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ORIGINAL ARTICLE

Economic aspects of the detection of occlusal dentine caries

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Abstract

Objective. To evaluate the cost of true-positive occlusal dentine caries detection in permanent molars assessed by: (I) visual–tactile examination, (II) visual–tactile examination combined with bitewing radiographs, and (III) selective radiographic examination of patients with lesions detected clinically. A second aim was to analyse the different strategies when the costs of the subsequent restorative care are considered. ***Methods.*** A model analysis was applied owing to the lack of original articles. Sensitivity and specificity were calculated from a systematic review and included *in vitro* and *in vivo* studies of medium and high quality. The direct costs for examinations and restorative care were extracted from the costs of the Public Dental Service in Sweden (2006). ***Results.*** The diagnostic costs per true-positive finding were dependent on the occurrence of occlusal caries and increased with decreasing prevalence. The strategy by which radiographs were exposed selectively on the basis of findings from visual–tactile examination resulted in higher initial costs compared with the first and second strategies. When the costs of the subsequent restorative care were added, the selective strategy was most beneficial by up to 26% savings per true-positive diagnosis. However, with this selective strategy, more cases of true-positive dentine caries were assumed would remain undetected as compared with the combined strategy with visual–tactile examination and radiographs for all. ***Conclusions.*** The cost for a true-positive caries diagnosis was inversely related to caries occurrence, and different diagnostic strategies may display contrasting outcomes when subsequent restorative care is taken into account.

Key Words: *Dental caries, diagnosis, health economy*

Introduction

Caries detection is carried out clinically by visual examination of tooth surfaces and with the use of a dental probe. For surfaces not accessible for direct inspection, bitewing radiography is common. The ultimate goal is to detect lesions at an early stage, thus allowing non-invasive preventive treatment [1,2]. Another goal is to assess the caries activity of each patient by monitoring the development of a lesion (progression or regression) over time. By tradition, the cut-off point between the preventive and restorative approaches is cavitation, which is a fairly advanced stage of the disease, usually with dentinal involvement. A comprehensive systematic review of high quality studies has estimated the sensitivity of occlusal dentine caries detection as ranging between 39% and 59%, with a generally high specificity over 90% [3]. Misclassifications are thus frequent, with clinicians possibly overlooking half of the lesions present on occlusal surfaces. The economic aspects of caries lesion detection have been given little attention in the literature and, to our knowledge, it is unknown which diagnostic methods are the most cost-effective. This is surprising, since early detection of caries and non-surgical interventions would surely alleviate costly restorative care. Also apparent is that the standard procedures for caries detection can vary from one country to the next; for example, from very rare to routine use of bitewing radiographs [4]. On the basis of a recent systematic review on caries diagnosis, risk

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assessment and non-invasive treatment carried out by the Swedish Council on Technology Assessment in Health Care [4], it was considered of interest to attempt to elucidate caries detection from the point of view of economy. The hypothesis was that the costs of a true-positive caries diagnosis would be influenced by the applied strategy. The first aim of the present study was therefore to evaluate the costs of a true-positive dentine caries diagnosis in occlusal surfaces of permanent molars assessed by (I) visual–tactile examination, (II) a combination of visual–tactile examination and bitewing radiographs, and (III) selective radiographic examination of those with lesions detected clinically. A second aim was to carry out an analysis of the different strategies when the costs of subsequent restorative care were also considered.

Material and methods

Search strategies

The search for relevant literature was conducted at the Cochrane Library and PubMed databases through October 2006 with the aid of an information specialist. The search terms were "dental caries/diagnosis" (Mesh) or "dental caries activity tests" (Mesh) and "physical examination" (Mesh), "visual" (TW), "probing" (TW), "tactile" (TW), "radiography, dental" (Mesh) or "X-ray film" (Mesh) with the addition of "cost and cost analysis/economics". The identified articles were printed out as abstracts and relevant articles were selected independently by two of the authors. An article was ordered in full text if at least one of the reviewers considered it potentially relevant according to the basic criteria for inclusion set up in advance: (i) *in vivo* or *in vitro* studies of human teeth using visual–tactile examination and/or bitewing radiographs, (ii) the material exceeding 30 teeth for *in vivo* and 50 teeth for *in vitro* studies with a described caries prevalence, (iii) a minimum of two independent examiners for *in vivo* and three independent examiners for *in vitro* studies, (iv) validated against the gold standard (histology), and (v) reporting sensitivity and specificity. Original studies published in English, German, French or any of the Scandinavian languages were accepted. Grey literature, such as textbooks, abstracts, letters, editorials and proceedings were not taken into account. The reference lists of the selected articles were hand-searched for additional relevant articles.

Evaluation of articles

A total of 42 publications (17 on visual–tactile examination alone and 25 on bitewing radiographs or combinations) were subjected to critical appraisal by at least two authors in accordance with predetermined criteria for methodology and performance. In the event of disagreement, the article was re-evaluated and discussed by the entire group until consensus was reached. Study quality and relevance were graded as "high", "medium" or "low" according to the QUADAS criteria [5,6] adjusted to fit the present systematic evaluation.

Economic model

No relevant articles were identified when the economic search terms were applied and it was decided to construct a mathematical model in an attempt to elucidate the questions concerning cost and effectiveness in connection with caries detection. Since no original data were available concerning the costs and consequences of an enamel caries diagnosis and non-invasive treatment, the model was restricted to dentine caries on occlusal surfaces of permanent molars and their restorative treatment. Sensitivity and specificity were calculated as the mean value from the selected clinical and experimental studies that were graded by high and medium quality [7–19]. These values formed the basis for the further calculations according to Table I. The costs of a clinical visual–tactile examination with bitewing radiographs were set at 43 Euros in accordance with the prices of the Swedish Public Dental Service in 2006. The radiographic examination constituted approximately 20% of the amount (9 Euros). The calculations (of cost) were performed on basis of different mean numbers of decayed occlusal surfaces in a population and expressed as Euro/true-positive diagnosis. In the next step, the costs of a filling (82 Euros) were added to the proportion of true-positive diagnoses, since restorative treatment was considered the logical consequence of a positive diagnostic outcome. The costs were calculated for three different strategies resembling the clinical situation: (I) visual–tactile examination alone, (II) visual–tactile examination combined with bitewing radiography of all cases, and (III) a selective radiographic strategy with bitewing radiography only in the event of a positive diagnosis at the visual–tactile examination. The first strategy was supported by 11 studies [7–17] (Figure 1) and the second combined strategy by 2 studies [10,19] (Figure 2). Since there were no published studies concerning the third strategy, a serial testing of visual–tactile examination and bitewing radiographs [10,15,17,18] (Figure 2) was applied. Although the occurrence of caries in a tested cohort will be increased when the second diagnostic test is included, it was assumed in the present modelling that the numbers of true-negative and true-positive cases of the included methods remained the same, i.e. if used as the first or the second test in order.

Table I. Calculation of cost per true-positive detection of occlusal dentine caries

	Caries	No caries	All
Test +	True positive = A	False positive = B	All Pos = (A + B)
Test –	False negative = C	True negative = D	All Neg = (C + D)
	A + C	B + D	All tested = (A + B + C + D)

Prevalence = (A + C)/(A + B + C + D); Positive predictive value = (A/(A + B)).
Cost per true-positive occlusal dentin caries, detection only: (CostDiagn * (A + B + C + D))/(A).
Cost per true-positive occlusal dentin caries, both detection and treatment included: [((CostDiagn*(A + B + C + D)) + ((CostTreat*(A + B))]/(A).

Abbreviations: All Pos = all positive cases according to test; All Neg = all negative cases according to test; CostDiagn = Cost per diagnostic test; CostTreat = Cost per caries treatment.

Results

The estimated sensitivity and specificity for occlusal dentine caries detection with the different methods are given in Table II. The diagnostic costs for a true-positive outcome by the three different strategies in relation to the caries occurrence are presented in Figure 3. In general, the costs decreased with increasing caries occurrence. The costs for visual–tactile examination (I), and this procedure combined with a routine radiographic examination of all cases (II), were similar irrespective of caries prevalence. A selective strategy (III), when radiographs were exposed only on patients in whom findings were positive at the visual tactile examination, increased the costs generally and most dramatically at a low occurrence of occlusal dentine caries. However, when the costs of the subsequent restorative care were included in the model, the selective bitewing strategy resulted in the lowest costs per true-positive case of dentine caries (Figure 4). Moreover, this selective strategy left more cases of dentine caries undetected compared with the all-cases strategy. Again, the total direct costs for diagnosis and restorative care, expressed as Euros per true-positive diagnosis, were dependent on the level of the disease and decreased by increasing occurrence of caries.

The wide range of sensitivity and specificity displayed in the original studies may affect the costs per true-positive diagnosis. A deviation of ± 0.1 units from the calculated mean values is therefore presented for the different strategies in Figure 5. When the values were increased by 0.1 units, the model analysis displayed that the costs per true-positive diagnosis were similar for all three strategies except for radiographic examination that showed somewhat higher costs at the lowest caries occurrence. A 0.1 unit decrease of the sensitivity and specificity increased the detection costs for all strategies, irrespective of occurrence of occlusal caries, but most significantly so in a low-caries population.

Discussion

It was disappointing to find that no study with health-economic aspects on caries detection was identified. The present study model was therefore conducted as a "surrogate exercise" on the basis of findings from a systematic review of studies *in vivo* and *in vitro* [4]. The limited number of studies meeting the quality criteria forced us to restrict the model to occlusal surfaces of permanent molars, albeit these the most caries-prone sites in children.

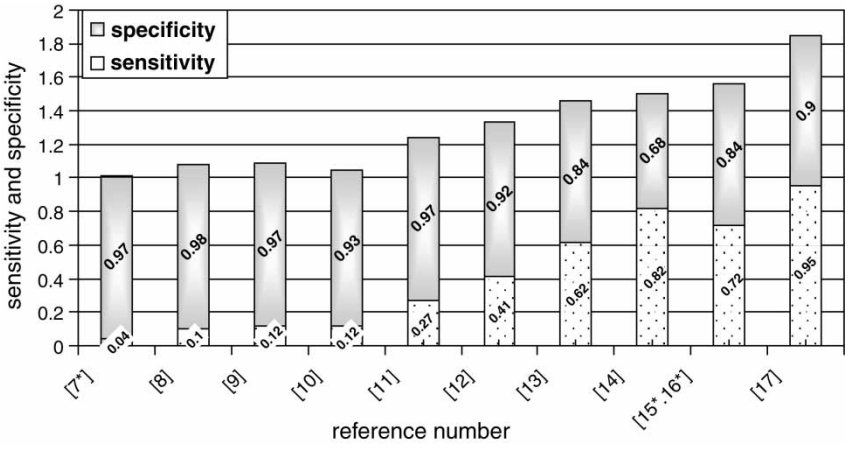

Figure 1. Detection of occlusal dentine caries in permanent molars by visual–tactile examination. Sensitivity and specificity calculated from studies with high and medium level of evidence. The bracketed numbers below the x-axis correspond with the reference list. An asterisk indicates an *in vivo* study.

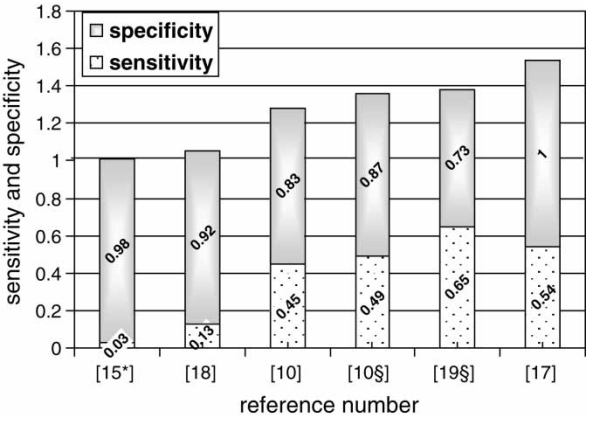

Figure 2. Detection of occlusal dentine caries in permanent molars from bitewing radiographs. Sensitivity and specificity calculated from studies with high and medium levels of evidence. The bracketed numbers on the x-axis refer to the reference list. An asterisk indicates an *in vivo* study and a section mark studies presenting combined results from visual–tactile and radiographic bitewing examinations.

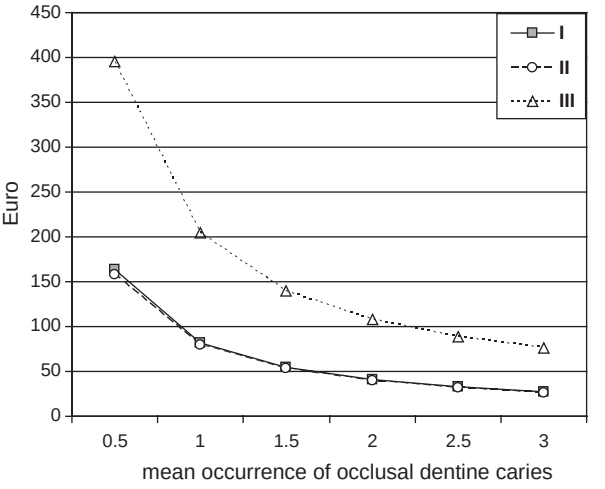

Figure 3. Cost of a true-positive occlusal dentine caries diagnosis by three methods: 1) visual–tactile examination, 2) visual–tactile examination + bitewing radiographs, and 3) visual–tactile examination + bitewing radiographs based on the presence of positive findings at the visual–tactile examination. The values on the x-axis denote the mean occurrence of occlusal dentine caries in a population (DSo).

We found some scientific support for the first two strategies, but no studies evaluating the third strategy were identified. A serial test of visual–tactile examination and bitewing radiographs was therefore applied as an estimate of the economic consequences, although "in real life" the occurrence of caries in an examined cohort will be increased when the second diagnostic procedure is included. It is therefore important to underline that this mathematical model is a simplification with limitations, and that the clinical relevance in different populations remains assumptive. Another point to stress is that the calculations of the costs are expressed per true-positive lesion, which is not the same as the total costs of a procedure. For example, the costs of the false-negative and false-positive findings were not taken into account in the present model and the number of bitewings radiographs taken per examination was not considered. The direct costs for examination and restorative care were extracted from the Public Dental Service in Sweden, which provides dental care free of charge to all children and adolescents up to the age of 20 years. No attempt was made to estimate indirect costs (e.g. due to absence from work), nor intangible costs (e.g. due to pain or similar). It is therefore emphasized that the values in Euros are only indicative and illustrate principles rather than true costs. The calculations were performed using different mean values of caries in order to illustrate the impact of the prevalence of the disease in the population. However, in most communities, the distribution of caries is skewed, which likely has an influence on the diagnostic procedures in the clinical situation, but this was not taken into account in the present calculations. If a high-risk part of a community could be identified, the economic outcome of the diagnostic measures would be more cost-effective as the occurrence of caries would be higher.

Table II. The sensitivity and specificity values used for three strategies; 1) visual–tactile examination, 2) visual–tactile examination + bitewing radiographs, and 3) visual–tactile examination + bitewing radiographs based on the presence of positive findings at the visual–tactile examination

Strategy	Sensitivity	Specificity	Reference
1) Visual–tactile	0.44	0.91	[7–17]
2) Visual–tactile and bitewing	0.57	0.80	[10,19]
3) Bitewing on positive findings	0.58	0.85	[*]

*Serial testing of sole visual tactile examination [7–17] and sole bitewing examination [10,15,17,18].

It has been suggested in a recent study that early caries diagnosis based on the use of radiographs in children younger than 6 years increases the likelihood of direct and future restorative care significantly [20]. Another study in adults suggests a threshold level for ordering follow-up radiographs at a 5% probability of detecting caries as being the most cost-effective [21]. The primary intention of this project was to study the costs for early caries diagnosis with lesions restricted to enamel, but this was abandoned for two reasons. At first, no firm evidence on the efficacy of various non-invasive measures was identified [4], and, secondly, the costs for such care as a consequence of a true-positive diagnosis on surface level could not be obtained. For example, in current systematic reviews it has been concluded that fluoride toothpaste is the most cost-effective method for caries prevention and control [22,23], and this is self-administered care of all surfaces in the mouth irrespective of diagnosis. For dentine caries, however, the situation is quite

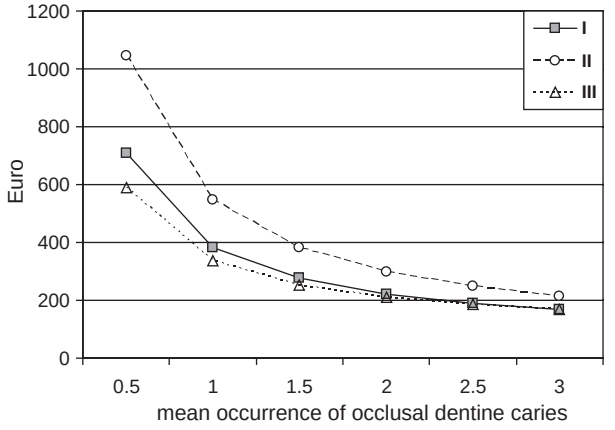

Figure 4. Cost of a true-positive occlusal dentine caries diagnosis with subsequent restorative care by three methods: 1) visual-tactile examination, 2) visual-tactile examination + bitewing radiographs, and 3) visual-tactile examination + bitewing radiographs based on the presence of positive findings at the visual–tactile examination. The values on the x-axis denote the mean occurrence of occlusal dentine caries in a population (DSo).

different. It is anticipated that restorative treatment would be the logical consequence of a positive diagnosis, although this may not always be the case bearing the recent concept of caries management in mind [2]. However, when occlusal dentine caries is visible on bitewing radiographs, the lesion is in a relatively advanced stage, i.e. beyond remineralization, and normally it is only a matter or time before being restored.

Although based on limited modeling only, our results make it plausible that the selective bitewing strategy, in which radiography was used after positive visual–tactile findings, led to the highest costs per true-positive occlusal caries diagnosis, especially in cases of low occurrence of caries in the population.

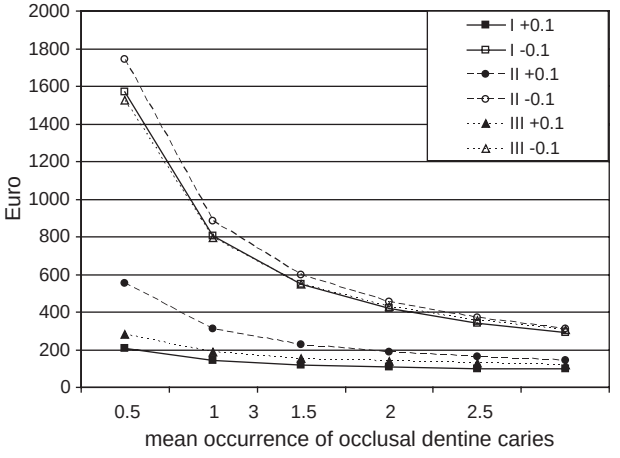

Figure 5. Cost per true-positive occlusal dentine caries diagnosis with sensitivity and specificity values increased or reduced by 0.1 unit from the mean: 1) visual–tactile examination, 2) visual–tactile examination + bitewing radiographs, and 3) visual–tactile examination + bitewing radiographs based on the presence of positive findings at the visual–tactile examination. The values on the x-axis denote the mean occurrence of occlusal dentine caries in a population (DSo).

The reason was that the two-step strategy identified the lowest number of true-positive cases and, at the same time, resulted in very few false-positive cases. The novel finding, however, was that the increased diagnostic costs of the selective bitewing strategy turned beneficial when the costs of the restorative care were included in the calculation. The costs of a filling vary by type of material, expected duration, caries risk and patient cooperation, but in this model the average price of a single-surface composite filling was taken from a recommended price list. The results are supportive of the concept that radiographic examinations should be performed on individual indications and based on the findings of the visual–tactile examination. However, this seems not always to be the routine among schoolchildren in Sweden and Norway. A pilot study conducted at the Swedish Council on Technology Assessment in Health Care has revealed that bitewing radiographs were used in more than 90% of all recall examinations of patients between 11 and 19 years of age [4]. The beneficial outcome of the selective bitewing strategy was most apparent at low caries occurrence, a situation representative of the average level of oral health in the Scandinavian countries. Therefore, the findings suggest that abandoning routine radiographic examinations in connection with regular check-ups in favour of bitewings exposed on individual considerations theoretically would save 26% of the cost or around 100 Euros per true-positive diagnosis, filling included.

The results of current systematic reviews [3,4] indicate that examiners may overlook around half of all the lesions present on occlusal surfaces, although the risk of diagnosing healthy occlusal surfaces as decayed seems very low. These frequent misclassifications of occlusal dentine caries bring an uncertainty that may affect the costs per true-positive diagnosis, as illustrated in Figure 5. This was clear in particular when the sensitivity and specificity were reduced by 0.1 units, which generally increased the costs of true-positive caries detection, especially at low average numbers of decayed occlusal surfaces. This further illustrates that bitewing radiographs are needed as an adjunct to visual–tactile examination depending on the individual indication.

In conclusion, the present model suggests that the cost of a true-positive caries diagnosis is inversely related to caries occurrence and that different diagnostic strategies may display contrasting outcomes when subsequent restorative care is taken into account. The selective strategy for bitewing examinations as an adjunct to visual–tactile examination results in initially higher costs per correctly identified dentine lesions compared to standard bitewing exposures, but when the costs of the subsequent restorative care are added, the latter strategy is most beneficial. Further studies on the health-economic aspects of caries diagnosis are needed in which both

the value of an avoided filling and the patient's willingness to pay are considered.

Declaration of interest: The authors report no conflicts of interest. The authors alone are responsible for the content and writing of the paper.

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