COMPARISON OF PANORAMIC AND BITEWING RADIOGRAPHY FOR THE DETECTION OF DENTAL CARIES : A SYSTEMATIC REVIEW OF DIAGNOSTIC TESTS.

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WEST MIDLANDS HEALTH TECHNOLOGY ASSESSMENT COLLABORATION

The WMHTAC produces rapid systematic reviews about the effectiveness of health care interventions and technologies, in response to requests from West Midlands Health Authorities. Reviews take approximately 6 months and aim to give a timely and accurate analysis of the available evidence, with an economic analysis (usually a cost-utility analysis) of the intervention accompanied by a statement of the quality of the evidence.

CONTRIBUTIONS OF AUTHORS

Kate Taylor-Weetman provided the question for the review and was responsible for the background and any specific information regarding the subject area. Jointly with Beverley Wake she undertook searches, designed the protocol, designed and piloted data inclusion, data extraction and study quality proforma, undertook assessment of study eligibility, validity and extracted and collated data from them; liased with experts and wrote and collated the report.

Beverley Wake was the systematic reviewer and project manager and was responsible for the day to day management of the report; and jointly with Kate Taylor-Weetman undertook searches; designed the protocol; designed and piloted data inclusion, data extraction and study quality proforma; undertook assessment of study eligibility, validity and extracted and collated data from them; liased with experts and wrote and collated the report.

Chris Hyde acted as senior reviewer and provided general advice on all methodological aspects of the review.

All the named authors commented on, and agreed the final version of this report.

ACKNOWLEDGEMENTS

Dr. Fujian Song acted as a methodological peer review
Dr. V.E. Rushton acted as a clinical expert and peer reviewer
Dr. J. Rout acted as a peer reviewer
Christine Leonard : Provided administrative assistance

West Midlands Health Technology Collaboration Recommendation:

The recommendation for the preferential use of panoramic radiography over bitewing radiography for the detection of caries is:

NOT SUPPORTED

The recommendation for the additional use of panoramic radiography with bitewing radiography for the detection of caries is:

NOT PROVEN

Anticipated Expiry Date

- This report was completed in June 2002.
- The searches on clinical effectiveness were completed in February 2002, searches on cost-effectiveness in May 2002.
- Expiry date 2010, unless more evidence becomes available.

EXECUTIVE SUMMARY

Background

In the UK, the accepted radiographic technique to aid the clinical detection of dental caries in posterior teeth is the bitewing radiograph. However it has been reported that panoramic radiography (OPT-orthopantomogram) is often being used solely for the detection of caries, usually in addition to bitewings, although this varies considerably between practitinoers.[1-3] Although selection criteria produced by the Faculty of General Dental Practitioners[4] exclude the use of OPT for this purpose, there is still concern that the criteria have not been widely adopted and that the number of OPTs taken continues to rise at a large cost to the NHS and the public.[5] A driver behind this may be the need to recoup costs spent on expensive panoramic radiography machinery.

The review aimed to compare bitewings to OPT for the detection of dental caries, particularly in terms of accuracy, by comparing (a) OPT and bitewings separately to a suitable reference standard and (b) comparing bitewings to bitewings + OPT to a suitable reference standard. Although (b) was considered to be the most relevant comparison, no studies were found for this comparison.

Clinical Effectiveness

- **Quantity and quality of included studies**

Five studies[6-10] were identified from systematic searches comparing bitewings and OPT to a reference standard. The included studies were highly heterogeneous in terms of study design, included patients i.e. studies looked at different dentitions and surfaces, reference standards and outcomes i.e. some studies looked at presence or absence of caries while others looked at severity of caries also and therefore it was not possible to combine the results in a meta-analysis.

Reference standards varied considerably throughout the 5 included studies, although they were all accepted as meeting the minimum criteria for this review, there were concerns that there were flaws with all of the reference standards.

Overall study quality was reasonable, however there was an important issue about the majority of studies[6,9,10] having a highly selective population and therefore this affects the generalisability of the studies as the disease spectrum of the study populations do not reflect the general UK population. Also where the incidence of disease is greater than would be expected in the general UK population, accuracy is likely to be over-estimated.

There was also an important issue of the quality of radiographs in the studies and in 3[8-10] of the studies a significant proportion of radiographs were excluded due to inadequate quality, this is likely to affect the estimates of accuracy in these studies although it represents an important problem which exists in clinical practice.

Each tooth/surface was not viewed in isolation for most studies and therefore knowledge of caries status of other teeth on a radiograph is likely to affect accuracy since this is a subjective test i.e. if the caries status of a tooth is unclear, it is more likely to be diagnosed as carious if there are other carious teeth on the radiograph (i.e. context bias). However this also reflects a real situation in dental practice.

- **Accuracy**

Overall the results of the included studies indicate that bitewings are likely to be more accurate at diagnosing dental caries, particularly proximal caries confined to dentine. There is likely to be no

difference between the modalities for diagnosing occlusal caries although one study[10] indicated OPT may be slightly superior in terms of specificity. There is likely to be no difference between the modalities for incipient or advanced caries.

Most included studies[6,9,10] used patients with a greater number/variety of carious lesions than is likely to be seen in an 'average' patients in the UK and therefore test accuracy may be over-estimated in these studies.

- **Repeatability**

The repeatability of the reading of dental radiographs is also an issue and this varied from being good to moderate. Only one study[10] reported the intra-observer variability for the two modalities separately and showed there to be a range of moderate agreement for both, although for panoramic radiographs the range was much wider (kappa scores of 0.07 to 0.61 for panoramic radiographs and 0.31 to 0.44 for bitewing radiographs). This indicates that particularly for panoramic radiographs the ability of even one reader to identify the same caries on a radiograph on different occasions may be limited and be an important issue for the effectiveness of such radiographs in practice. Repeatability is important since it will directly impact on test accuracy.
There is also an issue about the fact that it was often difficult to detect in the studies whether the two modalities were identifying the same carious lesions, which obviously impacts on both accuracy and repeatability.

Poor results for inter-observer repeatability for the reading of all dental radiographs, highlight the need for training of dentists in these skills, particularly since general dental practitioners are likely to be less trained than those considered 'experts' in the included studies.

- **Side effects**

None of the included studies looked at side effects of the tests, the most important of which is considered to be x-ray dosage. The individual impact of these x-rays in terms of ill-health is likely to be very small, [11] although x-ray dosage from panoramic radiography may be considerably higher than that from bitewing radiogrphs, particularly where equipment is old (42% machines are more than 10 years old).[3] It is important to reduce the number of unnecessary radiographs taken and therefore since OPTs provide no further information, particularly in terms of using them with bitewings, then their use in this area should be discontinued.

- **Patient Preference**

Some authors[12] have suggested that panoramic radiographs may be associated with less discomfort for the patient. Panoramic radiography is associated with a higher dose of radiation and a slightly higher cost to the paying patient and the NHS and that results from included studies in this review suggest that particularly for approximal caries are likely to be less accurate at detecting caries. No studies were identified which had studied patient preference in terms of these two tests and therefore no empirical evidence can be used on which to base a conclusion. It is possible that panoramic radiographs may have some use in patients who are averse to intra-oral radiography or those for whom it is impractical e.g. some disabled patients.

Cost-effectiveness

There were no existing economic evaluations comparing bitewing to panoramic radiographs, therefore a cost consequence analysis was carried out which identified the costs of two bitewing radiographs - £4.55

(cost to patient £3.64) and a panoramic radiographs- £10.15 (cost to patient £8.12). However it was not possible to determine which diagnostic test is more cost-effective, this may be irrelevant since there is no evidence that panoramic radiographs should replace or be used in addition to bitewing radiographs and since both of these options is associated with an increase in costs, there is no reason in terms of cost to use panoramic radiographs for the detection of dental caries.

Implications for policy

Although the present guidelines are clear that OPT should not be taken for the detection of dental caries alone,[4] there is concern that panoramic radiographs are still being taken solely for the diagnosis of dental caries[1,13] and this is clearly not acceptable, both in terms of unnecessary x-ray exposure to the patient but also unnecessary expense both to the patient and the NHS.

It is therefore the consideration of this review that the selection criteria need to be reinforced as guidelines for practice, clearly stating that panoramic radiography should not be used solely for the diagnosis of dental caries and the evidence as presented in this review be stated to show that there is no evidence that panoramic radiographs provide no more information on dental caries than that provided by the current standard practice of bitewing radiographs. Furthermore checks could be carried out by the Department of Health, to whom the Dental Practice Board of England and Wales is responsible, to ensure that panoramic radiography is not being used inappropriately.

Implications for further research

Further research in this area in order to substantiate the conclusions drawn in this review. Ideally a study would compare panoramic radiography, bitewing radiography (F-speed) and panoramic + bitewing radiography to a suitable reference standard for the UK, to determine the presence of caries. It is acknowledged by the authors that in reality diagnosis of dental caries always involves a clinical examination and therefore further studies should include this in the design of the study. The design of the study is also important and ideally the patients to be included would be consecutively or randomly drawn from a representative UK population.

Although further studies could confirm the findings of this review, further research specifically comparing accuracy of the two modalities is unlikely to be carried out as most evidence already points to the fact that panoramic radiographs are unnecessary for the detection of dental caries.

More useful information would probably be provide by studies of cost-effectiveness, a study should determine the costs of missing caries and therefore the cost-effectiveness of each type of radiograph. This approach could involve a modelling exercise.

From the studies included in this review it is clear that the reliability of dental radiographs in terms of repeatability and quality are important issues in dental practice due to the subjective nature of the tests. Since test accuracy is dependent upon reliability and quality, these are important issues to be considered in any further work carried out in this area.

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1. AIM OF REVIEW

The aim is to systematically review the evidence for the effectiveness (primarily in terms of test accuracy) and cost-effectiveness of panoramic radiography (OPT-orthopantomogram) in place of, or in addition to, the use of bitewing radiography (see appendix 8 for definitions) for the detection of occlusal and proximal dental caries in the posterior teeth of the deciduous and permanent dentitions (see appendix 7 for definitions).

2. BACKGROUND

2.1 RATIONALE BEHIND REVIEW

Radiographs are used as an adjunct to the clinical detection of dental caries, as clinical examination alone is incapable of revealing small lesions at inaccessible sites.[14] Clinical examinations alone are generally unable to recognise more than half the total number of lesions versus 90% for radiographic examination.

In the UK, the accepted radiographic view is the bitewing radiograph, which produces images of the crowns of premolar and molar teeth and adjacent interproximal bone. This enables the clinician to view the often obscured interproximal tooth surfaces and also the occlusal surfaces.

It is recognised however, that there are limitations to bitewing radiography. Although the specificity is high for both lesions with intact enamel and those with clinically detectable lesions in dentine, the sensitivity is low for intact enamel on occlusal surfaces and medium for approximal lesions with intact enamel, and occlusal and approximal lesions with clinically detectable lesions into dentine.[15]

It has been reported that another radiographic modality, the orthopantomograph is taken by dentists for diagnosis of dental caries[1], in individuals with a heavily restored dentition[2], and routinely for every new adult patient attending dental practice.[3]

The panoramic radiograph produces images of all teeth, the upper and lower jaws and other hard structures of the mandible and maxilla. Selection criteria (see appendix 14) produced in 1998 by the Faculty of General Dental Practitioners [4] clearly exclude the routine use of panoramic radiographs for new patients and for the heavily restored dentition, and report that the image quality of panoramic radiographs is inferior to that of intra oral radiographs - bitewings. It is therefore of concern to see that the number of OPT radiographs taken in the NHS General Dental Services has continued to increase. By 2000/1 2,096,343 OPT radiographs were claimed in the NHS GDS in England at a cost of £19,668,552[5]. This fact in addition to the potential inappropriate exposure of individuals to unnecessary radiation indicates the need to systematically review the evidence on the accuracy of OPTs compared with alternative tests to detect dental caries, in order to inform practice since there is evidence that OPTs are being used in place of or adjuvant to other radiographic techniques with the possible detrimental effect on health and a possible increase in costs to the NHS and patients.

2.2 DESCRIPTION OF UNDERLYING HEALTH PROBLEM

2.2.1 Nature of disease

Dental caries is a multifactoral disease caused by the interaction of host factors; tooth surface, saliva, acquired pellicle, diet and dental plaque. Caries does not occur in the absence of dental plaque or dietary fermentable carbohydrates. As well as biological factors, social, behavioural and psychosocial factors play an important part in the caries process.[16]

Acid formed from the fermentation of dietary carbohydrates by oral bacteria can lead to a progressive decalcification of the tooth's substance.[17] However the process of caries is a dynamic one with mineralization and demineralization events alternating over extended periods. The net balance of dissolution and remineralization over time determines whether a new clinical lesion ever progresses to the stage where it can be detected clinically and ultimately whether a filling is required. Similarly, an established lesion may be genuinely arrested or may progress or regress over variable time periods.[16]

The first visual clinical presentation of dental caries is commonly referred to as a white spot lesion. The clinical appearance of the white spot lesion is caused by the loss of sub surface enamel, resulting in the loss of enamel translucency. At the white spot stage, the progress of the lesion may be arrested or reversed by modifying any of the causal factors or increasing preventive measures. As the caries process progresses, the sub surface lesion increases in size, eventually leading to the collapse of the surface layer and formation of a cavity requiring restoration.[16]

There has however over recent years been an apparent change in the presentation of caries in which cavitation now seems to occur more often at a later stage and there has thus been an increase in the number of management options available to dentists.[16,18] Over the last ten years reports from clinicians and researchers in a number of countries have indicated that slow continuing progression of demineralization under apparently intact enamel seems to becoming more common. This may be due to slow lesion progression and the harder enamel associated with an increase in available fluoride in the environment being more able to support itself over demineralized areas of dentine. Ideally a lesion should be diagnosed at the earliest stage in order that preventative treatment has a chance to arrest lesion progression.[16]

Premature restoration carries a burden of increased and unnecessary cost to patients and healthcare systems in terms of both the initial restoration and maintenance over the years. On the other hand delayed operative care may be associated with unnecessary pain, provision of larger fillings which are more difficult and expensive to maintain and which may compromise the long-term survival of the teeth. In some cases avoidable endodontic therapy or tooth extraction may be the result. The benefits to patients, dentists and healthcare systems of defining the optimal threshold for restorative intervention are thus considerable and the bitewing radiograph plays an important role in this.[18]

2.2.2 Epidemiology

National decennial surveys of child and adult dental health have reported that experience of dental caries has improved over recent decades.[19,20] The decrease in the prevalence of dental caries is in part due to better diet, public awareness and preventive approaches including fluoride toothpaste and water fluoridation. [21]

Caries experience in children is identified using the dmft (deciduous teeth) and DMFT (permanent teeth) indices which identify the number of teeth with active untreated decay (d/D), number of teeth missing due to decay (m/M) and number of teeth filled due to decay (f/F). These indices only apply to children, as with increasing age the index is less valid as the reason for loss of teeth becomes less clear in adults. These indices tend to underestimate the true level of dental caries in individuals.[18]

The 1993 Survey of Children's Dental Health[20] reported that by five years of age 45% of children had experienced decay in their deciduous dentition rising to 61% at nine years of age. At age fifteen 63% had experienced decay in their permanent teeth. The 1998 Adult Dental Health Survey[19] found that over 55% of dentate adults had one or more decayed or unsound teeth, dentate adults had an average of 8.1 teeth restored and on average each adult had 1 decayed or unsound tooth. Hence despite the improvements in recent decades, dental caries still affects a significant proportion of the population.

Dental health is related to deprivation i.e. more deprived individuals tend to have more caries.[20] Risk is known to increase with the frequency of fermentable carbohydrate consumption and reduces with increasing use of fluoride.[17,22]

Oral problems also have an impact on the quality of life of individuals. It has been reported that 51% of those with teeth reported having experienced one or more oral problems that had an impact on some aspect of their life during the year preceding the Adult Dental Health Survey of 1998.[19] Oral pain was the most frequently reported problem by 40% of individuals.

2.3 CURRENT SERVICE PROVISION

Visual clinical examination is one aspect of detecting caries, however several areas of the tooth are not visible to the human eye including below fillings, at the contact point of teeth and below the gingival (gum) level. In addition, the changing nature of dental caries, resulting in slower progression of demineralisation and later cavitation, has resulted in deep invasion of dentine which is concealed under enamel that superficially appears to be intact[18]. Therefore to aid visual examination, radiography may be used as an adjunct to the clinical examination. In the UK, intraoral bitewing radiography comprising two bitewing radiographs is commonly utilised, and an accepted adjunct to clinical diagnosis of dental caries.

Each bitewing provides an image of the posterior teeth typically from the first premolar extending distally to the second or third molar tooth. Under NHS GDS regulations, some 3.2 million claims were made in England in 2000/1 to the Dental Practice for 2 bitewing radiographs.

There is evidence (already referenced elsewhere) that some dentists routinely take orthopantomograms of new patients attending their practice, [3] of those with a heavily restored dentition [2] and for the diagnosis of dental caries, [1]despite recently published selection criteria exluding cases such as these. The number of orthopantomographs claimed for under NHS GDS regulations since the publication of the selection criteria in 1998 has continued to increase and in England during 2000/1, 2.1 million OPT radiograph claims were made.

2.4 DESCRIPTION OF DIAGNOSTIC TESTS UNDER EVALUATION

Intra-oral or posterior bitewing radiography provides an image of the posterior teeth typically from the first premolar extending distally to the second or third molar tooth (effective dose 2-10 µ Sievert per radiograph, one on each side of mouth). Bitewing radiographs taken with rectangular columnation are considered to be the Radiographic Reference Standard for diagnosis of caries in the UK (see appendix 8 for more details on radiographic techniques).

Also in common use in general dental practice is the OPT providing an image of the complete upper and lower jaws although the anterior teeth are usually not clear due to superimposition on the cervical vertebrae (effective dose 7-26 µ Sievert). In practice dosage may be significantly higher since approximately 40% OPT equipment is >10 years old.[3] Also it should be noted that doses are higher, the younger the patient.

2.5 POLICY QUESTIONS TO BE ADDRESSED BY THIS REVIEW

Bitewing radiographs are the current recommended practice [4]for detecting caries on the occlusal and proximal surfaces of posterior (molar and premolar) teeth, while panoramic radiography is not currently recommended for this purpose (see appendix 14). However since it is perceived that the use of panoramic radiography to detect such caries is continuing this review aims to address whether there is any evidence for the use of panoramic radiography either in place of or more commonly in addition to bitewing radiographs.

2.5.1 Method of comparison

Three methods of comparison were available to the reviewers and are outlined below:-

(a) Comparison of bitewing and panoramic radiography without a comparison with a recognised reference standard. In this case bitewing radiography would be taken to be the reference standard to which panoramic radiography could be compared. The problem with this approach is that it would not answer the review question since we are interested in finding out which test is better at detecting dental caries. It was therefore decided not to include any studies looking at this comparison only.

(b) Indirect comparison of bitewing and panoramic radiography. This approach involves including studies which look at bitewing OR panoramic radiography compared to a recognised reference standard. The problem with this approach is that it may not be able to answer the review question as the reference standards, study conditions and populations in separate studies are unlikely to be sufficiently similar to use as comparisons. It was therefore decided not to include any studies looking at bitewing radiography vs. reference

standard only or panoramic radiography vs. reference standard only, although it is accepted by the reviewers that such studies may be useful in confirming or refuting evidence provided by stronger study designs.

(c) Direct comparison of bitewing and panoramic radiography. This approach involves the direct comparison in each study of bitewing radiography to a reference standard and panoramic radiography to a reference standard. Ideally studies should also compare bitewing radiography with panoramic radiography to the reference standard. It was therefore decided that only studies using direct comparison would be included in this review.

It was decided that the review would look primarily at diagnostic test accuracy and cost-effectiveness. However, important secondary outcomes for diagnostic tests include test reliability/repeatability, acceptability to patients particularly in terms of cost and adverse effects and clinical effectiveness i.e. ability of the test to influence clinical decisions and overall patient outcomes relating to the disease e.g. numbers of extractions or restorations required. This review will be divided into effectiveness (including accuracy, reliability, acceptability and clinical effectiveness) and cost-effectiveness.

2.6 REFERENCE STANDARD

Properly carried out bitewing radiographs are the 'gold standard' in the UK, however since this review aimed to compare bitewings to OPT an appropriate reference standard needed to be selected. This was an important issue in this review and there appeared to be no consensus in the literature on what this should be. A good reference standard would be histologically confirmed presence of dental caries, however this is not practical except for extracted teeth. Therefore the reviewers decided, after soliciting expert opinion that a suitable reference standard for UK practice should be standard panoramic and bitewing radiographs with a clinical examination and follow-up where possible. Other reference standards would be considered acceptable where empirical evidence was available that such reference standard test/s were validated.

3. EFFECTIVENESS

3.1 METHODS

3.1.1 Search Strategy

A scoping search was carried out to identify any existing reviews in the field. The following were searched for primary studies assessing the effectiveness of panoramic vs bitewing radiography for the detection of dental caries:

- Electronic bibliographic database searches ; **MEDLINE** (Ovid) 1966-February 2002; **Embase** (Ovid) 1980-February 2002 and **CINAHL** (Ovid) 1982-February 2002 (see Appendix 1 for detail on search terms used)
- Citation checking of studies and reviews obtained
- Contact with experts in the field (see Appendix 2 for list)

- Internet search engines including lycos, excite and netscape using terms such as 'bitewing radiography', 'panoramic radiography' and 'dental caries'.
- Search of specific internet sites such as www.dpb.nhs.uk/index.shtml (Dental Practice Board), www.derweb.ac.uk/index.html (Dental Educational Resources on the Web), www.medweb.emory.edu/medweb (Medweb) and www.dundee.ac.uk/dhsru (Dental Health Services Research Unit).
- There were no language restrictions.

3.1.2 Inclusion and exclusion criteria

The following inclusion and exclusion criteria were applied independently to all identified studies by 2 reviewers. A 'kappa' score of 0.76 (95% CI : 0.61-0.9) was calculated to detect interrater agreement (i.e. Kappa ranges from 0-1) and showed there was good agreement between the two reviewers on which studies should be included and which excluded. For those studies where this could not be decided on abstract alone references were obtained in full and all disagreement were resolved by discussion between the two reviewers.

- **Population** : The population should be deciduous or permanent dentitions *in vivo* or *in vitro* and must be pre-molars or molars i.e individual teeth (where other teeth are included in studies, the results for molars and pre-molars should be recorded separately if possible). The population may also be surfaces of teeth but must not be people as a unit i.e. these studies will be excluded.

- **Intervention** : The interventions to be compared are panoramic radiography (orthopantomogram) and bitewing radiography, including panoramic + bitewing radiography compared to bitewing radiography alone. Studies were excluded if they did not compare standard panoramic radiography and bitewing radiography.

- **Comparator/Reference Standard** : The comparator must be a suitable reference standard such as standard OPT + bitewings + clinical examination + follow-up, or histologically confirmed caries for extracted teeth. Other reference standards will be acceptable if they have been validated with empirical evidence. Where the reference standard was OPT + bitewings only or was not clear, these papers were excluded.

- **Outcomes** : The primary effectiveness outcome is test accuracy as measured by sensitivity, specificity or other measures of test accuracy. Other outcomes include accuracy, reliability, acceptability and clinical effectiveness. Where test accuracy was not measured or could not be calculated the study was excluded.

- **Study design** : Any study design will be considered (see Appendix 4), although the type of study design will ultimately be used to determine quality of the included studies i.e. an independent, blind comparison with reference standard among an appropriate population of consecutive patients would be considered to be of the highest quality.

3.1.3 Data extraction strategy

Data concerning study characteristics, study quality and results were extracted by BW and checked by KTW using a series of standard data extraction proforma (Appendix 8). Any differences were resolved by consensus.

3.1.4 Quality assessment strategy

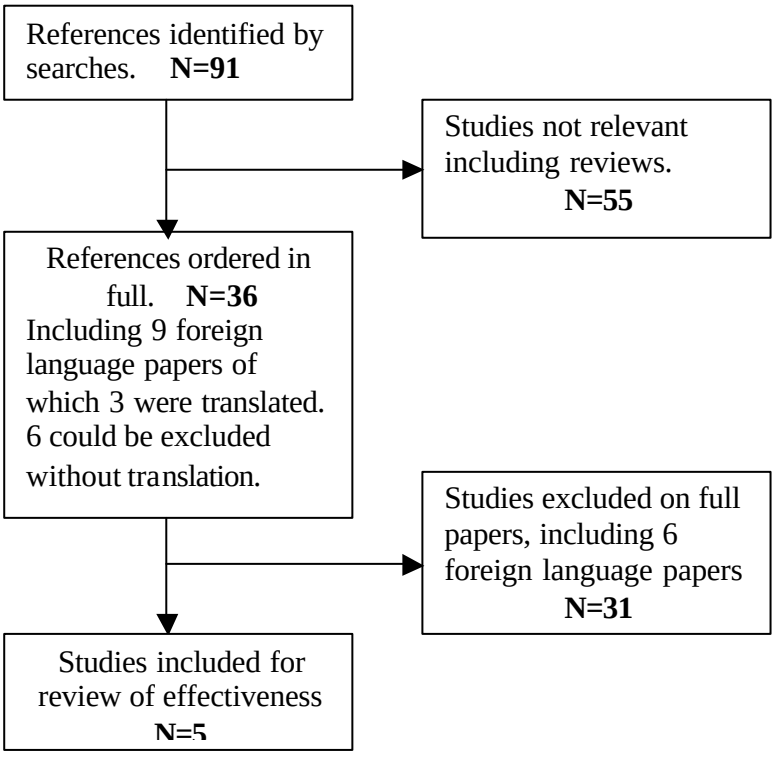
A structured form to assess study quality was devised from existing checklists [23] and piloted before being applied to the included studies. The quality assessment was performed by BW and checked by KTW and any differences resolved by consensus.

3.2 RESULTS

3.2.1 Quantity and quality of research available

Number of studies identified

The search identified 91 studies of which 36 were considered relevant on application of the inclusion/exclusion criteria to the abstracts or insufficient information was provided in the abstract to include or exclude the study. Therefore these 36 studies were ordered in full of which 9 needed translation. Studies clearly identifiable as reviews from the abstract were also excluded at this stage. Of the 36 studies ordered in full, 5 [6-10] were included in the review, some studies required translation while others were clearly not included when the full paper was seen.



Included study characteristics

The 5 included studies [6-10] were very heterogeneous in nature in terms of many characteristics such as study design, outcomes and reference standards. The trials will now be described qualitatively to enable the results section to be clearly understood.

Clifton 1998[6]

This trial is a prospective study of test accuracy carried out in the USA, and differed from all other included studies by the fact that it studied extracted, deciduous teeth. The 64 teeth were all molars and constituted 192 proximal and occlusal surfaces. They were selected to provide a variety of lesions. The reference standard was histologically confirmed caries using a light microscope. Eight observers viewed bitewing and panoramic radiographs of each tooth in a randomised order and graded presence or absence on a 5-point ordinal scale from 1=certainty of absence of caries to 5=certainty of presence of caries.

Results for test accuracy are given as ROC curves i.e. average Az scores for area under the curve for the eight observers. Tukey's pair-wise comparison is the statistical test used to determine statistically significant differences between bitewing radiographs and panoramic radiographs.

Intra-observer variability was also studied as 5/8 observers repeated some of the observations. This was measured using the paired t-test and an intra-class correlation coefficient. Inter-observer variability was investigated using ANOVA.

Douglass 1986[7]

This trial differs from all the other included studies in that it is a retrospective study of test accuracy. It was carried out in the USA on asymptomatic patients using a complete set of posterior bitewing, panoramic and periapical radiographs from the Dental Longitudinal Study (DLS) which was initiated in 1968 and then took radiographs every 3 years. Only radiographs from the initial visit in 1968 were used in this study. The 8709 included teeth were all molars or premolars of permanent dentition and the study did not look at individual surfaces i.e. results were presented as number of carious teeth. The reference standard was a consensus of all three radiographs read simultaneously with a follow-up validation of this consensus using a clinical examination and further radiographs. Four observers viewed the radiographs in a random order and graded presence or absence on a 4-point ordinal scale of D_0=no caries, D_1=enamel caries, D_2=dentine caries, D_3=advanced caries into dentine. Using this scale teeth were then defined as either carious or non-carious (i.e. disease or no disease).

The results are divided into two experiments, the first where D_0 and D_1 indicate no disease and a second analysis where D_0 only indicates no disease. Results for test accuracy are given as sensitivity and specificity. Intra-observer variability and inter-observer variability were also studied and analysed using Kappa score.

Hansen 1980[8]

This trial is a prospective study of test accuracy for the detection of interproximal caries carried out in Norway. 3206 surfaces of posterior permanent teeth were included from a random sample of Oslo citizens. The surfaces were the distal surfaces of the canines and the mesial and distal surfaces of the bicuspids and molars, excluding third molars. The reference standard was a clinical examination with bitewing and panoramic radiographs and the paper considered that there were no false positives. One observer viewed bitewing and panoramic radiographs of each tooth. For bitewing radiographs primary caries were defined as confined to enamel or involving enamel and dentine and secondary caries were also studied. Outcomes were then reported as carious or non-carious surfaces. For panoramic radiographs outcomes reported were carious or non-carious surfaces only.

Results for test accuracy are given as % of caries detected by each modality and from this information 2x2 tables could be drawn and sensitivity calculated. Since it was assumed that there were no false positives, specificity could not be calculated. Intra-observer variability was not measured.

Scarfe 1994[9]

This trial is a prospective study of test accuracy for the detection of proximal caries carried out in the USA using cases of caries and matched controls. For this study two bitewing radiographs were taken for each side of the mouth, therefore four bitewing radiographs were taken in total compared to the other studies where only two bitewing radiographs were taken. This is important since the use of 2 radiographs on each side of the mouth mean that the chances of having all posterior teeth on the image are increased. Patients were selected to maximise the number of contacting carious proximal surfaces, and then, only carious teeth with minimal identifying characteristics were included to prevent operator bias and reader recognition of same subject. The proximal surfaces only, of permanent teeth were included resulting in 367 control surfaces and 505 diseased surfaces being identified from the 35 included sets of radiographs, of which 200 diseased and 200 control surfaces were selected for inclusion. Included surfaces were proximal surfaces from the distal surface of the canine to the distal surface of the last molar.

The reference standard was a consensus agreement of two‘expert viewers’ using bitewing, standard panoramic and orthogonal panoramic radiographs as to the presence or absence (control group) of caries and the extent of the caries on a 5-point ordinal scale of C0=caries free, C1=enamel caries less than halfway through the enamel (incipient caries), C2=enamel caries that penetrate at least halfway through the enamel but do not include the dentinoenamel junction, C3=caries of both enamel and dentine definitely at or through the dentinoenamel junction that extend less than halfway towards the pulp cavity and C4=caries of enamel and dentine that penetrate at least halfway towards the pulp cavity. Eighteen seperate observers viewed bitewing and panoramic radiographs in a random order and graded presence or absence on a 5-point ordinal scale from 1=certainty of presence of caries to 5=certainty of absence of caries.

Using the data, two experiments were performed. The first experiment determined the overall diagnostic accuracy of the modalities using the 1-5 scale for the presence or absence of caries

while the second experiment looked at the ability of the radiographs to detect the severity of the caries based on the C0 to C4 scale.

Results for test accuracy are given as ROC curves and critical ratio analysis of maximum likelihood areas used to assess accuracy between modalities. Intra-observer variability and inter-observer variability was not studied although from the methods described it should have been possible to study both.

Thomas 2001[10]

This trial is a prospective study of test accuracy, carried out in the UK in 1996, for the detection of occlusal caries in dentine. Patients were included from a study of new recruits to The Army Catering Corps following a clinical examination providing they had one or more unrestored occlusal surface in a molar. Individual teeth were then selected providing they had ; no restoration, including fissure sealant, covering part of the occlusal surface, no obvious proximal caries, no buccal or lingual caries or restoration. 299 occlusal surfaces of permanent molars were included in the study i.e. the population was highly selected, which impacts on generalisability.

The reference standard was electronic conductance, which has been validated in clinical trials, and the study divided into two experiments. One with the validation threshold of the electronic conductance meter reading (ECM) of >9 indicating presence of dentinal caries and the second with the validation threshold at an ECM of >12 indicating the presence of deep dentinal caries. Seven examiners viewed bitewing and panoramic radiographs which were coded to preserve patient anonymity and prevent examiner bias and coded each occlusal surface based on a 5-point ordinal scale where 1=almost definitely no dentine caries present to 5=almost definitely dentine caries present.

Results for test accuracy are given as sensitivity and specificity at the two validation thresholds and similarly as ROC curves where area beneath the curve is presented and statistical significance of any differences performed using ANOVA. Intra-examiner variability was measured by each examiner viewing 20% of the radiographs on a separate occasion and analysed using Kappa.

Table 1 - Summary of characteristics of included studies (see also appendix 10)

Clifton 1998[6]	Compared BW (bitewings) to OPT(panoramic radiographs) using a reference standard Reference standard is histologically confirmed caries 64 extracted deciduous molars with 192 surfaces included Proximal and occlusal caries studied Outcomes were the presence or absence of caries Test accuracy measured using ROC curves
Douglass 1986[7]	Compared BW to OPT using a reference standard Reference standard is a consensus using OPT, BW and peri-apical radiographs and is really just adding up all lesions 8709 permanent posterior teeth included Results given as carious teeth and surfaces not defined Outcomes were the presence or absence of caries, indirectly the severity of caries was also studied as a second analysis altered the threshold of 'caries present' to include enamel caries as well as dentine caries. Test accuracy measured using sensitivity, specificity, PPV and NPV
Hansen 1980[8]	Compared BW to OPT using a reference standard Reference standard is a clinical examination + OPT +BW 3206 surfaces of permanent posterior teeth included Proximal caries only studied. Outcomes were the presence or absence of caries Test accuracy was measured using % of caries detected, therefore sensitivity can be determined.
Scarfe 1994[9]	Compared BW (4 film) to OPT using a reference standard Reference standard is consensus of all experts using BW, standard OPT and orthogonal OPT, differences resolved by discussion. 367 control surfaces and 505 diseased surfaces of permanent posterior teeth identified and 200 of each included in study. Proximal caries only studied. Outcomes were the presence or absence of caries (expt. 1) and the severity of caries (expt. 2). Test accuracy was measured using ROC curves
Thomas 2001[10]	Compared BW to OPT using a reference standard Reference standard is an electronic conductance meter 299 occlusal surfaces of permanent molars included Occlusal caries only studied. Outcomes were the presence or absence of caries and indirectly the severity of caries since the threshold of the reference standard was changed in a second analysis to include deep dentine caries as well as dentine caries.

Included study quality

Indicators of study quality and a study quality checklist were designed from a published table of diagnostic test study quality [23] and results are listed in Appendix 12.

Study Design

All but one [7] of the included studies were carried out prospectively which is the preferred study design for studies of test accuracy. Only one of the included studies had patients recruited consecutively or as a random sample [8], however it was difficult to detect sources of selection bias in some of the studies as the selection methods weren't clear.[7,10] In 2 studies the included subjects were highly selected.[6] This may be an issue, although teeth are the unit of study and not patients, examiners view radiographs of several teeth at once and therefore on a radiograph containing various carious teeth, a tooth where the diagnosis is not obvious is more likely to be concluded as carious due to knowledge of other teeth present on the radiograph (i.e. context bias).[9]**.** In all the included studies the included teeth/surfaces were well defined and it was made clear on which teeth/surfaces the test was carried out. In $^4/_5$ studies those reading the radiographs for bitewing and panoramic modalities were blinded to the outcome of the reference standard, even if the same person carried out both readings the radiographs were given in a random order to reduce bias. However for one study [8] it is not clear if blinding took place since only one examiner was involved in the study and blinding is not mentioned in the methods.

Comparator

The 'reference standard' test to which the other tests were compared was described adequately in $^4/_5$ studies and was considered an acceptable reference standard although throughout the studies it varied considerably e.g. histologically confirmed caries to a consensus of all radiographs taken with a follow-up clinical examination. In one study [8] the reference standard was a clinical examination with panoramic and bitewing radiographs. This would normally be acceptable, however there was some concern because results for each of the modalities alone were given as % of caries identified from the reference standard which were identified by each modality. This meant that it was assumed by the study that there were no false positives and therefore specificity could not be calculated i.e. was 100%.

Methods

Reading scales of radiographs were adequately described in all included studies. The scales were all 4 or 5 point ordinal scales except in one study where a nominal scale was used,[8] and related in each study to either the certainty of presence of caries or the type of caries present or both. The tests themselves i.e. bitewing and panoramic radiographs were well described in terms of machine used, film used, x-ray source and viewing conditions in $^3/_5$ trials [6,9,10], but in two of the included studies [7,8] the tests were not described in any detail. This may affect the ability to combine study results due to comparable tests, however since it is not possible to combine studies due to the heterogeneity of the design and other factors such as the reference standard used, there is little threat to validity from this factor. In all but one of the studies [8] an adequate number of examiners read the radiographs from which an average score was obtained, the numbers of examiners ranged from 4 [7] to 18 [9]. In one study [8] only one examiner read the radiographs from the diagnostic tests. In three of the studies[8-10] some radiographs were excluded because they were

not of adequate quality, this may be an important consideration in the effectiveness of the relevant radiographic techniques.

Outcomes

Outcomes were clearly stated in all included studies and were generally sensitivity and specificity or ROC curves. All were acceptable outcomes for the review except for the concern already expressed over one paper [8] as results were given as % caries detected by each modality. From these results sensitivity but not specificity could be calculated. Intra-observer variation was considered in 3 studies [6,7,10] and inter-observer variability in 2 studies [6,7]. None of the included studies looked at other outcomes such as acceptability or adverse events. In none of the studies was there considered to be a significant (>10%) amount of data missing as should have been present. An important factor is the number of radiographs excluded due to being poor quality. This was described in 3 studies, in Hansen[8] 15% of radiographs were 'not suitable', in Scarfe[9] 26% were poor quality and in Thomas[10] an unknown number of radiographs were excluded due to poor quality.

Generalisability

The majority of the populations of the included studies will not be relevant to the general population of a UK practice since they were mostly not general populations e.g. new army recruits who had bitewing and panoramic radiographs taken as standard procedure or teeth selected due to the number and type of caries present.

The most important threat to generalisability is likely to be that the disease spectrum of the included population may not represent the disease spectrum in the UK general population. In order to combat this problem, teeth/surfaces were the units of population rather than people/mouths. However, although this was the case radiographs of individual teeth were not viewed in isolation and were viewed along with other teeth present in the mouth. Therefore the presence or absence of caries in neighbouring teeth is likely to have affected the viewers decision to class an individual tooth as carious or non-carious even if this was only subconsciously.

Most included studies[6,9,10] used patients with a greater number/variety of carious lesions than is likely to be seen in an 'average' patients in the UK and therefore test accuracy may be over-estimated in these studies.

Table 2 - Summary of quality of included studies (see also appendix 12)

Clifton 1998[6]	Retrospective design Population was highly selected to provide variety of lesions Tests were adequately described 8 observers blinded to the outcome of the reference standard No radiographs excluded on the grounds of poor quality
Douglass 1986[7]	Prospective design Population selected who had complete information for study Tests were not adequately described 4 observers blinded to the outcome of the reference standard No radiographs excluded on the grounds of poor quality (retrospective)
Hansen 1980[8]	Prospective design Population selected randomly Tests were not adequately described Likely to be only one examiner and not known if blinded to outcome of reference standard 17/117 (15%) sets of radiographs excluded on grounds of poor quality
Scarfe 1994[9]	Prospective design Population was highly selected but method not given Tests were adequately described 18 observers blinded to the outcome of the reference standard 12/47 (26%) sets of radiographs excluded on grounds of poor quality
Thomas 2001[10]	Prospective design Population selection may be consecutive based on fulfilling inclusion criteria but unclear. Tests were adequately described 7 observers blinded to the outcome of the reference standard Unknown quantity of poor radiographs excluded

3.2.2 Effectiveness Results

Test Accuracy

Clifton 1998[6]

Results were presented as ROC curves and given as average Az scores i.e. area under the curve with standard deviations and a p-value calculated for differences between the modalities using Tukey's pair-wise comparison.

ROC curves and associated p-values revealed a superior diagnostic accuracy of bitewings over panoramic radiography for the detection of **proximal** caries i.e. p-value of 0.012 and average Az scores of 0.78 (SD 0.11) for bitewings and 0.5 (SD 0.09) for panoramic radiographs.

There was no significant difference between the average Az scores of bitewings and panoramic radiographs for **occlusal** caries i.e. p-value 0.31 and average Az scores of 0.55 (SD 0.06) for bitewings and 0.53 (SD 0.06) for panoramic radiographs.

Douglass 1986[7]

Results are presented as sensitivity and specificity for molars and pre-molars separately and for caries overall i.e. no distinction made between proximal and occlusal caries.
Two analyses were carried out using different definitions of disease and no disease i.e. caries graded as D_0=no caries, D_1=enamel caries, D_2=dentine caries, D_3=advanced caries into dentine. The two analyses were undertaken with (a) D_0 and D_1 as no disease and secondly as (b) D_0 only representing no disease i.e. a sensitivity analysis.

The results overall showed that panoramic radiographs were substantially less sensitive (30.3 vs 57 for molars and 19.3 vs 62.5 for pre-molars) for detecting dental caries than bitewings and this difference was more pronounced when D_0 only was used to indicate no disease (23.9 vs 60.6 for molars and 13.9 vs 64.4 for pre-molars). There were no differences in specificity between the modalities.

Hansen 1980[8]

Results are presented as % of **total approximal caries** identified by the reference standard which were identified by each modality. Bitewings revealed 79.5% of carious surfaces while panoramic radiographs revealed 33% of carious surfaces identified by the reference standard.

From the results given in the paper sensitivity was calculated as 33% for panoramic radiographs and 80% for bitewings. It was not possible to calculate specificity since it was assumed by the investigator that there were no false positives i.e. specificities of 100%. The negative predictive value could also be calculated and was 89% for panoramic radiographs and 96% for bitewings.

Scarfe 1994[9]

Results are presented as ROC curves and the differences between modalities determined using critical ratio analysis of maximum likelihood areas with relevant p-values i.e. determined by area beneath the curve. Results were divided into two separate experiments (1) looked at the test accuracy of detecting the presence or absence of caries i.e. overall accuracy and (2) the accuracy of each modality at detecting specific degrees of severity of caries. All caries were **proximal caries only**. The severities of caries considered were ; (2A)-incipient caries, (2B)-enamel caries, (2C)-enamel/dentine caries and (2D)-dentine/pulp caries.

For overall diagnostic accuracy bitewings were shown to be superior to panoramic radiographs i.e. p-value of 0.009. For the degree of caries bitewings were shown to be superior to panoramic radiographs for the detection of (2B)-enamel caries and (2C)-enamel/dentine caries with p-values of 0.0001 and 0.0000 respectively. For incipient caries (2A) and dentine/pulp caries (2D) there were no significant differences in accuracy between the two modalities.

Thomas 2001[10]

Results of this study are given as sensitivity and specificity and as ROC curves i.e. area under the curve and are for **dentine caries on occlusal surfaces only**. Two separate analyses were carried out using different validation thresholds of the electrical conductance meter used as the reference standard i.e V1=ECM>9 is dentine caries present and V2=ECM>12 is deep dentine caries present.

Sensitivity was higher for bitewings over panoramic radiographs at both validation thresholds when variance due to examiners was taken into account, however for V2 threshold this result was statistically significant ($p<0.05$ for sensitivities of 0.42 for bitewings and 0.32 for panoramic radiographs).

Specificity was statistically significantly lower for bitewings compared to panoramic radiographs at both validation thresholds (0.93 vs 0.97 at V1 and 0.91 vs 0.94 at V2)

Values for the area under the ROC curve were not given overall i.e. were given for each examiner only. Significance testing revealed no significant differences at threshold V1 between bitewings and panoramic radiography. At threshold V2 significant results were found for 2/7 examiners both in favour of bitewings over panoramic radiographs for the detection of occlusal dentine caries.

Table 3 - Summary of test accuracy from included studies (see also appendix 11)

Clifton 1998[6] Occlusal caries and proximal caries	Study revealed superior diagnostic accuracy of bitewings over panoramic radiography for the detection of **proximal** caries i.e. p-value of 0.012 No statistically significant difference between the average Az scores of bitewings and panoramic radiographs for **occlusal** caries i.e. p-value 0.31
Douglass 1986[7] Overall caries only	Overall panoramic radiographs were substantially less sensitive (30.3 vs 57 for molars and 19.3 vs 62.5 for pre-molars) for detecting dental caries than bitewings and this difference was more pronounced when D_0 only was used to indicate no disease (23.9 vs 60.6 for molars and 13.9 vs 64.4 for pre-molars). There were no differences in specificity between the modalities.
Hansen 1980[8] Overall caries only	Sensitivity was calculated as 33% for panoramic radiographs and 80% for bitewings
Scarfe 1994[9] Proximal caries only	Overall diagnostic accuracy of bitewings was shown to be superior to panoramic radiographs i.e. p-value of 0.009. For the degree of caries bitewings were shown to be superior to panoramic radiographs for the detection of (2B)-enamel caries and (2C)-enamel/dentine caries with p-values of 0.0001 and 0.0000 respectively. For incipient caries (2A) and dentine/pulp caries (2D) there were no significant differences in accuracy between the two modalities.
Thomas 2001[10] Occlusal caries only	Sensitivity was higher for bitewings over panoramic radiographs at both validation thresholds when variance due to examiners was taken into account, however for V2 threshold this result was statistically significant ($p<0.05$ for sensitivities of 0.42 for bitewings and 0.32 for panoramic radiographs). Specificity was significantly lower for bitewings compared to panoramic radiographs at both validation thresholds (0.93 vs 0.97 at V1 and 0.91 vs 0.94 at V2)

Repeatability

Clifton 1998[6]

Intra-examiner variability and inter-examiner variability were measured using ANOVA on 5 of the 8 viewers included in the study. For intra-observer variability a paired t-test ($p=0.74$) indicated no systematic bias between repetitions and the intra-class correlation coefficient was 0.62 i.e. moderate to good reliability. For inter-observer variability ANOVA revealed statistically significant differences between observers for **occlusal** lesion detection ($p<0.05$).

Douglass 1986[7]

Intra-examiner variability and inter-examiner variability were measured using Kappa scores on the 4 viewers used in the study. For intra-observer variability Kappa repeated over 3 month intervals revealed good agreement between observers i.e. Kappa scores of between 0.7 and 0.8. For inter-observer variability Kappa revealed good inter-examiner agreement and ranged between 0.68 and 0.8 for the 4 examiners used in the study.

Hansen 1980[8]

Inter-examiner and intra-examiner variability were not measured.

Scarfe 1994[9]

Inter-examiner and intra-examiner variability were not measured although data was available to calculate them.

Thomas 2001[10]

Intra-examiner variability was studied using a Kappa score for the 7 viewers used in the study. Each examiner viewed 20% of the radiographs on separate third occasion, a minimum of a week after the initial study. Kappa scores were consistently low (for bitewing radiographs this ranged from 0.31 to 0.44 and for panoramic radiographs this ranged from 0.07 to 0.61) and only showed moderate intra-examiner agreement. Inter-examiner variability was not measured.

4. ECONOMIC ANALYSIS

4.1 METHODS

Initial searches indicated that there were not likely to be any studies on cost-effectiveness or cost-utility for the detection of dental caries with bitewing and panoramic radiographs, therefore the review aimed to relate costs to effectiveness by providing a simple cost-consequence analysis relating costs to test accuracy and other indicators of test effectiveness where possible. The methods employed to carry out this goal were as follows:-

1. Searches would be undertaken to identify any published economic analyses which compared bitewing to panoramic radiography for the detection of dental caries, and any studies identified would be systematically reviewed.

2. Information would be collated on costs associated with bitewing and panoramic radiography, both that available from published papers providing information on one or both of the tests and that identified by other means.

3. It would be attempted to relate cost to consequences using the information gathered in (1) and (2) above and any information gained in the effectiveness section.

4.1.1 Systematic review of economic analyses

Search Strategy

- Electronic bibliographic database searches ; **MEDLINE** (Ovid) 1966-May 2002; **Embase** (Ovid) 1980-May 2002;**NHS EED** (NHS Economic Evaluation Database) 1966-May 2002 **Cochrane Library 2001** Issue 3 (see Appendix 1 for search terms used).
- Citation checking of studies and reviews obtained
- Contact with experts in the field (see Appendix 2 for list)
- Internet search engines including lycos, excite and netscape.
- Search of specific internet sites such as www.dpb.nhs.uk/index.shtml (Dental Practice Board), www.derweb.ac.uk/index.html (Dental Educational Resources on the Web), www.medweb.emory.edu/medweb (Medweb) and www.dundee.ac.uk/dhsru (Dental Health Services Research Unit).
- There were no language restrictions.

Inclusion/Exclusion Criteria

The inclusion and exclusion criteria were the same as those for effectiveness studies. No language restriction was applied. Exclusion and inclusion criteria were applied by one reviewer (BW) and checked by the other (KTW).

4.1.2 Collated information on costs

Search Strategy

Studies identified from the systematic search as described above, providing relevant information on costs of bitewing or panoramic radiography were used. In addition any other information published or unpublished was used to determine the relative costs of the two tests.

Inclusion/Exclusion Criteria

Very broad inclusion criteria were used in order to get as much information on costs as possible. We were interested in UK costs only.

4.1.3 Cost-consequence analysis

Since it was not possible to carry out a cost-effectiveness or cost-utility analysis with the data available a simple cost-consequences analysis was carried out in which the costs associated with bitewing and panoramic radiographs was related to results on test effectiveness (generally accuracy) gained from the effectiveness section of this review.
Other important factors relating to the use of the diagnostic tests including test repeatability, radiation exposure, radiographic quality in practice and patient preference are dealt with in the discussion part of this review.

4.2 RESULTS

4.2.1 Systematic review of economic analyses

Quantity and quality of research available

- **Studies identified**

No studies on cost-effectiveness of bitewing compared to panoramic radiography were identified.

4.2.2 Collated information on costs

Quantity and quality of research available

- **Studies identified**

Studies identified from formal searching – 43 papers were identified from a search of MEDLINE, Embase, CINAHL and NHS EED of which 11 were considered potentially relevant on abstract. 0/11 provided information on costs relevant to this review. The search used was that described in 4.1.1 and the search strategy can be found in Appendix 2. All the cost data in this review is therefore taken from the 'Statement of dental remuneration (2002)', which provides details of remuneration to the profession and costs to the paying patient for dental services.

The basic costs for bitewing radiographs and panoramic radiographs are as follows:-
Two bitewing radiographs - £4.55 (cost to patient £3.64)
Panoramic radiograph - £10.15 (cost to patient £8.12)

4.2.3 Cost-consequence analysis

Table 4 - Cost and consequences of BW and OPT for detection of dental caries

Costs	Consequences
Two bitewing radiographs - £4.55 (cost to patient £3.64) Panoramic radiographs - £10.15 (cost to patient £8.12). However this radiograph may also be taken for reasons other than detection of caries and therefore it is not possible to quantify the costs of detecting caries.	It is not possible to quantify exactly, the cost of missed caries since this is dependent not only on the site and severity of the caries but also on other factors which will influence the advancement of such caries i.e. at the next examination the caries may not be associated with any cost or may be associated with a large cost such as a root filling and crown (up to £117.15 for the NHS or £93.72 for the patient, minus the cost of the examination) (See Appendix 13)
There was no consensus on accuracy from the included studies and therefore costs for missing caries cannot be determined	There was no consensus on accuracy from the included studies and therefore it is not possible to determine the likelihood of caries being missed using each of the radiographs

The key feature emerging from the cost-consequence analysis is that since there is no consensus on test accuracy for bitewing and panoramic radiographs and no certainty on the actual costs associated with missing caries on these radiographs, it is not possible at this time to determine which diagnostic test is more cost-effective. However it may be possible to draw conclusions based upon the available evidence. Since panoramic radiography is likely to be associated with higher costs particularly where a machine has not already been purchased and since there is no evidence that the accuracy associated with panoramic radiographs is higher than bitewings for the detection of dental caries, there is no rationale for either replacing bitewings with panoramic radiographs for this purpose or using them as an adjunct to bitewing radiography.

4.3 SUMMARY OF RESULTS

Accuracy

- It was not possible to combine the results of test accuracy from each of the studies in a meta-analysis since the studies were recruited from difference populations and have not used comparable reference tests. [24] Therefore results are presented in a qualitative form only.
- Results indicate that bitewing radiographs are likely to be a more accurate test for diagnosing dental caries overall than panoramic radiographs, however this may be particularly true for the detection of proximal caries and caries which are confined to dentine.
- Results indicate that BW may be superior to OPT particularly in terms of sensitivity for proximal caries or caries overall but there is likely to be no difference in specificity for caries overall or OPT may be superior in terms of specificity for occlusal caries.
- Results from these studies indicate that there may be little difference in terms of test accuracy between BW and OPT for the detection of incipient or advanced caries.
- Most included studies[6,9,10] used patients with a greater number/variety of carious lesions than is likely to be seen in an 'average' patients in the UK and therefore test accuracy may be over-estimated in these studies.

Cost

- There were no existing economic evaluations comparing bitewing to panoramic radiographs, therefore a cost consequence analysis was carried out which identified the costs of two bitewing radiographs - £4.55 (cost to patient £3.64) and a panoramic radiographs- £10.15 (cost to patient £8.12). However it was not possible to determine which diagnostic test is more cost-effective.

Repeatability

- The repeatability of the tests in relation to intra-observer variability ranged from moderate to good agreement, although the range of values varied between the three studies [6,7,10]which studied this. Two of the studies [6,10] used kappa scores to measure variability while one used correlation coefficient.[6] Only one study[10] reported the intra-observer variability for the two modalities separately and showed there to be a range of moderate agreement for both, although for panoramic radiographs the range was much wider (kappa

scores of 0.07 to 0.61 for panoramic radiographs and 0.31 to 0.44 for bitewing radiographs).

- The repeatability of the tests in relation to inter-observer variability was only studied by two of the included studies[6,7] and there was not agreement between them. One study found that there were significant differences between observers in relation to detection of occlusal caries, while the other revealed there to be good agreement between examiners based on a kappa score. Both studies looked at similar numbers of examiners i.e. 4 [7] and 5[6] examiners.

Side Effects

- None of the included studies looked at side effects of the tests, the most important of which is considered to be x-ray dosage. However the individual impact of these x-rays in terms of ill-health is likely to be very small. [11]

Radiograph quality

- There was some indication from the included studies that the quality of both types of radiograph may be relatively poor in many cases. 3 studies[8-10] excluded radiographs on the grounds of insufficient quality to determine caries. In one study no details were given concerning the number of radiographs excluded, while in the other studies the % of radiographs excluded was 15%[8] and 26%[8-10]. Unfortunately neither study indicated which radiographs i.e. bitewings of panoramic radiographs were responsible for the set of radiographs being excluded on quality grounds. Therefore we cannot draw any conclusions about the relative quality of either radiograph for detecting dental caries. However it is clear that a large number of radiographs taken in dental practice may not be of suitable quality to detect dental caries[25].

Patient preference

- None of the included studies considered patient preference, in terms of which type of radiograph was more acceptable to patients.

Assumptions, limitations and uncertainties

- This review has made the assumption that a proportion of the increasing number of panoramic radiographs taken in this country are being used for the detection of dental caries either in place of or more likely as an adjunct to bitewing radiographs. Therefore this reviews assumes that although current guidelines do not recommend the use of panoramic radiographs for the detection of caries that either these guidelines are not being adopted or else the reasons behind them are not fully understood. There were limitations in the ability of the authors to compare the results of the included studies since the studies looked at different teeth, different surfaces and different severities of caries.

Implications for policy

- Although it is not currently policy for panoramic radiographs to be used in place of, or in addition to bitewing radiographs for the detection of dental caries, there is some concern that a proportion of the growing number of panoramic radiographs being taken in this country may still be being used for this purpose. Therefore it is suggested that tighter controls of the use of panoramic radiography may be needed in order to prevent patients

individually and the population as a whole from being exposed to unnecessary radiation which provides no more information than the currently accepted practice of bitewing radiographs for the detection of dental caries.

Need for further research

- There is a clear need for further research in this area in order to substantiate the conclusions drawn in this review. Ideally a study would compare panoramic radiography, bitewing radiography (E-speed) and panoramic + bitewing radiography to a suitable reference standard for the UK, to determine the presence of caries. It is acknowledged by the authors that in reality diagnosis of dental caries always involves a clinical examination and therefore further studies should include this in the design of the study. For extracted teeth histologically confirmed caries would be the ideal standard. The design of the study is also important and ideally the patients to be included would be consecutively or randomly drawn from a representative UK population. This is particularly important since it was a finding of this review that most of the included studies used a highly selected population which does not accurately reflect the disease spectrum of the UK population. This is important since accuracy is likely to be over-estimated in studies where patients (and therefore radiographs) with a higher proportion of caries than an average UK population are included. Although further studies could confirm the findings of this review, further research specifically comparing accuracy of the two modalities is unlikely to be carried out as most evidence already points to the fact that panoramic radiographs are unnecessary for the detection of dental caries.
- More useful information would probably be provide by studies of cost-effectiveness, a study should determine the costs of missing caries and therefore the cost-effectiveness of each type of radiograph. This approach could involve a modelling exercise.
- From the studies included in this review it is clear that the reliability of dental radiographs in terms of repeatability and quality are important issues in dental practice due to the subjective nature of the tests. Since test accuracy is dependent upon reliability and quality, these are important issues to be considered in any further work carried out in this area.

5. IMPLICATIONS FOR OTHER PARTIES

- Faculty guidance known as selection criteria produced in 1996, already exist and may have superseded the original guidelines written by the Dental Practice Board of England and Wales in 1986 (see Appendix 14). These guidelines clearly indicate that panoramic radiographs are not suitable for use for the detection of dental caries. Although the guidelines are clear there is concern that panoramic radiographs are still being taken solely for the diagnosis of dental caries[1,13] and this is clearly not acceptable, both in terms of unnecessary x-ray exposure to the patient but also unnecessary expense both to the patient and the NHS.

- It is therefore the consideration of this review that the selection criteria need to be reinforced as guidelines for practice, clearly stating that panoramic radiography should not be used solely for the diagnosis of dental caries and the evidence as presented in this review be stated to show that there is no evidence that panoramic radiographs provide no

more information on dental caries than that provided by the current standard practice of bitewing radiographs. Furthermore checks could be carried out by the Department of Health, to whom the Dental Practice Board of England and Wales is responsible, to ensure that panoramic radiography is not being used inappropriately.

6. DISCUSSION

- Only 5 studies were identified as being relevant to the question posed by this review and although all tests looked at accuracy of panoramic and bitewing radiographs, the heterogeneity of the studies made it difficult to draw conclusions based upon all studies. The most obvious sources of heterogeneity between the studies were the differences in population and therefore spectrum of disease, differences in reference standards used and differences in study design and quality.

- The reference standards used were different in all studies and therefore do not allow any pooling of study results. As well as being different, some reference standards were considered more suitable than others, for instance the use of light microscopy to histologically confirm caries is not likely to be challenged as suitable reference standard for this review, although it is still affected by subjectivity, however the use of a consensus standard where all radiographs were used to determine numbers of caries by simply adding the number of caries seen is questionable as a reference standard. It is noted that the UK 'gold' standard is properly carried out bitewing radiographs, however in order to compare bitewings to OPT another reference standard was required.

- The tests as described in the studies were not substantially different, however subtle differences the x-ray exposure and different methods of film development (manually or automatically) may represent a problem in combining study results even in a qualitative manner.

- The repeatability of the reading of dental radiographs is also an issue and this varied from being good to moderate. Only one study[10] reported the intra-observer variability for the two modalities separately and showed there to be a range of moderate agreement for both, although for panoramic radiographs the range was much wider (kappa scores of 0.07 to 0.61 for panoramic radiographs and 0.31 to 0.44 for bitewing radiographs). This indicates that particularly for panoramic radiographs the ability of even one reader to identify the same caries on a radiograph on different occasions may be limited and be an important issue for the effectiveness of such radiographs in practice. Repeatability is important since it will directly impact on test accuracy.

- The quality of radiographs in practice is an important factor for consideration, however no information was provided from included studies on the relative qualities of panoramic and bitewing radiography. Three studies[8-10] excluded radiographs on the grounds of insufficient quality to determine caries. In one study no details were given concerning the number of radiographs excluded, while in the other studies the % of radiographs excluded was 15%[8] and 26%[8-10]. Other studies have considered the problem of quality of radiographs and indicate that the quality of panoramic radiographs may be poorer than bitewings since panoramic radiographs suffer from the problem of degradation as

information is transferred from the x-ray beam to the screen and then to the film [13] and because compared to intra-oral techniques panoramic radiographic quality is highly dependent on accurate technique and careful processing. [25] One study of panoramic radiographs presented to the Dental Practice Board of England and Wales found that 26% of the radiographs were of no diagnostic value. [25] A number of important factors could be responsible for the poor quality of some radiographs such as incorrect positioning of the patient, technique and ability of those carrying out the test, quality of the equipment such as age of the equipment as well as inherent problems of the radiographic techniques such as the problem with panoramic radiographs that the images are degraded by shadows of surrounding tissues and of the air. [13] 'Ghost' images of the spine and mandible can further reduce the quality of panoramic radiographs and thus the ability to detect dental caries. [26]

- Safety of radiographs is also an issue and although dental radiographs are associated with a very small risk, representing only 0.4% of the total collective dose of the per caput dose from all x-ray examinations (i.e. approximately 5 µSv per bitewing radiograph and =10 µSv per panoramic radiograph) [11] it is still unethical to put patients at risk by taking unnecessary radiographs. In fact guidelines to the dental profession state that although diagnostic investigation due to utilizing ionising radiation offers potential benefits for the healthcare of patients and are an accepted part of medical practice, it is recognised that exposure to such radiations is associated with an increase in the long-term of malignant disease in those persons who are irradiated, and there is also a putative but low risk of serious hereditary disease in their descendents. And therefore it is necessary to consider the potential harm albeit relatively small, arising from even the lowest of absorbed radiation dose and to avoid those exposures which have no merit.[27] It is also important to note that poor equipment quality may also lead to unnecessary exposure, older equipment although regularly maintained may be associated with higher radiation doses and that published data on radiation exposure based on up-to-date equipment e.g. newer panoramic radiograph machines and E-speed film for bitewing radiographs may underestimate the exposure in practice where up-to-date equipment is not always available.[3] It is therefore important to reduce unnecessary exposure from tests which can add nothing to the diagnosis of disease in a patient. There is some concern that OPT may be associated with significantly higher doses, particularly where older machinery is used. This is a widespread problem since approximately 40% of equipment in UK practice is = 10 years old [3] and therefore likely to be associated with doses possibly twice as high as aspected.

- Patient preference is also an important factor of diagnostic tests and some authors[12] have suggested that panoramic radiographs may be associated with less discomfort on behalf of the patient, however it should also be noted that panoramic radiography is associated with a higher dose of radiation and a slightly higher cost to the paying patient and the NHS and that results from included studies in this review suggest that particularly for approximal caries are likely to be less accurate at detecting caries. No studies were identified which had studied patient preference in terms of these two tests and therefore no empirical evidence can be used on which to base a conclusion. It is possible that panoramic radiographs may have some use in patients who are adverse to intra-oral radiography or those for whom it is impractical e.g. some disabled patients.

7. CONCLUSIONS

- There is no conclusive evidence that panoramic radiography is superior to bitewing radiographs for the detection of any type of dental caries both in terms of place (proximal or occlusal) or severity (incipient, enamel, dentine or pulpal) in primary or secondary molar teeth. All included studies found bitewing radiographs to be superior to panoramic radiographs on some measure of test accuracy and only one study found any evidence to the contrary i.e. Thomas et al[10] found that panoramic radiographs were superior in terms of specificity only for the detection of occlusal caries in permanent molars. There was a high degree of variability between observers in this study, which may bring the quality of the study into question.
- It was not possible to combine the results of test accuracy from each of the studies in a meta-analysis since there was a high degree of heterogeneity between the studies i.e.the studies were recruited from difference populations which affects the spectrum of disease and have not used comparable reference tests.[24] Therefore results are presented in a qualitative way only.
- On the whole the quality of the included studies was reasonable, however there was an issue about recruitment of the study population which was random in one study only.[8] It was also clear from 3[8-10] of the studies that an important proportion of radiographs were of poor quality and it is not known if there were any systematic reasons for this within studies, however since the quality of radiographs and particularly panoramic radiographs has been brought into question in other papers[3], it is likely that poor quality is an unfortunate norm in dental practice. An important issue in terms of study quality is generalisability. In those studies where the patient group was highly selected e.g. to provide a 'selection of carious' lesions the generalisability of the study results is compromised i.e. the results cannot accurately be generalised to the UK population. Including patients (and therefore radiographs) with high numbers of lesions is also likely to over-estimate the accuracy of tests.
- Repeatability of reading of radiographs is an important issue in dental practice and although there was no conclusive evidence from the included papers that repeatability was different between bitewings and panoramic radiographs, one study[10] indicated that although overall repeatability may be similar for panoramic radiographs the ability of readers may be more varied. Whether this indicates a training issue or an inherent problem with panoramic radiographs or an erroneous finding of one study is not known. Repeatability is however, an important issue since measurements of accuracy are affected by repeatability of tests and it is particularly important in dental practice.
- It is important to reduce the number of unnecessary radiographs taken in dental practice and since there is no conclusive evidence that panoramic radiographs provide any more information on the presence of dental caries than is provided by bitewing radiographs, it is the conclusion of this review that panoramic radiographs should not be used instead of or in addition to bitewing radiographs for the detection of dental caries. The authors do however note that more evidence is needed to substantiate this.
- Since no cost-effectiveness information was available, it was not possible within the scope of this review to carry out a cost-effectiveness study. However this may be irrelevant

since there is no evidence that panoramic radiographs should replace or be used in addition to bitewing radiographs and since both of these options is associated with an increase in costs, there is no reason in terms of cost to use panoramic radiographs for the detection of dental caries.

- Issues of patient preference may be important since panoramic radiographs may be associated with less discomfort than bitewing radiographs for those patients who find intra-oral radiography (bitewings) uncomfortable or for patients in which intra-oral radiography is not practical e.g. disabled patients. However bitewing radiographs are not associated with pain and it is therefore unlikely that most patients would opt for panoramic radiography given that it is likely to be associated with an increased radiation dose and possible an decreased accuracy in detecting dental caries. However the authors do conclude that panoramic radiographs may be useful for detecting caries in patients who are averse to the use of bitewing radiographs and therefore are an acceptable alternative.

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Appendix 1 - SEARCH STRATEGIES USED DURING THE REVIEW

(a) The following search strategy was used to identify studies of the effectiveness of panoramic and bitewing radiographs in the detection of dental caries. It was used to search Medline, Embase and CINAHL and adapted where necessary.

1 exp dental caries/ or "dental caries".mp.
2 dental decay.mp.
3 1 or 2
4 limit 3 to human
5 exp radiography,dental/ or "dental radiography".mp.
6 exp radiography, panoramic/ or "##'Panoramic radiograph$'.mp.##"/ or "panoramic radiograph$".mp.
7 orthopantomogra$.mp.
8 panor$.mp.
9 opg.mp.
10 opt.mp.
11 6 or 7 or 8 or 9 or 10
12 4 and 5 and 11

(b) The following search strategy was used to identify studies of the cost-effectiveness of panoramic and bitewing radiographs in the detection of dental caries. It was adapted from a York CRD (Centre for Reviews and Dissemination) report and was deliberately broad in order to detect any relevant cost studies which may be of use. It was used to search MEDLINE, Embase and CINAHL databases.

1. exp dental caries/ or "dental caries".mp.
2. dental decay.mp.
3. 1 or 2
4. limit 3 to human
5. exp radiography,dental/ or "dental radiography".mp.
6. 4 and 5
7. economics/
8. exp "costs and cost analysis"/
9. exp "fees and charges"
10. (cost or costs or costed or costly or costing).tw.
11. (economic$ or price$ or pricing).tw.
12. 7 or 8 or 9 or 10 or 11
13. 6 and 12

(d) The NHS EED (NHS Economic Evaluation) database was searched using the following keywords:

‘Dental caries’, ‘dental radiography’, ‘bitewings’, ‘panoramic radiography’, ‘orthopantomogram’, ‘pantomography’ .

Appendix 2 - EXPERTS CONTACTED DURING THE REVIEW

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Appendix 3 - INCLUDED STUDIES OF EFFECTIVENESS

Clifton TL, Tyndall DA, Ludlow JB. Extraoral radiographic imaging of primary caries. *Dento-Maxillo-Facial Radiology* 1998; **27**(4):193-198.

Douglass CW, Valachovic RW, Wijesinha A, Chauncey HH, Kapur KK, McNeil BJ. Clinical efficacy of dental radiography in the detection of dental caries and periodontal diseases. *Oral Surgery, Oral Medicine, Oral Pathology* 1986; **62**(3):330-339.

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Scarfe WC, Langlais RP, Nummikoski P, Dove SB, McDavid WD, Deahl ST, *et al.* Clinical comparison of two panoramic modalities and posterior bite-wing radiography in the detection of proximal dental caries. *Oral Surgery, Oral Medicine, Oral Pathology* 1994; **77**(2):195-207.

Thomas MF, Ricketts DN, Wilson RF. Occlusal caries diagnosis in molar teeth from bitewing and panoramic radiographs. *Primary Dental Care* 2001; **8**(2):63-69.

Appendix 4 - STUDIES OF EFFECTIVENESS EXCLUDED ON FULL PAPER

The following papers were excluded as they did not meet the inclusion criteria (see 3.1.2 for inclusion/exclusion criteria).

Ahlqwist M, Halling A, Hollender L. Rotational panoramic radiography in epidemiological studies of dental health. Comparison between panoramic radiographs and intraoral full mouth surveys. *Swedish Dental Journal* 1986; **10**(1-2):73-84.

Berkey CS, Douglass CW, Valachovic RW, Chauncey HH, McNeil BJ. Statistical methods for comparing dental diagnostic procedures. *Community Dentistry & Oral Epidemiology* 1990; **18**(4):169-176.

Bishay N, Petrikowski CG, Maxymiw WG, Lee L, Wood RE. Optimum dental radiography in bone marrow transplant patients. *Oral Surgery Oral Medicine Oral Pathology Oral Radiology & Endodontics, 87(3):375-9, 1999 Mar* 1999; **87**(21 ref):375-379.

Davies EE, Meister F, Lommel TJ. Panoramic versus periapical surveys. A comparison of findings on freshman dental students. *Dental Radiography & Photography* 1977; **50**(3):41-47.

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Grasser H, Barth HH. [Comparison of orthopantomographs and dental films in the diagnosis of interdental caries and apical osteitis]. [German]. *Deutsche Zahnarztliche Zeitschrift* 1987; **42**(9):818-821.

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Hurlburt CE, Wuehrmann AH. Comparison of interproximal carious lesion detection in panoramic and standard intraoral radiography. *Journal of the American Dental Association* 1976; **93**(6):1154-1158.

Kogon SL, Stephens RG, Reid JA. The selection of the most efficient radiographic survey for young adult patients. *Dental Journal - Journal Dentaire* 1978; **44**(7):317-319.

Loh FC. Orthopantomographic survey. *Annals of the Academy of Medicine, Singapore* 1986; **15**(3):387-392.

Mittal RK, Givila CP, Mathur RM. A study of orthopantomography in conservative dentistry. *Journal of the Indian Dental Association* 1986; **58**(3):107-110.

Molander B, Ahlqwist M, Grondahl HG, Hollender L. Comparison of panoramic and intraoral radiography for the diagnosis of caries and periapical pathology. *Dento-Maxillo-Facial Radiology* 1993; **22**(1):28-32.

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Valachovic RW, Douglass CW, Reiskin AB, Chauncey HH, McNeil BJ. The use of panoramic radiography in the evaluation of asymptomatic adult dental patients. *Oral Surgery, Oral Medicine, Oral Pathology* 1986; **61**(3):289-296.

Appendix 5 - QUALITY ASSESSMENT FORM AND QUALITY ASSESSMENT FRAMEWORKS

QUALITY ASSESSMENT FORM

Study Identifier _____

Was the study design prospective? Y N Can't tell

Notes_____

Were the patients recruited consecutively/randomly? Y N Can't tell

Notes_____

Was the population well defined? Y N
(Age, sex, population source, disease, eligibility)

Notes_____

Were no. teeth/tooth surfaces defined? Y N

Notes_____

Is population representative? Y N Can't tell

Notes_____

Were the tests adequately described? Y N

Notes_____

Were test/reading settings well defined? Y N

Notes_____

Is 'reference standard' suitable to UK practice? Y N Can't tell

Notes_____

Were the outcomes clearly stated? Y N Can't tell

Notes_____

Were those carrying out and assessing the test of interest blinded to the outcome of the reference standard?
Y N

Was intra observer variation examined? Y N Can't tell

Was inter observer variation examined? Y N Can't tell

What % of data were missing? _____

Were reasons for drop-outs/missing data given? Y N Can't tell

The following tables show the frameworks used in this review for considering study quality and the likelihood of bias affecting results in the included studies

Validity Criteria for tests of diagnostic accuracy
Criteria of internal validity
A valid reference/reference standard should be used
Definition of a cut-off point for the reference standard is required
Blind measurement of the index test and the reference test
There should be avoidance of verification bias i.e. assessment of the tests should be carried out independently
The index test should be interpreted independently of all clinical information
The design of the study should be a prospective design using consecutive series of patients
Criteria of external validity
The spectrum of disease should be described and inclusion/exclusion criteria mentioned
The setting of the tests should be described
Previous tests/referral filter should be described
The duration of illness before diagnosis should be described
Comorbid conditions should be described
Demographic information should be provided
Information about the execution of the index test should be described
An explanation of the cut-off point for the index test should be provided
The percentage of missing data should be given
Reproducibility of the index test should ideally be studied

Taken from 'The evidence base of clinical diagnosis' edited by Andre Knottnerus[23]

Study Feature	Qualities Sought
Sample of patients	Consecutive or randomly selected sample, recruited as single cohort unclassified by disease state, recruited from clinical setting and point in referral process where test would be used, selection and referral processes fully described, clinical and demographic characteristics fully described and complete.
Reference diagnosis	Method and tests described in detail, positive and negative diagnoses clearly described, diagnosis likely to be close to truth, available for all patients, based on same tests and information in all patients, blinding procedures used to prevent knowledge of result of experimental test influencing the reference diagnosis, made before treatment commenced.
Experimental test	Application of test described in detail, positive and negative test results clearly described, blinding procedures used to ensure that test is undertaken without knowledge of reference diagnosis, test undertaken before treatment commenced, results reported for all patients including those with 'grey zones'.

Taken from 'Systematic Reviews of evaluations of diagnostic and screening tests' by J.J. Deeks[24]

Appendix 6 - DATA EXTRACTION FORM

Author _____

Publication Date _____

Study Design _____

Sampling Design _____

Country of Study _____

Dates of study _____

Population
Demographics of patients
Age _____

Sex _____

Other _____

Total number of patients _____

Total number of teeth _____

Intervention (Tests)

Tests compared _____

_____

Reference standard _____

Outcomes
Occlusal caries Y / N

Type of scale _____

Approximal caries Y / N

Type of scale _____

Other _____

Test of Accuracy

Test	Reference Standard	
	+ve	-ve
+ve		
-ve		

Test	Reference Standard	
	+ve	-ve
+ve		
-ve		

Test	Reference Standard	
	+ve	-ve
+ve		
-ve		

Measures of Accuracy

Test 1	Test 2	Test 3
Sensitivity		
Specificity		
PPV		
NPV		
LR +		
LR -		

% missing data _____

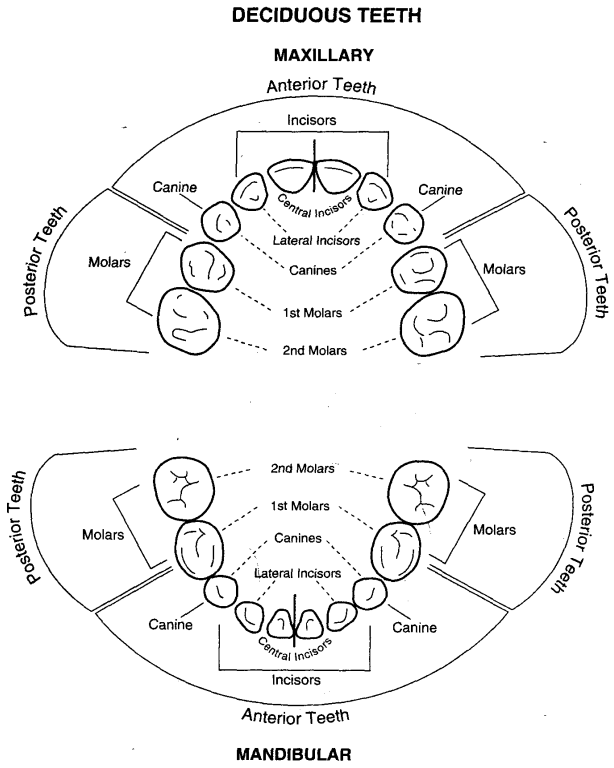
Reasons _____

Other data :

28-30

Appendix 7 - TOOTH ANATOMY AND CLASSIFICATION OF CARIES

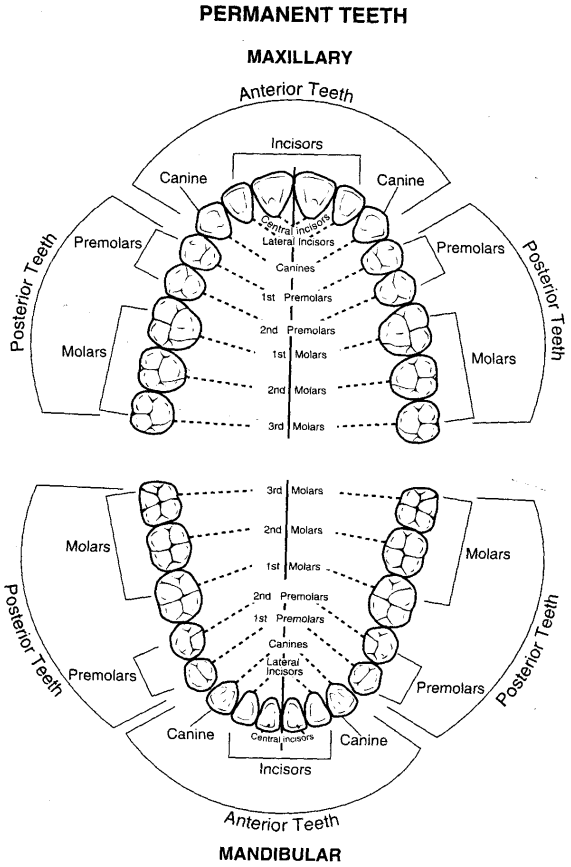
Primary/Deciduous Dentition



There are 20 teeth in the primary/deciduous dentition, 10 in the maxillary arch and 10 in the mandibular arch. The full primary dentition has 5 teeth in each of the 4 quadrants. The two front teeth are the central and lateral incisor, followed posteriorly by one canine and then a first and second primary molar. The anterior teeth are the incisors and canines while the posterior teeth are the molars.

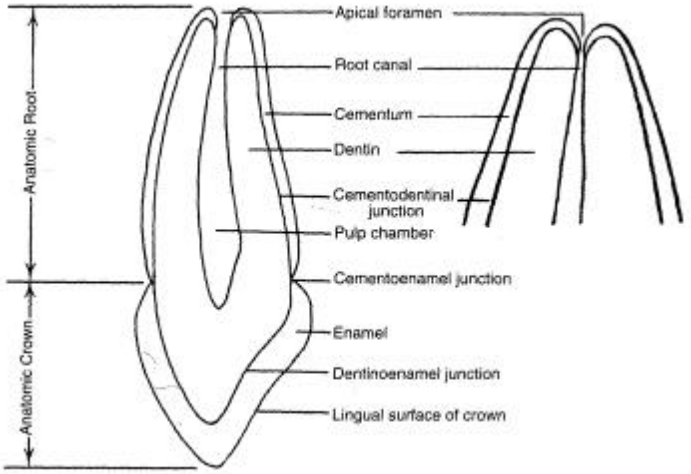
Permanent Dentition

The permanent dentition is composed of 32 teeth, 16 maxillary and 16 mandibular. The complete dentition therefore has 8 teeth in each quadrant. The two front teeth in each quadrant are the central and lateral incisor, followed posteriorly by one canine and then a first and second premolar. Posteriorly to these are the first, second and third molar teeth. The anterior teeth are the incisors and canines while the posterior teeth are the molars and premolars.



Tooth Anatomy

The tooth above the gum line is known as the crown of the tooth and has an outer surface of enamel, followed by a layer dentin and then the pulp chamber containing the blood vessels and nerve supply of the tooth, this chamber lies mostly below the gum line. Below the gum line the pulp chamber is covered by a continuation of the dentin and then by a layer of cementum.



Tooth Surfaces

The teeth of interest to this review are the posterior teeth which have 5 surfaces. The surface on top of the tooth which generally meets with the teeth of the opposite half of the jaw is known as the occlusal surface while the surfaces which connect with adjacent teeth in the same half of the jaw are known as the approximal surfaces. The approximal surfaces are either mesial (towards the midline or distal (towards the back of the jaw). The remaining surfaces are those closest to the tongue (or the palate in the upper jaw), known as the lingual and palatal surfaces respectively and those closest to the mucosal surface of the mouth i.e. the cheek, known as the buccal surface.

Type of Caries

Caries can be are defined in three ways; by tooth, by surface/s and by depth e.g. enamel or dentine-enamel caries.

Caries are described by the surfaces on which they exist

Taken from 'Dental Anatomy -its relevance to Dentistry' [29]

Appendix 8 - DESCRIPTION OF DIAGNOSTIC TESTS

Radiographs

Image formation on radiographs is the exposure of radiographic film to x-rays after they have passed through the tissues. An x-ray film consists of a flexible transparent plastic base which is coated on either side with an emulsion of silver halide crystals suspended in gelatine. The emulsion is covered by a further protective layer of gelatine. The film can either be direct exposure or screen film. As the atomic composition of the tissues are variable, x-rays are absorbed to different degrees, allowing an image to be recorded on the film. A physicochemical change affects those silver halides which have been irradiated, resulting in the formation of a latent image. This image is made visible by reducing the altered silver halide grains to black metallic silver through the action of a developer solution. This process may be performed either manually or automatically, in accordance with the manufacturer's instructions. Correct temperature and immersion times are essential, after which the film is rinsed in water to wash off the surface alkaline developer before placing it in the acidic fixer solution. This arrests the development process and removes those silver halide particles that were not affected by the developer solution. The film is then thoroughly washed in running water to remove any remaining processing chemicals absorbed into the emulsion. Because x-ray film is light sensitive, processing must be performed in a darkened room illuminated only by appropriate safe light conditions. Automatic processing is more rapid, and uses a system of rollers to transport the film through a series of solutions at a higher temperature, producing a dry film ready for viewing.

Bitewing Radiography

Bitewing radiographs are a type of intra-oral radiograph i.e. the film is placed inside the mouth. They are so-called because the patient stabilises the film by occluding onto an attached tab or wing on the film. They record images of the crown of the tooth and the coronal portions of the roots of maxilliary and mandibular posterior teeth and their investing tissues. The film is usually positioned with its long axis horizontal and parallel to the crowns of the teeth. The x-ray beam is directed with a downward angle of approximately 5-10^{o} to the occlusal plane and at right angles to the film, passing between the contact points of the crowns of the teeth being examined so that their images do not overlap. This enables the assessment of caries on the occlusal and approximal surfaces of the posterior teeth.

Direct exposure, or non-screen film is used for intra-oral radiography. The image is formed on the emulsion by the direct action of the x-rays. Since it is also sensitive to light, it is sandwiched between two sheets of black paper and contained in a sealed packet to exclude light. Because some of the x-ray photons do not react with the emulsion and pass through the film, a sheet of lead foil is placed on the surface away from the x-ray source to protect the deeper tissue and reduce back scatter. A raised embossed dot on one corner of the film aids correct orientation during viewing.

Panoramic radiography

A dental panoramic radiograph displays, on a single film, both sides of the mandible and maxilla, together with a number of other cervicofacial anatomical structures including the maxillary antra. Originally, panoramic radiographs were achieved by placing a curved film lingually within the mouth and rotating an external slit-beam x-ray source in one plane around the patient's jaws. Subsequent development has retained the slit beam source but used two, three and finally continuously moving centres of rotation. The x-ray tube and film holder rotate around the patient's head, and the film moves behind a slit guard so exposing it a portion at a time. This technique produces an image which corresponds to the dental arches; the image layer (or focal trough) is of variable thickness, being narrower anteriorly due to the close proximity of the anterior part of the jaws to the centre of rotation. Objects in the centre of the focal trough will appear sharp, whereas those lying closer to the centre of rotation appear widened and less definite. Objects that are closer to the film, i.e. on the vestibular side of the jaws, appear narrowed and less distinct. Computer driven panoramic machines have increased the range of projections available for imaging the jaws, temperomandibular joints and maxillary sinuses.

Screen film is used for panoramic radiography and is placed between two intensifying screens contained within a cassette. The intensifying screens fluoresce when exposed to x-rays, emitting a blue or green light to which the film is sensitive. The emulsion of screen film contains dyes to increase the absorption of the specific wavelength of light emitted by the intensifying screen. The light is multi-directional and this results in some loss of definition of the image compared with direct exposure film, but less radiation exposure is required to produce the image. To minimise the loss of definition, it is important that the gap between the film and the intensifying screen is as small as possible.

Taken from 'Atlas of Dental and Maxillofacial Radiology and Imaging'[30]

Appendix 9 - MEASURES OF TEST ACCURACY

For any comparison of two diagnostic tests (e.g. reference standard versus new test) with a dichotomous outcome, a 2x2 table of outcomes can be drawn. From this the common measures of the discrimination of a diagnostic test (D) for the outcome can be determined.

Conclusion of diagnostic test (D)	Result of reference/reference standard		
	Positive	Negative	Total
Positive	a	b	a+b
Negative	c	d	c+d
Total	a+c	b+d	a+b+c+d

- **Sensitivity**

The sensitivity of the diagnostic test (D) is the probability of getting a positive test result with test (D) in people with the disease.

$$\text{i.e. } a / a+c$$

- **Specificity**

The specificity of the diagnostic test (D) is the probability of getting a negative test result with test (D) in people who do not have the disease

$$\text{i.e. } d / b+d$$

- **ROC curves**

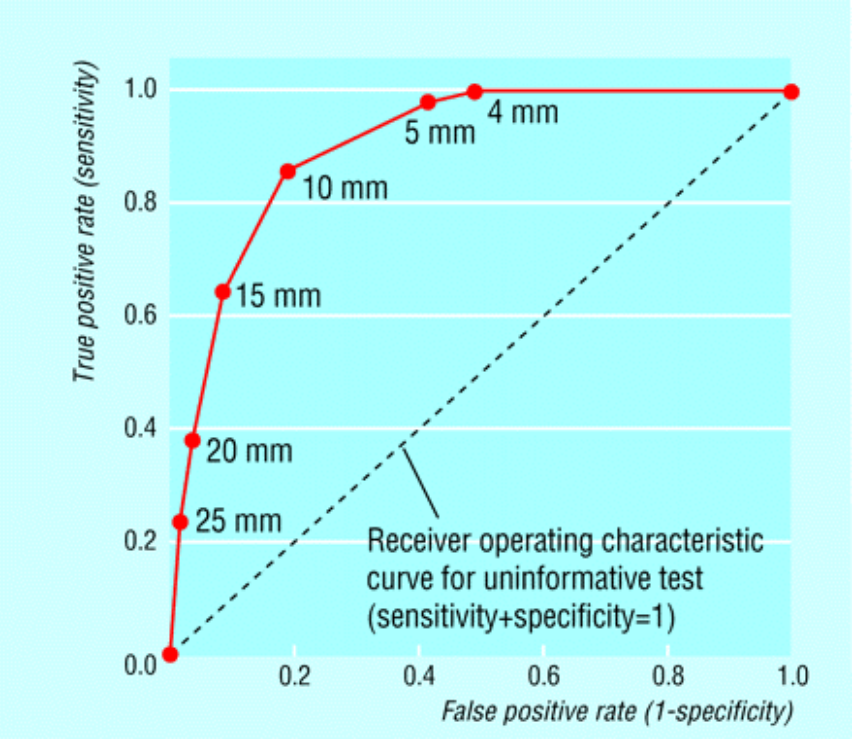
The receiver operating characteristic (ROC) curve represents the relationship between sensitivity and specificity for tests with a variable cut-off point, on an ordinal scale or interval scale. Sensitivity on the y-axis is plotted against 1-specificity on the x-axis for varying values of the cut-off point. The area under the curve plotted (AUC) represents the test accuracy. A value of 0.5 (likelihood ratio of 1 for all its cut-off points) for the AUC would represent that the test is totally

uninformative, while a result of 1.0 for AUC would represent a perfect test i.e. the more an ROC curve moves towards the upper left hand corner of the graph, the better the test is. In other words it is moving towards 100% sensitivity and specificity. The steepness of the slope between 2 cut-off points is the likelihood ratio of an observation falling in between these 2 points.

In simple terms an AUC reading of 0.7, for example, means that if 1 patient is drawn at random from each of the two groups of those truly having the disease and those not having the disease and are given the test then if the test results are used to determine which is the patient with the disease, the test will be right 70% of the time. [23]

Different tests can be compared by plotting them on ROC curves and analysing the difference between the respective AUC. This can be done using statistical tests of significance or other methods.

Shown below is an example of a ROC for varying values of cut-off point, shown here as length recordings i.e. mm.



Taken from 'Systematic Reviews of evaluations of diagnostic and screening tests' by J.J. Deeks[24]

Appendix 10 - TABULATION OF STUDY CHARACTERISTICS

Table 5 - General study characteristics and demographics

	Clifton	Douglass	Hansen	Scarfe	Thomas
Publication Date	1998	1986	1980	1994	2001
Country of Study	USA	USA	Norway	USA	UK
Study Dates	Not Stated	1968	Not Stated	Not Stated	September 1996
Study Design	Prospective study of test accuracy	Retrospective	Prospective study of diagnostic accuracy	Prospective study of diagnostic accuracy	Prospective study of test accuracy
BW and OPT compared to ref standard?	Yes	Yes	Yes	Yes (4 film bitewings)	Yes
BW and BW+OPT compared to ref standard?	No	No	No	No	No
Number of observers	8 dentists (5/8 repeated measurements for repeatability)	4 dentists, calibrated with each other	Not stated but thought to be one examiner only	18 dentists (13 faculty members and 5 post-doctoral students.	Seven (six general dentists and one registrar in dental radiology)
Sampling Design	'64 primary molar teeth selected to provide a variety of lesions as well as caries free surfaces'	Included all men from the Dental Longitudinal Study who had 4 complete cycles of radiographs from 1968, taken every 3 years	Random sample of Oslo citizens aged 35	Patients selected to maximise number of contacting carious proximal surfaces and then only carious teeth with minimal identifying characteristics included to prevent reader recognition of same subject	Subjects included if has one or more unrestored occlusal surfaces in a molar. Teeth selected if had :- No restoration, including fissure sealant, covering part of the occlusal surface, no obvious proximal caries, no buccal of lingual caries or restoration.
Tooth Type	*In vitro* molars	*In vivo* molars and pre-molars.	*In vivo* molars and pre-molars	*In vivo* posterior teeth	*In vivo* molars
Surfaces studied	Proximal and occlusal	Results given as carious teeth	Proximal surfaces from distal surface of the canine to the distal surface of the 2nd molar	Proximal surfaces from distal surface of the canine to the distal surface of the last molar	Occlusal
Dentition	Deciduous	Permanent	Permanent	Permanent	Permanent
Total number of teeth/surfaces	64 molar teeth, 192 proximal and occlusal surfaces	8709 posterior teeth	3206 approximal surfaces of posterior teeth	367 control surfaces, 505 diseased surfaces (200 of each selected for inclusion)	299 occlusal surfaces
Age of patients	Children	28-76	35	Not given but adults	16-18
Sex of patients	Not given	Male	Not given	Not given	Male
Total number of patients	Not given	602	117 (only 100 sets of radiographs suitable)	47 (only 35 sets of adequate quality)	49
Other demographics	None given	Boston healthy veterans	Oslo residents	Patients who attended dental school clinics in San Antonio, Texas.	New army catering corps recruits

Table 6 - Description of tests used

	Clifton	Douglass	Hansen	Scarfe	Thomas
Reference Standard used in study	Light microscopy of tooth sections. Sections 200µm thick and oriented mesodistally in articulators and putty	Peri-apicals + OPT + BW interpreted simultaneously to give 'consensus radiographic standard' i.e. adds up all lesions. A follow-up validation analysis for false negatives and positives was carried out 3 years later and confirmed 81% (for false positives) and 90%(for false negatives) of the original consensus reference standard.	Clinical examination + OPT + BW	Consensus of all expert reviewers using BW, OPT and orthogonal panoramic radiographs. Where consensus could not be reached the surface was excluded.	Electronic conductance meter (ECM II) (LODE diagnostics) Has been validated in clinical trials.
Other details about design of study	Viewing order for each observer was unique, precomputed and randomised.	Order of viewing of radiographs was randomised	Radiographs were viewed using viewbox and opaque plastic eye mask with magnifying lens. Have to assume from the data given that there were no false positives for BW or OPT	**Expt 1:Overall accuracy i.e. presence or absence caries Expt 2: Detection of degree of caries: 2A-incipient caries, 2B-enamel caries, 2C-enamel/dentine caries, 2D-dentine/pulp caries.** Viewers independently assessed the 35 sets of radiographs. Anterior surfaces were from distal surface canine to mesial surface 2nd premolar. Posterior surfaces proximal to and including distal surface 2nd premolar. Films viewed with a light box with masked and subdued lighting.	All films viewed in a Rinn x-ray viewing box with extraneous light masked with black card and x2 magnification available. Images of individual teeth rejected if there was approximal overlap extending into dentine.
Description of BW radiography	Conventional D-speed (Eastman Kodak) X-ray source – Gendex 1000, at 70kVp, 15mA and 0.33s	Not given	Two bitewing radiographs taken	4 posterior BW No.2 films with long-cone (40cm) distance and rectangular columnation. Film positioning device. X-ray source-GE 1000 intra oral system, focal spot 1mm and 2.55mm aluminium total filtration 100kVp. Used E-speed film at 70kV, 10mA, 48 impulses. Films developed automatically.	Kodak D-speed film and kwikbite film holders. X-ray source Philips Oralix Denso-Mat (65 kVp, 7.5mA) with exposure 0.4 sec. Films developed manually.
Description of OPT radiography	Orthophas machine on Program-1 setting and T-MAT G films with Lanex regular intensifying screens. X-ray source 64kVp and 16mA	Not given	Siemans machine used.	Machine used was OrthOralix SD. Focal spot 0.5mm, total inherent filtration= 2.5mm. 1.2kW. Exposure time 12 secs. Films developed automatically.	Fuji Film Super HR-E 30 film with Kodak Lanex regular intensifying screens. X-ray source 75kVp. Films developed automatically.

Table 7 - Description of outcomes and outcome measurement

	Clifton	Douglass	Hansen	Scarfe	Thomas
Occlusal caries as outcome	Yes	No – caries overall only	No	No	Yes
Approximal caries as outcome	Yes	No – caries overall only	Yes	Yes	No
Outcome - presence or absence of caries?	Yes	Yes	Yes	Yes (**Expt. 1**)	Yes
Outcome-severity of caries?	No	Yes (indirectly since the threshold was altered in the **second analysis** to allow for enamel caries to be defined as presence of caries)	No	Yes (**Expt. 2**)	Yes (indirectly since the second threshold of the reference standard (**V2**) looked at deep dentine caries compared to dentine caries in **V1**)
Type of scale and grading used (caries)	Ordinal scale 1-5 where 1=certainty of absence of caries and 5=certainty of presence of caries	Ordinal 4 point scale where D_0=no caries, D_1=enamel caries, D_2=dentine caries, D_3=advanced caries into dentine. (1)D_0 and D_1 =no disease, D_2 and D_3 = caries, (2)a second analysis recalculated sens. and spec. for D_0 =disease and D_1 to D_3 = caries. *These results shown in italics in results table*. Available separately for molars and premolars	A scale used to define caries on BW and then described as carious or not. For OPT described as carious or non-carious only	**Expt 1**:5-point ordinal scale used to determine presence of caries, 1=definitely present, 2=probably, 3=unsure, 4=probably not present, 5=definitely not present **Expt 2** :5 point ordinal scale, C0=caries free, C1=enamel caries< ½ way, C2 enamel caries at least ½ way, C3=caries of enamel and dentine, C4caries of enamel and dentine > ½ way towards pulp cavity. Proximal caries only.	Study looked for dentine caries on occlusal surfaces only 5-point ordinal scale. 1=almost definitely no caries present, 2=probably not dentine caries present, 3=unsure, 4=dentine caries probably present, 5= almost definitely dentine caries present. 4 and 5 = CARIES PRESENT 2 validation thresholds used: V1-ECM>9=dentine caries, V2-ECM>12=deep dentine caries.
Type of caries	Dentine lesions (21% of proximal and 33% occlusal) Confined to inner dentine layer (2% proximal and 36% occlusal)		Primary caries defined as confined to enamel or involving enamel and dentine. Secondary caries also recorded.		
Measures of test accuracy	ROC curves and Tukeys pairwise comparison for statistical significance.	Sensitivity and specificity. Negative Predictive Value and Positive Predictive Value.	Results given as % caries detected by each modality but 2x2 table can be drawn	ROC curve areas where 0.5=random choice and 1=perfect. Critical ratio analysis of maximum likelihood areas used to assess accuracy between modalities.	Sensitivity and specificity and ROC curves plotted. Tested using ANOVA.
Measures of reliability	Intra-examiner variability and inter-examiner variability measured using the paired t-test and ANOVA respectively.	Intra-examiner variability and inter-examiner variability measured using kappa	None	No analysis carried out, although results available	Each examiner viewed 20% of the radiographs on separate third occasion, a minimum of a week later, so that intra-examiner reproducibility could be assessed. Kappa score used.

Appendix 11 - TABULATION OF STUDY RESULTS

Table 8 - Results for test accuracy

	Clifton	Douglas	Hansen	Scarfe	Thomas
Sensitivity (OPT)	Not given	(1) Molars-30.3 SD 2.4 (1) Pre-molars-19.3 SD 2.3 *(2) Molars- 23.9* *(2)Pre-molars- 13.9*	33%	Not given	**V1** : 0.2 (SD 0.09) **V2** : 0.32 (SD 0.11)
Sensitivity (BW)		(1) Molars-57 SD 2.6 (1) Pre-molars-62.5 SD 2.9 *(2) Molars- 60.6* *(2)Pre-molars- 64.4*	80%		**V1** : 0.25 (SD 0.1) **V2** : 0.42 (0.14)
Specificity (OPT)		(1) Molars-98.5 SD 0.2 (1) Pre-molars-99.1 SD 0.1 *(2) Molars- 98.5* *(2) Pre-molars-99.1*	100% since paper assumed no false positives		**V1** : 0.97 (SD 0.03) **V2** : 0.94 (SD 0.04)
Specificity (BW)		(1) Molars-97.2 SD 0.3 (1) Pre-molars-97.6 SD 0.2 *(2) Molars- 96* *(2)Pre-molars- 96.3*	100% since paper assumed no false positives		**V1** : 0.93 (SD 0.05) **V2** : 0.91 (SD 0.06)
ROC curves	Average Az scores and standard deviation and p-value from Tukeys pairwise comparison **Occlusal:** BW : 0.55 SD 0.057 OPT : 0.53 SD 0.062 P=0.31 **Proximal:** BW : 0.78 SD 0.11 OPT : 0.65 SD 0.09 P=0.012 (significant)	None supplied	None supplied	Critical ratio analysis of maximum likelihood areas between modalities with relevant p-values *(results relate to BW being superior to OPT where significant*)*: **Expt 1**: CR=2.36, p=0.009 * **Expt 2** : **2A** : CR=0.33 p=0.37 **2B** : CR=3.84 p=0.0001* **2C** : CR=4.51 p=0* **2D** : CR=0.28 p=0.39	**Occlusal only**: Values for area under ROC curve not given overall i.e. for each examiner only. Significance testing revealed no significant differences at threshold V1 between BW and OPT. At threshold V2 significant results found for 2/7 examiners both in favour of BW over OPT for detection of occlusal caries.
Other measures	None	PPV : (1) Molars – 64.9 OPT vs 64.4 BW PPV : (1) Premolars – 59.1 OPT vs 65.2 BW NPV : (1) Molars – 94 OPT vs 96 BW NPV : (1) Premolars – 94.5 OPT vs 97.3 BW	NPV can be determined i.e. 96% for BW , 89% for OPT	None	None
Overall findings on test accuracy as quoted in paper	ROC curves revealed superior diagnostic accuracy of BW for proximal caries but no significant difference for occlusal caries	Panoramic radiographs were substantially less sensitive for detecting dental caries than bitewings. The difference was more pronounced when D_3 only was considered as no caries (results in italics). Specificities were similar	Bitewings revealed 79.5% of carious surfaces while panoramic radiographs found only 33%	For overall diagnostic accuracy BW superior to OPT. For detection of enamel or enamel/dentine caries BW superior to OPT. No statistical difference in accuracy between BW and OPT for incipient or dentine/pulp caries.	Taking variance due to examiners into account, at V1 and V2 sensitivity for BW higher than OPT (sig. For V2 $p<0.05$). Specificity with BW sig. lower ($p<0.05$) than OPT when both validation thresholds used.

Table 9 - Results for repeatability

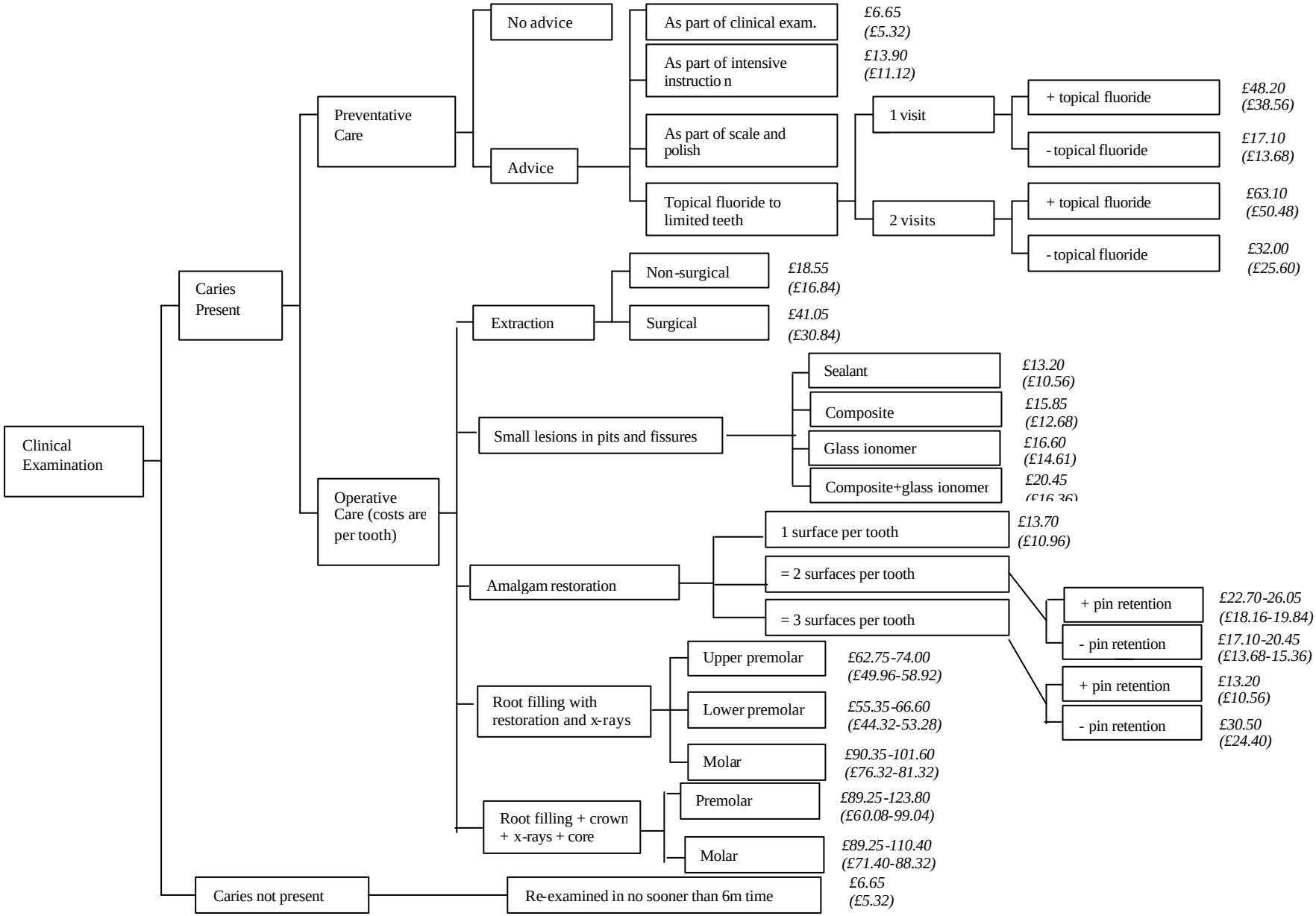
	Clifton	Douglas	Hansen	Scarfe	Thomas
Intra-observer variability	Paired t-test P=0.74 indicated no systematic bias between repetitions and intra-class correlation coefficient was 0.62 – moderate to good reliability. Carried out for 5/8 examiners.	Kappa repeated over 3 month intervals remained between 0.7 and 0.8 indicating good agreement	Not studied	Although results available for each viewer for overall diagnostic accuracy, no analysis of reliability presented.	Kappa scores were consistently low (for BW ranged from 0.31 to 0.44 and for OPT ranged from 0.07 to 0.61) and only showed moderate intra-examiner agreement.
Inter-observer variability	ANOVA revealed significant differences (p=0.0061) between observers for occlusal lesion detection	Kappa ranged from 0.68 to 0.8 between the 4 examiners indicating good inter-examiner agreement	Not applicable		Although results available no analysis presented.

Appendix 12 - TABULATION OF STUDY QUALITY

Table 10 - Study Quality

	Clifton	Douglass	Hansen	Scarfe	Thomas
Prospective study design?	Yes	No	Yes	Yes	Yes
Was patient recruitment unbiased i.e. consecutive or random?	No - Selected *in vitro* population	Can't tell – Patients with complete sets of radiographs included	Yes	No – patient groups highly selected	Can't tell but selected based on study criteria
Was tooth/surface type well defined?	Yes	Yes	Yes	Yes	Yes
Is the population representative of general UK patients?	Can't tell-extracted teeth	No – U.S. veterans	Can't tell – Oslo citizens	No – patients with high degree of caries selected	No – army catering corps recruits
Were tests adequately described?	Yes	No	No	Yes	Yes
Were reading scales adequately described?	Yes	Yes	Yes (given in separate paper)	Yes	Yes
Was a suitable/validated reference standard used?	Yes	Yes	Can't tell	Yes	Yes
Were an adequate number of examiners used i.e. >3?	Yes	Yes	No	Yes	Yes
Were outcomes clearly stated in terms of types of caries and measures used?	Yes	Yes	Yes	Yes	Yes
Was intra-observer variation studied?	Yes	Yes	No	No	Yes
Was inter-observer variation studied?	Yes	Yes	No	No	No
Were those carrying out the tests blinded to the outcomes of the reference standard?	Yes	Yes	Can't tell	Yes	Yes
Was more then 10% data missing for results of test accuracy which were described as included?	No	No	No	No	No
Were reasons given for drop-outs/missing data?	N/A	N/A	Yes	Yes	N/A
Were any radiographs excluded on grounds of poor quality?	No	No – retrospective study	Yes – 17/117 sets of radiographs 'not suitable' for inclusion (15%).	Yes – 12/47 sets of radiographs excluded as poor quality (26%).	Yes, but quantity unknown as readable radiographs was one of the inclusion criteria.

Appendix 13 - CARIES TREATMENT PATHWAY FOR PERMANENT POSTERIOR TEETH



Appendix 14 - CURRENT RECOMMENDATIONS FOR THE USE OF PANORAMIC RADIOGRAPHY

(a) Guidelines for the use of panoramic radiography in general dental practice produced by the Dental Practice Board of England and Wales (1983).

Guideline :

1. Examination of a patient new to the practice, or for a patient for whom a comprehensive radiograph examination has not previously been undertaken at the practice.

2. As an aid of examination/diagnosis when considering the need for orthodontic treatment (this normally applies to patients of 8 or 9 years of age when they can be expected to be into the mixed dentition stage.

3. To assist in orthodontic treatment at a later stage of dental treatment.

4. Prior to oral surgery, such as the extraction of impacted wisdom teeth or enucleation of a cyst.

5. After facial trauma

6. For following up progress of pathology or post-operative bony healing

7. Investigation of temperomandibular joint dysfunction.

(b) Guidelines from the Faculty of General Dental Practitioners (UK) as drawn up by the work of Rushton and Horner (1996).

These guidelines were developed to raise awareness of dentists of the limitations of panoramic radiography as it was considered that there may be inappropriate use of this technique.

Guidelines for the use of panoramic radiographs :-

1. Where a bony lesion or unerupted tooth is of a size or position which precludes the demonstation of its full extent on intraoral radiogrpahs. It is implicit in this statement that intra oral films should be used as a first choice method of imaging.

2. Prior to a dental surgical procedure under general anaesthesia. Here it can reasonably be argues that the risks associated with exposure to radiation and all efforts should be made to avoid the need for a repeat general anaesthetic procedure.

3. As part of an assessment of periodontal bone support where there is pocketing greater than 5mm in depth, unless other radiographs such as vertical bitewings are available. The

concurrent presence of symptomatic ectopic third molars may influence the selection in favour of panoramic radiography.

4. Prior to a dental clearance or multiple dental extractions where a clinical decision to remove teeth has already been made, where appropriate intraoral films are unavailable and where only a gross assessment of root morphology is required.

5. As part of an orthodontic assessment where there is a clinical need to know the state of development of the dentition and the presence/absence of teeth. The sue of clinical criteria to select patients rather than routine screening of patients is recommended.