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Accurate diagnosis of occlusal carious lesions – a stereo microscope evaluation of clinical diagnosis

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Summary

This study was undertaken to validate the caries status of 214 teeth by serial sectioning and microscopy after caries diagnosis using four methods. Two hundred and fourteen extracted human teeth with varying degrees of caries were mounted in the jaws of nine training manikins. All tooth surfaces were examined and recorded for caries by four dentists using bitewing radiographs, fibre-optic transillumination (FOTI), mirror alone and a mirror and sharp probe on two separate occasions. Thereafter the teeth were serially sectioned and assessed microscopically for depth of caries lesion on a graded score of 0 - 7. This report assessed the diagnostic outcome of 2 183 observations for occlusal surfaces. Sound diagnoses predominated over unsound until caries was present in the inner half of dentine. Specificity was between 90% and 95% and sensitivity 26% and 50% depending on which diagnostic method was used and where the sound/unsound threshold was set. Negative and positive predictive values were similarly influenced and varied between 53% and 80% and 73% and 90%, respectively. Probit analysis showed no significant differences ($P < 0.05$) between examiners and diagnostic methods. Diagnosis of occlusal caries undertaken in an *in vitro* simulated clinical situation is inaccurate until the caries lesion extends deep into the dentine no matter which of the four methods was used.

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Introduction

Epidemiological caries surveys have been undertaken by the Dental Research Institute for the past 25 years[1,2] investigating diverse aspects of this disease in primary and permanent dentition[1,3] and links with variables such as dental treatment,[4] aetiological factors,[5] dietary studies[6] and social class,[7] among others. These studies have formed a database consisting of approximately 20 000 individuals spanning a quarter of a century and serve as an invaluable record and source of baseline data. Caries prevalence was diagnosed in all cases using a sharp probe and plane mirror according to the currently prevailing WHO criteria.[8]

Much has changed in the field of dental caries and diagnosis over these years. The incidence of caries has undergone a dramatic decline,[9] the nature of occlusal carious lesions, in particular, has changed,[10] and consequently this lesion is difficult to detect and is appreciably difficult to diagnose.[11] Conventionally dental caries has been treated when it has affected the dentine,[12] a stage which is readily apparent with clear, visual changes to the tooth substance. Modern practitioners would like to intervene with preventive treatment before a filling is needed[11, 13] but dentists differ widely in the interpretation of the disease in its early stages[14] and disagree on diagnostic thresholds at which to begin treatment.

The instruments traditionally used to diagnose caries have come under scrutiny as well. The probe and mirror are considered as being too crude to diagnose incipient caries,[15] stand accused of damaging the integrity of the surface enamel[16] and have been criticised for transmitting cariogenic flora from one site to another.[17]

These factors have led to a reassessment of the caries disease spectrum and a renewed interest in the arena of caries diagnosis, and have encouraged a burgeoning interest in alternative caries diagnostic methods. The development of sophisticated techniques of caries diagnosis, such as fibre-optic transillumination (FOTI), electrical conductance measurements, enhanced radiographics and infra-red lasers, is in part an attempt to meet this demand.

However many epidemiologists and caries researchers will be confronted with a dilemma similar to ours: how does one reconcile and compare 25 years of historical caries epidemiological data, gathered with a probe and mirror, with similar data using visual diagnosis as currently advocated[8] and any newer caries detection device in the future? In designing a study to answer these questions a great many variables need to be considered. For instance, the choice of comparative and calibration tests; *in vivo* or *in vitro* diagnosis testing; which caries diagnostic validation techniques are required, and so on.

In an effort to resolve all facets of this dilemma, a study was devised[18] which used four caries detection methods on teeth mounted within training manikin heads in a simulated clinical situation. The current paper is an extension of this study, the object being to validate the caries status of the teeth using the 'strong' method of serial sectioning and microscopy.[19]

Methods and materials

The four participating dentists had received their training on three continents and ranged in experience from a recently qualified dentist to a highly experienced epidemiologist, an international expert in children's dentistry and a specialist in the FOTI technique. Thus caries diagnosis trends which could be limited to particular precepts or schools of thought were eliminated. Prior to the investigation, caries examiners were calibrated for caries diagnosis using extracted teeth mounted in plaster blocks[20] and all examiners discussed specimen radiographs to agree on the presence of radiolucency extending from surface enamel to deeper tissues reaching the pulp. Ethics clearance to acquire teeth for the study was obtained from the Committee for Research on Human Subjects of the University of the Witwatersrand, Johannesburg (clearance certificate number 11/5/90).

Human teeth of unknown history were collected from dental clinics in and around Johannesburg, and stored in distilled water with thymol at 6°C. The teeth were sorted as to type and then randomly selected to make up a full jaw of teeth in approximately 'normal' anatomical position. Most of the teeth appeared caries free to simulate the low *in vivo* caries rate. Others represented the entire spectrum of caries from suspicious areas through macroscopic and secondary caries to restored teeth to simulate the normal clinical experience which would be typically encountered in surveys. Large, easy-to-find lesions were deliberately kept to a minimum. In total 214 teeth were set in the jaws of nine training manikins.

Next, bitewing radiographs of the jaws were made for examination of the occlusal, mesial and distal surfaces using Kodak DF-54 Size 0 X-ray film (Eastman Kodak Co, Rochester, NY) and a Philips Oralix X-ray machine (Philips, Eindhoven, The Netherlands) with an exposure time of 0.8 s, 7.5 mA and 65 kVp. The films were developed using Ilford Phenisol X-ray developer (Iso-photo, Rivonia, South Africa) for three minutes, after which they were examined for signs of caries using a light box with a 10x magnifier. Presence of caries was indicated as a radiolucency as described above. Thereafter all four dentists examined each of the 997 tooth surfaces by three methods: with FOTI in a darkened room – a dark spot or shadow indicated caries with a 150 W halogen light source and a 0.5 mm tip diameter; with a plane mirror alone; and with a plane mirror and sharp probe using WHO 1987 criteria[8] for the presence or absence of dental caries. White spot lesions were not diagnosed as caries. Only one examination method was used at a time and each method was repeated on two separate days.

After the 32 examinations each tooth was removed from the jaws and the mesial and buccal surfaces marked with different coloured nail varnish to facilitate orientation of the sections during microscope examination. The teeth were mounted in clear polyester resin and serially sectioned using a low speed, water-cooled diamond disc saw (Isomet Buehler Ltd, Evanston, Illinois, USA) in a vertical mesio-distal plane. The cutting interval was set at 350 μm which meant that the number of sections per tooth varied from 5 to 12 depending on tooth type and size. Both sides of each section were viewed dry at magnifications of 8x to 40x in incident and transmitted light using a Wild M420 Makroskop (Heerbrugg, Switzerland).

A microscope assessment score termed 'truth'(Tr) was drawn up using criteria combined from two previous studies.[21,22] Tr essentially reflects the deepest extent of the lesion.

0 – no lesions apparent – sound tooth
1 – white lesion in outer half of enamel
2 – white lesion extends to inner half of enamel but not beyond amelo-dentinal junction
3 – discoloured lesion extends to outer half of enamel
4 – discoloured lesion extends to inner half of enamel but not beyond amelo-dentinal junction
5 – discoloured lesion extends to outer half of dentine
6 – discoloured lesion extends to inner half of dentine
7 – restored surface

The buccal, mesial, distal, lingual and occlusal surfaces were scored by a single assessor who was blind to the previous diagnoses. The most severe score for each surface was recorded. The data were entered into a SUN SPARC-center 2000 computer using SAS[23] and examined using appropriate statistical techniques.

Sensitivity and specificity tests and positive and negative predictive values[24] were calculated using a threshold fixed between Tr 2 and 3 (deep white lesion and shallow discoloured enamel lesion) and Tr 4 and 5 (deep discoloured enamel lesion and shallow discoloured dentine lesion). Sensitivity measures how well the test correctly identifies those with the disease while the positive predictive value measures the chance that the disease is present when the test indicates its presence. Conversely specificity measures how well the test excludes those who do not have the disease while the negative predictive value indicates the chance

with which health is correctly identified when the disease is diagnosed as being absent. At face value the two concepts appear to describe the same thing but it is important to remember that specificity and sensitivity are properties of the test itself while positive and negative predictive values are determined by the characteristics of the test and the prevalence of the disease in the sample being studied.

The data were also subjected to a Probit analysis[23] to determine effects of examiner, Tr and method on diagnosis. The Probit analysis requires a baseline to be selected for comparison to other variables. The visual method of caries diagnosis was selected as baseline as this is the current method of choice of the WHO[8] and British Association for the Study of Community Dentistry.[25] One of us (JAH), the most experienced caries diagnostician, was selected as baseline examiner. The restored component, Tr 7, was selected as a baseline comparison for caries as it was felt restored surfaces would act as a form of internal diagnostic control. Further analyses were done using two other baseline comparisons to indicate sound/ unsound tooth surfaces. Tr 5 flagged dentine caries, the point at which caries has traditionally been treated while Tr 3 indicated shallow enamel lesions, the phase at which the clinician should be alerted to possible caries progression.

All tooth sections (229) from one manikin head were re-examined to test for reproducibility – the kappa score, modified percentage reproducibility and McNemar tests were calculated.

Results

Three teeth were lost during the procedure and a total of 2 008 sections were obtained from 211 teeth. Both sides of each section was examined, except for the outer buccal and lingual sections of each tooth where only the inner aspect of the section could be examined. Data from 3 594 observations formed the basis of this study. The section thickness allowed a complete bucco-lingual series to be cut for each specimen with minimal damage or fracture. Lesions were easily seen and spread over more than one sectioned surface. Typically a Tr 1 white lesion would be spread over two or more sections while an extensive dentine lesion might encompass up to six sections. There was never a case where a lesion was present on one side of one section only and we are confident that no lesions were overlooked. Restored teeth included one porcelain crown, one composite resin and 13 amalgam fillings. The restoration in one specimen was missing in the sectioned material and it was unclear whether it had been in place during diagnosis. As traces of amalgam fragments were present within the sectioned cavity the surface was given a Tr rating of 7 rather than 6.

Separate Probit analyses were run for each replicate. Similar results were found in both, so to cut down on needless repetition this paper is limited to the results of replicate 1. Reproducibility of microscope assessment revealed a kappa score = 0.82; modified percentage reproducibility = 94.5% and the McNemar test showed a χ^2 value = 0.67 which is not significant at the $P<0.05$ level. This report deals with the 139 occlusal surfaces only; the data pertaining to smooth surfaces will be dealt with in a future report. Each Tr score contained the following numbers of surfaces: 0–59; 1–6; 2–4; 3–11; 4–15; 5–22; 6–12 and 7–10.

Fig. 1 shows the mean as well as the maximum and minimum range of sound and unsound occlusal diagnoses when the diagnosis for each examiner using each method was plotted against Tr 0-7 of the occlusal surfaces. For instance examiner DFC using FOTI and visual diagnosis recorded the maximum of sound surfaces (57 sound) for Tr 0 while the minimum sound score (47 surfaces) for Tr 0 was recorded by examiner JAH using radiographic diagnosis. All other examiner/method combinations fell between these two values resulting in a mean for all sound scores of 54 surfaces out of the possible 59 surfaces. Similarly the maximum of unsound scores for Tr 0 was eight surfaces obtained by examiner JAH using FOTI while examiner DFC using visual diagnosis diagnosed the minimum (one surface) of unsound scores for this category. The mean unsound score was 2.8 for Tr 0. In Fig. 1 it can be seen that sound scores predominate until the crossover between Tr 5 and 6, the threshold between shallow and deep dentine lesions, whereafter unsound scores predominate. Table I indicates specificity, sensitivity, negative and positive predictive values for caries

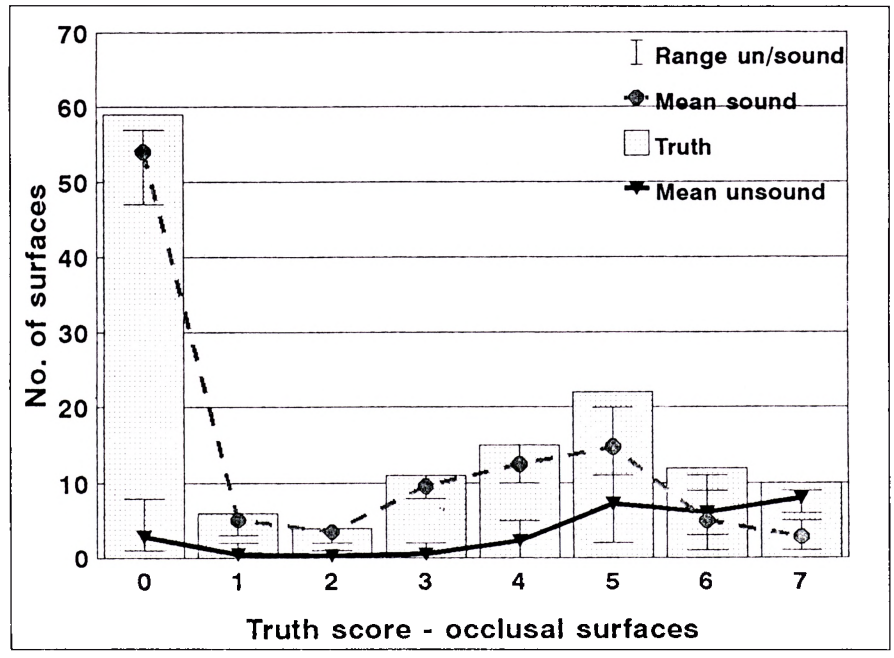

Fig. 1. Accuracy of sound and unsound diagnoses relative to microscope score (Tr 0 - 7) of occlusal surfaces. The bar indicates the number of specimens in each score grouping (Tr); the error bar shows the maximum and minimum range of un/sound scores registered across all four examiners and methods within each group; the lines indicate the mean accuracy of the un/sound diagnosis.

Table I. Percentage specificity, sensitivity, negative and positive predictive values for comparing the four caries detection methods on occlusal surfaces

A – if the threshold for sound/unsound is set between 'Truth' values 2 and 3				
	Specificity	**Sensitivity**	**Negative predictive value**	**Positive predictive value**
FOTI	92	39	59	84
Probe	95	38	59	90
X-ray	93	26	53	82
Visual	95	35	58	90
B – if the threshold for sound/unsound is set between 'Truth' values 4 and 5				
	Specificity	**Sensitivity**	**Negative predictive value**	**Positive predictive value**
FOTI	90	54	80	73
Probe	92	50	79	76
X-ray	93	38	74	76
Visual	93	48	79	77

diagnosis where the threshold for sound and unsound surfaces was set between Tr 2 and 3 (the 'possible caries progression' situation where the enamel is affected – Table IA) and between Tr 4 and 5 (dentine involvement, the 'traditional' initiation of caries treatment – Table IB).While specificity is high at both thresholds indicating good accuracy when recognising sound surfaces, the variable sensitivity scores between the two thresholds reflect the challenges associated with accurately identifying carious lesions which are defined microscopically. Low sensitivity in Table IA is indicative of the problems associated with detecting lesions which include the microscopically apparent shallow enamel component. When the threshold is set at the shallow dentine lesion the increased sensitivity indicates the concomitant ease with which the more severe dentine lesions are identified, all other Tr values between 0 and 4 being regarded as sound. The predictive values reflect the changing balance of the caries prevalence from a 1:1 healthy:diseased ratio at the enamel threshold to the 2:1 ratio at the dentine threshold whatever method was used. This is illustrated in the two-by-two Tables II A and B using FOTI diagnosis as an example. The negative predictive value for occlusal surfaces is markedly lower at the enamel threshold (Table IA) than the dentine threshold (Table IB) as a result of the increased false-negative component, i.e. the many shallow enamel lesions which were overlooked by the examiners. The positive predictive value decreases at the higher threshold level mainly because the false-positive component increases relative to the true positive.

Table II. Two-by-two contingency table used to calculate specificity, sensitivity, negative and positive predictive values for occlusal caries diagnosis when using FOTI*

A – If the threshold for sound/unsound is set between 'Truth' values 2 and 3			
		Truth	
		Healthy	Diseased
Diagnosis	Sound	252 True negative	169 False negative
	Unsound	20 False positive	112 True positive

B – If the threshold for sound/unsound is set between 'Truth' values 4 and 5			
		Truth	
		Healthy	Diseased
Diagnosis	Sound	339 True negative	82 False negative
	Unsound	35 False positive	97 True positive

Specificity = true negative/ (true negative + false positive)
Sensitivity = true positive/ (true positive + false negative)
Negative predictive value = true negative/ (true negative + false negative)
Positive predictive value = true positive/ (true positive + false positive)

*Note that the figures reflect the total number of diagnoses made by four examiners. The sum of the diagnoses are less than 556 (4 x 139 surfaces) as three surfaces were overlooked during the exercise.

In addition Table IA and B show that with the exception of low sensitivity for bitewing radiographs all caries detecting techniques had similar scores when differentiating sound/unsound occlusal surfaces within each threshold grouping. This was further highlighted by the Probit analysis which indicated that no significant difference was apparent between methods (P varying between 0.09 and 0.63) or examiners (P between 0.06 and 0.18) when occlusal surfaces (2183 observations) were examined for caries.

When diagnosis was compared with Tr the significance differed according to the comparative baseline set. Similar results were obtained when the baseline was set at Tr 5 (shallow dentine lesions) or Tr 7 (restored component). The high P values (P = 0.0002 - 0.0001) indicated that the ratio for sound:unsound within the other Tr groupings varied significantly from that of Tr 5 and Tr 7. In other words the

examiners recognised dentine lesions and restored surfaces and diagnosed them as unsound compared with the other Tr groupings which recorded predominantly sound surfaces. When the baseline was set at Tr 3 (shallow enamel lesion) significant differences were apparent on either side of the threshold. Tr 0 was significant ($P = 0.03$) as was Tr 5 – 7 ($P = 0.0001$). Sound surface diagnosis (Tr 0) was significant as it had a greater sound:unsound ratio than the threshold Tr 3. The sound:unsound ratio was similar for Tr 1 through to Tr 4 as evidenced by the P values which varied between 0.1 and 0.7. From Tr 5 - 7 the unsound component of the ratio increased relative to the sound and strong significance was apparent in all cases ($P = 0.0001$).

Discussion

The results indicate that the four participating dentists were unable to accurately diagnose 50% of occlusal caries until it had reached the inner half of dentine which is way beyond the desired level of occlusal caries detection. Enamel caries at the level where preventive therapy could be beneficial is not being recognised to any significant degree. While the design of this *in vitro* study specifically exploited several weaknesses associated with caries determination, the results reflect the present deficiencies of clinical caries diagnosis.

- The examiners diagnosed caries in extracted teeth mounted in the jaws of training manikins under well simulated clinical conditions. Although there is no doubt that the limitless time and absence of patient considerations were to the examiners' advantage we feel that the low accuracy figures obtained in this study can in part be ascribed to the difficulties associated with caries detection within the oral cavity.
- A large number of teeth (211) were used in this study which encompassed the entire spectrum of caries and suspicious conditions based on caries rates in local populations. Obvious, easy-to-find lesions which would cause an overestimation of the specificity of the diagnostic tests were kept to a minimum. There was a high frequency of sound sites in the teeth used in this study reflecting the current low caries incidence and permitting dependable assessments of sensitivity and specificity. In a study using similar tooth numbers[26] only approximal surfaces were examined.
- All teeth were validated, not just those diagnosed as carious, to fully explore the true and false-negative component. While the false- and true positive cohort can to a limited extent be determined *in vivo*, the issue of false- v. true negative can never be ethically explored in the clinical situation. In such cases the only 'strong' validation method available, in the absence of extraction, would be subsequent cavity preparation[19]. The results of *in vivo* caries detection studies tend to be skewed towards the true positive (sensitivity) by prior selection of specimens for validation at the expense of the true negative (specificity). *In vitro* microscope validated caries diagnosis studies will also often only section those teeth which exhibit lesions[26] with a similar effect on specificity.
- The poor diagnostic accuracy is exacerbated by the 'strong' microscope validation method. Hemisection of tooth specimens has been used as a validation technique in some studies[22] but the serial section technique of our study has indicated that the true caries status of a specimen cannot be reflected by one cut surface. This is borne out by recent 3D caries-reconstruction studies[27]. From our previous publication which reported on the diagnostic methods[18] it is evident that little difference exists between the caries status of the teeth when compared within the four diagnostic methods, all of which are considered as 'weak' validation methods. It has been shown that study design (*in vivo* v. *in vitro*) is a major variable influencing the validity of the caries diagnostic test with the accuracy magnified by the validating test either way.[19]
- Validation scoring was according to a logical eight-point histological scale which permitted thresholds for sound/unsound surfaces to be set between different levels of caries progression. In this way early carious lesions at the level where preventative therapy could be beneficial were histologically identified in addition to gross dentinal lesions. Sensitivity, accuracy and predictive values could be assessed and compared using the four diagnostic methods at any caries threshold. The microscope identification of white spots (which were not considered to be carious by the examiners) provided additional markers for further exploration of the extent of the false/true negative segments within the sound surface component.
- Microscope assessment was done by a non-clinician who had no prior knowledge of the diagnostic outcome and who adhered rigidly to the morphological assessment criteria. However while this ensured objectivity any maturation defects were not recognised as such[28] and could have been mistaken for carious staining.

The confidence with which occlusal caries was positively diagnosed in this study is greatly worrying. Poor accuracy in the case of enamel caries can perhaps be ascribed to expected differences in diagnosing caries of wet and dry teeth, but even this issue is ambivalent. Diagnosis of early enamel changes could be hampered should the teeth be dry but this would not affect the diagnosis of dentinal caries.[29] Others are of the opinion that white spot lesions are easier to see when teeth are dry.[11] Whatever the case, low detection of enamel caries might be condoned in the clinical situation as such lesions may undergo natural remineralisation if they are not identified timeously for clinical reversal. In the case of dentine lesions this study indicates that at best the disease is correctly identified in 92% of cases (Examiner JAH, FOTI, Tr 6), at worst 9% (Examiner NPD, X-ray, Tr 5) although the mean accuracy was 45%. The data from this study does not reveal which diagnostic method is 'the best' for detecting occlusal caries in our *in vitro* clinical situation. Probit analysis indicated no significant difference in diagnostic accuracy between the four methods, thus indicating that caries diagnostic data using the four methods are interchangeable.

A previous study[11] has pointed out that there is a lack of accurate validation of clinically diagnosed caries. While microscope validation is regarded as an ideal 'gold standard' reference by many,[10, 30] some opponents feel it is open to misinterpretation and errors.[25] Van

Rijkom and Verdonschot[19] found that the validation method ('strong' or 'weak') did not significantly influence reported validity of new caries diagnostic methods while others[28] expressed concern that maturation defects could obscure small lesions or be mistaken for carious staining. This is probably true in our investigation as well.

A recent study employed a similar methodology to ours but their point of investigation was the diagnostic performance of examiners rather than the validating of caries by microscope.[31] Their work is complementary to our study and many common experiences have been highlighted.

We made no distinction between actively carious, arrested or reversed lesions. This may be criticised in some quarters but we felt that such distinctions were too unclear using our stereo microscope validation method. In this context problems were encountered in pinpointing mainly Tr 3 scores within specimens which had stained fissures, surrounded by demineralised enamel with no cavitation. With the methodology used it was difficult to decide whether such lesions were Tr 2 or Tr 3 specimens. However while we feel that the scoring of shallow enamel lesions may be subject to some debate, we do not perceive that this has materially affected the results of the study, which show that the examining dentists were unable to accurately diagnose carious lesions until these penetrated well into the dentine.

This study has indicated that 'clinical' occlusal caries diagnosis according to WHO criteria[8] using bitewing radiographs, FOTI, mirror alone and with a mirror and sharp probe is sufficiently similar to enable direct comparisons to be made of data gathered by such methods. While the low accuracy of caries diagnosis is disturbing in the extreme, the study was not able to reveal which diagnostic method is 'the best', all methods being equally inaccurate. It appears that instrumentation to increase diagnostic accuracy of caries is a goal to be aimed at in the years ahead.

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