv Xray	Occl	0.62	0.76	0.24	0.305	-0.706	1.011	0.714
21	Visual	Occl	0.4	0.97	0.03	0.253	-1.881	2.134	1.508
	Visual	Occl	0.88	0.46	0.54	1.175	0.1	1.075	0.760
	LF	Occl	0.92	0.53	0.47	1.405	-0.075	1.48	1.046
	LF	Occl	0.82	0.28	0.72	0.915	1.372	-0.457	-0.323
22	LF	Occl	0.7	0.77	0.23	0.524	-0.739	1.263	0.893
	LF	Occl	0.63	0.89	0.11	0.332	-1.227	1.559	1.102
	LF	Occl	0.63	0.77	0.23	0.332	-0.739	1.071	0.757
	LF	Occl	0.63	0.87	0.13	0.332	-0.739	1.071	0.757
23	LF	Occl	0.26	0.9	0.1	0.643	-1.282	1.925	1.361
24	DIFOTI	Interprox	0.56	0.76	0.24	0.151	-0.706	0.857	0.605
	DIFOTI	Occl	0.67	0.87	0.13	0.439	-1.126	1.565	1.106
	DIFOTI	Smooth	0.43	0.87	0.13	0.176	-1.126	1.302	0.920
	Conv Xray	Interprox	0.21	0.91	0.09	0.806	-1.341	2.147	1.518
	Conv Xray	Occl	0.18	0.98	0.02	0.915	-2.054	2.969	2.099
	Conv Xray	Smooth	0.04	0.96	0.04	1.751	-1.751	3.502	2.476
25	DD	Interprox	0.75	0.96	0.04	0.674	-1.751	2.425	1.714
26	Visual	Occl	0.44	1	0	0.151	-6	6.151	4.349
	Conv Xray	Occl	0.12	0.98	0.02	1.175	-2.054	3.229	2.283
	LF	Occl	0.33	1	0	0.439	-6	6.439	4.553
27	Dig Xray	Interprox	0.27	0.95	0.05	0.613	-1.645	2.258	1.596
	Dig Xray	Interprox	0.37	0.96	0.04	0.332	-1.751	2.083	1.472
	Dig Xray	Interprox	0.33	0.94	0.06	0.439	-1.555	1.994	1.409
	Dig Xray	Interprox	0.41	0.94	0.06	0.228	-1.555	1.783	1.260
28	Conv Xray	Interprox	0.41	0.76	0.24	0.228	-0.706	0.934	0.660
	Conv Xray	Interprox	0.62	0.91	0.09	0.305	-1.341	1.646	1.163

APPENDIX C

Figure 1. Normal-deviate values of Z_{carie} (sensitivity) plotted against Z_{sound} (1 – specificity). (VI = Visual Inspection; CR = Conventional Radiography; ERM = Electrical Resistance Measurement; XR = XeroRadiography; DR = Digital Radiography; RVG = RadioVisioGraphy; FOTI = Fiber-Optic transillumination)



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