EVALUATION OF TWO RADIOGRAPHIC SCORING SYSTEMS USED TO MONITOR CARIES PROGRESSION IN DECIDUOUS TEETH.

BY

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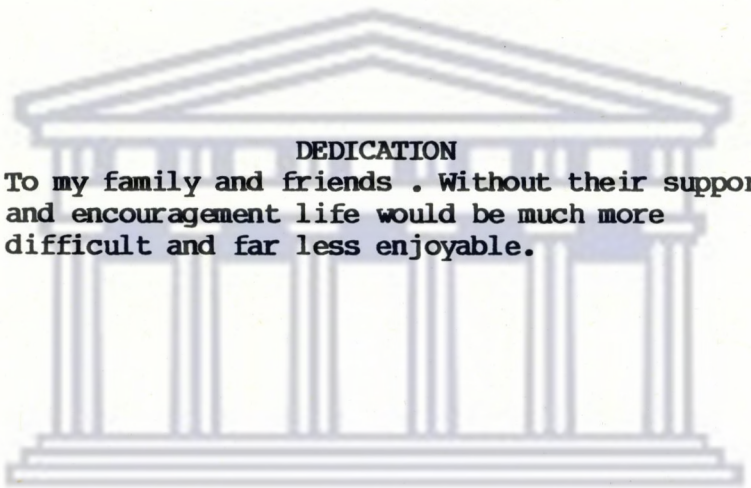
Not only is there but one way of doing things rightly, but there is only one way of seeing them, and that is seeing the whole of them.

John Ruskin.

DEDICATION

To my family and friends . Without their support and encouragement life would be much more difficult and far less enjoyable.



ABSTRACT

The investigation was designed to evaluate the scoring systems of Pitts (1984), and that of Murray and Majid(1978), when used to monitor caries progression in deciduous teeth. The evaluation was based on the reproducibility and discriminatory ability of the two systems.

The Reproducibility Study was designed to compare the reproducibility of the two systems, and in addition, to illustrate, firstly the use of the subject as the sampling unit in measuring reproducibility, and secondly, a more sensitive method of measuring reproducibility when analysing caries progression data.

The Progression Study was designed to compare the effect on discriminatory ability . In addition the use of the subject as the sampling unit in monitoring caries progression was illustrated in the analysis of this part of the investigation.

A sub-sample of the posterior bitewing radiographs of 301, 5 year old children from a Duraphat clinical trial (Murray et al. 1977, Murray and Majid 1978) were re-examined. For the Reproducibility Study 150 sets of radiographs were examined a total of 4 times, (repeated examinations for each method). For the Progression Study three serial bitewing radiographs of 50 children were examined using the two methods.

For the Reproducibility Study, Kendall's Tau-B was used as an approximation of the Weighted Kappa as a measure of reproducibility. While the Pitts method appeared to be more reliable, the difference between the two methods was not significant($p > .05$). The surface cannot be used as an independent unit in measuring reproducibility. A method using the subject as the sampling unit was illustrated. Attention was drawn to the need to develop a measure of reproducibility for progression studies which would take into account the magnitude of the disagreement (instead of just disagreement) into the overall index of reproducibility. The use of Weighted Kappa is suggested as a more appropriate measure of reproducibility.

In the Progression Study Method 1 is more sensitive to the various stages of the disease process and provides a more complete overall picture of the carious process. The proportion of enamel lesions recorded for Method 1 were consistantly higher than that for Method 2. The behaviour of outer and inner enamel lesions differed considerably and Method 1 allowed the behaviour of these lesions to be considered separately.

The progression rates were found to be faster with Method 2. With Method 1 30% of enamel lesions per subject had progressed to dentine or been filled 12 months later, the corresponding figure for Method 2 was 50%. Method 2 by excluding outer enamel lesions introduces two biases. The combination of these biases favour overestimating the proportion of lesions deemed to have progressed.

The use of Method 2 may lead to the unnecessary loss of valuable data; more surfaces were excluded as being unreadable because of overlap. The average proportion of surfaces per subject recorded as unreadible due to overlap was 7% at baseline, 8% at 12 months and 8% at 24 months, the corresponding figures for Method 2 were 13%, 13% and 22% for Method 2. Method 1 thus appears to offer some advantages.

The use of the subject as the sampling unit in analysing caries progression data offers a number of advantages when compared to the use of the surface as the sampling unit. The findings of the study indicate the proportions of high risk subjects (subjects in whom a large proportion of lesions progressed in a given time period) was low. With Method 1 in only 11% of the subjects did 80-100% of the enamel lesions progress after 12 months.

The findings indicate that the Pitts system is the more useful scoring system in studies monitoring caries progression in deciduous teeth.

CONTENTS

CHAPTER 1

LITERATURE REVIEW

1.1. Introduction

Information on caries progression rates is important in the planning of dental health programmes and policies, in determining the correct clinical approach, in the evaluation of appropriate time intervals for taking radiographs, and in planning of appropriate time intervals for dental recalls. Such information is of added significance in view of the changes taking place in the incidence, prevalence, and the rates of progression of dental caries in different parts of the world.

In the various studies carried out to monitor caries progression there has been a diversity in the selection of examination criteria, and, in the methods used in analysing the data. These variations make it difficult to make meaningful comparisons of the results and conclusions of the studies that have been carried out (Pitts 1983).

In this chapter the literature pertaining to the monitoring of caries progression rates will be reviewed. The chapter has been subdivided into sections, the first section dealing with use of bitewing radiographs to monitor caries progression, the second with the methods used to monitor caries progression, the third with the assessment of the methods used, the fourth with the methods used to analyse caries progression data, the fifth with progression rates reported for permanent teeth, and the final section with the progression rates reported for deciduous teeth.

1.2. The use of radiographs for monitoring progression of caries.

1.2.1 The historical development of the use of bite-wing radiographs to monitor caries progression.

Various methods have been used to monitor caries progression, both in vivo and in vitro. Progression has been monitored on the basis of the changes in the size of the lesion either in terms of depth, area, or volume over a certain time period. Apart from a study by Mertz-Fairhurst et al.(1979) in which direct measurements of the oral cavity were made, investigations monitoring caries progression in vivo have been carried using bite-wing radiographs.

Mertz-Fairhurst et al.(1979) measured the caries progression of sealed and unsealed caries in pits and fissures by direct measurement of the depth of the cavity using a resin matrix. The matrix consisted of measuring wire, and the change in depth between two examinations was related to the progression of the lesion. This method is however unsuitable for depth measurements on proximal lesions due to the poor accessibility of cavities on these surfaces.

Advice that periodic bite-wing examinations should be used to monitor proximal lesions was available as long ago as 1925 (Raper 1925). A number of different techniques have since been used and will be discussed in detail under 1.2.2

1.2.2 Limitations of bite-wing radiographs in monitoring dental caries.

Despite the fact that bite-wing radiographs are the most commonly used diagnostic aid to monitor caries progression in proximal surfaces their are a number of limitations inherent in their use.

1.2.2.1 Dental caries detection and radiographs.

Caries occurs when there is a loss of mineral from the enamel and the dentine. Radiographs reflect the differences in radio-densities resulting from the differences in the mineral concentration of the dental structures. Unless there is removal of certain amount of minerals during the carious process to create a certain minimum difference in radio-density it will not be observed on the radiograph. This amount is determined by a number of factors of a physical and technical nature , as well as properties of the visual system (Grondahl and Hollander 1986). These have been outlined below:

A. Physical and technical factors:

1. Radiation
   1.1 Quality and quantity.
   1.2 Geometry
2. Mineral loss
   2.1 Extension
   2.2 Spatial distribution
3. Film

3.1 Contrast

3.2 Resolution

B. Technical factors

1. Film processing

1.1 Processing time

1.2 Condition of processing solutions

2. Viewing conditions

2.1 Illumination

2.2 Environment

C. Visual system

From the above classification it is clear that the the actual image finally seen on radiogaphs is dependant on a large number of factors. The situation is complicated further by the fact that the radiolucency seen on the radiograph is a two-dimensional representation of a three dimensional lesion introducing further variables and uncertainties, all of which collectively make interpretation and comparison of different radiographs difficult (Pitts 1983).

The correct diagnosis of caries is important in epidemiological surveys, in caries prophylactic trials, and in studies of caries progression. In studies of caries progression not only the correct diagnosis (absence or presence) but also the correct estimation of the depth of the caries is important. The sensitivity of the use

radiographs to monitor caries progression has to be in the light of the uncertainties involved in their interpretation be viewed with caution.

1.2.2.2 Comparison of radiographic, histologic, and clinical appearance of carious lesions.

The very early stages of the carious process are characterised by a lesser degree of mineral loss with the result that the earliest lesion will often not be detected by radiographs. Several studies, on extracted teeth and in vivo, have shown that the extent of radiographic image is less than the true extent of the lesion, thus underestimating the true extent of the lesion (Ekanayake 1986).

Gwinnett (1971) in a study comparing clinical radiographs and histopathological sections of proximal carious lesions has shown that caries can involve more than half of the enamel before any radiolucency can be detected on radiographs.

Buchholz (1977) has shown that while a radiograph demonstrated the smallest perceptible indication of an proximal lesion, histologically extensive demineralisation of the dentine had taken place.

Purdell-Lewis et al.(1974) compared the visual, radiological and microradiological appearance of proximal caries of premolar teeth extracted for orthodontic reasons. When microradiological appearance and radiological data were compared it was revealed that 61% of

surfaces that were scored as caries free on radiographs had some level of enamel involvement. Early demineralisation involving the outer third of the enamel is rarely depicted on radiographs. The diagnostic threshold of proximal caries occurs when demineralisation has involved more than the outer third of enamel.

Rugg-Gunn(1972) in an in vivo study found that 83.9% of lesions with white areas or surface shine and 51.2% of lesions with white areas and loss of surface shine were not depicted as caries on radiographs.

Stuart et al. (1984) compared xeroradiographs and film for detection of proximal surface caries. They found that the observers typically failed to detect at least 20% of the carious lesions and also considered approximately 20% of the intact lesions to be carious. Lesions were detected with increasing accuracy as they penetrated farther into the dentine. Most false positive decisions were the result of the presence of hypoplastic pits or an unusual contour of the crown. Most false negative decisions were made on surfaces with relatively small amounts of demineralisation at the depth of the carious lesions.

There appears to be underestimation of the true depth of the lesion on radiographs of primary teeth as well. Dwyer et al. (1973) found that carious lesions in primary teeth were far in advance of the lesion demonstrated on radiograph.

There is however proof (Pitts 1983) that the size of a shadow seen on the radiograph is directly related to the size of the carious lesion. In monitoring caries progression the progression is assessed on the rate of change in depth, and provided that the depth at each stage is consistently underestimated the assessment should be reasonably accurate.

Although the image of the carious lesion depicted on radiograph underestimates the gross extent of the lesion it appears at present to be the best available diagnostic aid that can be used to monitor proximal caries progression in vivo.

1.3 Methods of monitoring caries progression using bite-wing radiographs.

1.3.1 Measurement of area and or volume of the cavity from radiographs.

In one of the earlier studies Shepherd (1945) projected bite-wing radiographs on to graph paper and drew the cavity outline under magnification (x10). Progression was determined by plotting the area of the cavity against the year of examination.

Gilda and Goldberg (1948), placed bite-wing radiographs of teeth with proximal cavities on a photographic enlarger and projected it onto graph paper. The outlines were drawn and cut out.

They derived the area of the tracing by using the following formula:

Area of tracing =

$$\text{Area of standard (1 cm}^2\text{)} \times \frac{\text{Weight of tracing}}{\text{Weight of standard}}$$

They also showed that the cavity volume can be obtained using the formula $V = A^{1.5}$. This formula was derived as follows:

The cavities of proximal surfaces were filled with temporary fillings of known density. The volume of the cavity was obtained by dividing the weight of the filling material by its density. When the cavity volume was plotted against the cavity area the equation $V = A^{1.5}$ seemed to satisfy the graph. They concluded that in a study of caries progression the cavity volume can be derived from the equation $V = A^{1.5}$.

Lobene and Zulqar-nain (1966) demonstrated a linear relationship between the area and the volume of cavities. They filled cavities with gutta percha and radiographed the teeth. The radiographs were projected on graph paper x49 magnification, cavity outlines drawn and weighed with an analytical balance. 1 cm square area of the graph paper was considered to be equivalent to 1 mg. of graph paper.

$$\text{Area of cavity (mm)} = \frac{\text{Average weight of tracing} * 10}{49}$$

$$\text{Volume of cavity} = \frac{\text{Weight of gutta percha}}{\text{Density of gutta percha (2.5245)}}$$

A graph of the volume against area revealed a linear relationship.

1.3.2 Weight measurements.

Muhler et al.(1967) used weight measurements to monitor caries progression. Radiographs taken at six monthly intervals were placed between two slides in a projector 12 feet away from the screen resulting in *23.5 magnification. The outline of the radiolucency was drawn on bond paper with a thickness of 0.03mm, cut and weighed. The percentage gain in size of the lesions determined by the difference in the weight of the paper tracing of the same lesion at every six month interval.

1.3.3 Cavity -pulp distance measurements :

Craig et al (1981) monitored caries progression in deciduous teeth by recording the depth of the lesion. To measure the depth of the lesion each radiograph was mounted on in a photographic enlarger in a

darkened room and projected at x2.0 magnification onto heavy bond white paper. The distance between the base of the lesion and the pulp was measured using fine calipers.

Macdonald (1983) also analysed the progression of caries in deciduous teeth in terms of cavity-pulp distance. Radiographs were read on a film viewer using a poloron x10 magnifying lens with a 0.001mm measuring graticule attached to it.

1.3.4 Conclusion

The studies mentioned above are generally associated with large recording errors and some are inapplicable to in vivo studies. Most studies on caries progression have thus used scoring and grading systems Ekanayake (1986).

1.3.5 Scoring or grading systems.

Grading systems are used to divide the carious process into different stages, each particular stage is given a specific code. Surfaces which are filled, overlapped, unerupted etc. may be given codes as well.

Backer Dirks, Amerongen and Winkler (1951) introduced a "reproducible method for caries evaluation". For proximal surfaces repeated standardised bite-wing radiographs were taken, and an assessment made of the change in depth of penetration of the radiolucency. A series of

"scoring codes" were used to record the degree of lesion penetration. This system, with modifications, has become widely accepted (Pitts 1983).

1.3.5.1 Conventions adopted by investigations using scoring systems to monitor caries progression.

The investigations have been subdivided into two broad groups: those having adopted scoring systems with enamel subdivision and those having adopted scoring systems without enamel subdivision. The investigations using systems without enamel subdivision have been summarised in Table 1.1, those using systems with enamel subdivision in Table 1.2. Both tables have been reproduced from Ekanayake (1986) with minor modifications and additions.

A summary of the conventions used (in general terms) is outlined in Figure 1.1. The diagram has been reproduced from Pitts (1983) with modifications.

1.3.5.2 Areas of disparity in the scoring systems.

As can be seen from Tables 1.1 and 1.2 the studies carried out to monitor caries progression have varied widely in the selection of selection of diagnostic criteria.

Areas of the grading system in which the greatest variation has occurred include : status of the ADJ, subdivision of the enamel, and the recording of overlapped surfaces. The treatment of these areas in past studies merits a more detailed discussion.

1.3.5.2.1 Subdivision of the enamel

As can be seen from Tables 1.1 and 1.2 attempts to subdivide the enamel have not been consistent. Various schemes have been suggested ranging from grading all radiolucencies in the outer enamel as sound (Murray and Shaw 1975) to a more detailed ones such as the one used by Moller and Poulsen (1973) who recorded even a radiolucency in enamel not extending more than one fourth of the enamel as the first grade of caries.

A number of studies (Table 1.1) failed to subdivide the enamel. It appears as if Marthaler (1966) was the first to describe a scoring system with enamel and dentine subdivisions. There does now appear to be a an increasing degree of agreement regarding the subdivision of enamel which favour criteria similar to those put forward by Grondahl et al.(1977), and these criteria have been used in a number of studies since then.

For deciduous teeth there has been variation as well. Shwartz et al. (1984) divided the enamel into outer and inner halves, Murray and Majid (1978) subdivided enamel but only considered lesions to be carious if they had penetrated the inner half of enamel. Craig et al. (1981) and Van Erp and Meyer-Jansen (1970) made no attempt to use a

measurement scale for lesions penetrating through enamel. The disparity in the choice of criteria stem from a number of considerations and is considered in further detail in Chapter 2.

Without enamel subdivision it is difficult to evaluate the behaviour of the enamel lesion (Pitts 1984). Pitts(1984) proposed a comprehensive standardised system for grading proximal carious lesions from bitewing radiographs which would be compatible with the WHO recommendation for grading clinically diagnosed caries. The system is described in greater detail in Chapter 3.

1.3.5.2.2 Status of the Amelo-dentinal junction (ADJ).

By definition the ADJ is neither in the enamel nor in the dentine, but is the dividing line between the two tissues (Pitts 1984). The ADJ is thought to represent the most likely threshold beyond which the probability of cavitation increases dramatically. Interpretation of radiolucencies around the ADJ thus becomes important when attempting to formulate criteria. The criteria must be such that there is compatibility between the radiographic appearance, the clinical picture and the determination of treatment needs from the radiographic data.

This remains a controversial area as a number of studies (see 1.2.2.2) have revealed a poor correlation between clinical tissues changes and previously accepted radiographic data. The diversity of criteria used in the various studies only adds to the confusion. Some schemes have included lesions extending up to and including the ADJ in

their enamel grades (method 1 and 4, Fig 1.1) whilst others have established a separate category for lesions reaching the ADJ (methods 2 and 5, Fig 1.1). Within this group there are further variations in that some exclude any spread into dentine whilst others allow spread "just into dentine". The other alternative (methods 3 and 6, Fig 1.1) is for all lesions extending to, or just beyond the ADJ to be regarded as dentine caries.

The dilemma lies in that if only broad criteria are used, (inclusion of the ADJ into one of the other categories when reporting) comparisons between studies become suspect, whilst if all smaller subdivisions are reported, results can be manipulated and compared (Pitts 1983).

The differentiation of a narrow separate ADJ can, however, lead to poorer of examiner reproducibility and the introduction of spurious score transitions with lesions apparently progressing or regressing to different codes. This can come about as a result of the difficulty likely to be experienced when attempting to decide whether a lesion extends nearly to the ADJ, just touches it but does not extend beyond it, or extends beyond the ADJ.

The treatment of the lesions at the ADJ in a number of the studies in the past e.g. Backer-Dirks (1951), Grondahl et al. (1977), Hollander and Koch (1969)) is unclear as they refer only to "enamel" or "dentine " lesions, and do not specify what treatment was accorded to lesions at the ADJ. This creates further problems when attempting to compare the results of the various studies.

1.3.5.2.3 Recording of overlapped surfaces.

Few studies have specified exactly what criteria have been applied to overlapped surfaces or how many overlaps were encountered. Such information is important since a dramatic reduction in the number of surfaces available for a study would affect the significance of the results (Pitts 1983).

Often when reporting results all degrees of overlaps have been pooled with surfaces unreadable or absent for other reasons, thus precluding any assessment of the relative contribution of overlaps to the total number of lost surfaces (Pitts 1983).

The studies that do report degree of overlapping have reported dramatically differing results for overlaps even when reporting on the same series of films, presumably due to the use of differing, although frequently unspecified criteria. McDonald (1982) cites report by Naylor in which four studies are quoted. The average number of unreadable surfaces in these studies accounted for 20-28% of the total number of surfaces; about half being due to overlapping of greater than half the enamel. Sewerin (1981) found that only 38.6% of surfaces showed no overlapping, while 16 % were severely overlapped. Marthaler (1966) found that 88% of all unreadable surfaces in a preliminary study were due to overlapped surfaces. Murray and Shaw (1975) reported that of the erupted surfaces only 73.3% were completely visible to both examiners. In a study by Cook (1981) in which three radiographic examinations were carried out 19.43, 23.6 and 21 percent of the surfaces examined at the first, second and third

examinations respectively were found to be unreadible. The implications of the loss such of data in terms of the findings of the study is discussed in detail in Chapter 5.

Even in studies where considerable efforts were made to ensure a high technical standard of radiography some surfaces are inevitably overlapped. Haugejorden (1974) suggested that it might be useful to determine the extent of overlap in an attempt to avoid losing valuable information by the exclusion of all surfaces overlapped at any examination. Pitt(1983) concluded that "it would seem sensible therefore to include scoring codes which quantify the degree of overlap and which allow for the recognition of obvious caries in the presence of an overlap." In this way the unnecessary loss of valuable information can be avoided.

1.3.5.2.4 Difficulties arising as a result of the disparity in the scoring systems.

As can be seen from Tables 1.1 and 1.2 there have been a large number of conventions adopted for grading radiographic lesions, and that they include a variety of diagnostic thresholds. The scope and complexity of criteria employed in the studies (including the more recent ones) varies widely, ranging from the simple division into intact, carious and restored surfaces to a six point scale dividing both the enamel and the dentine into thirds (Pitts 1984).

The selection of the criteria determines the level of examiner variability, as well as the discriminatory ability. Some workers elect to minimise examiner variability by expanding the minimal threshold for diagnosis e.g.. in the study by Murray and Shaw (1975) they do not score a radiolucency as a lesion until it extends beyond one half of the enamel thickness. Other workers select more sensitive diagnostic thresholds, which while being more sensitive for assessing the progression also introduce a greater level of examiner variability. The FDI recommendations for clinical trials stresses that although examiner consistency is very important, the chosen method must be sufficiently discriminatory to detect an important treatment effect efficiently. They go on to stress the need for standardisation and establishment of precise criteria for the diagnosis of dental caries.

A number of other problems arise as a result of the use of disparate criteria in the various studies. When examining even the same set of materials the use of disparate criteria could produce significantly different results. The use of different criteria in different trials makes it difficult to make meaningful comparisons of the results of the various studies. These problems highlight the need for greater standardisation of diagnostic criteria in future trials.

1.3.6 Use of image analysis for measuring the radiolucencies seen on radiographs

Pitts (1984) investigated the use of image analysis for the detection and measurement of proximal lesions on bitewing radiographs. Refinements of the technique were reported in a later paper by Pitts and Renson (1986). The technique involves the use of a computer aided, software driven TV based system. It allows a lesion to be identified and processes the image data to construct a lesion boundary. Estimates of the percentage depth of penetration of the enamel and scaled measures of the area are then derived from the coordinates of the lesion boundary.

The method was shown to be capable of making reproducible assessments of depth and area (Pitts and Renson 1985). The same authors in 1986 compared image analysis of bitewing radiographs and visual assessments of the depth of radiolucency in enamel with a histologically validated norm. They found that image analysis is more accurate, reproducible and objective than the visual assessment of the depth of radiolucency in enamel. In a more recent report by the same authors (Pitts and Renson 1987) their findings indicate that sensitive inter-group comparisons may be facilitated by this new method.

The use of computer graphics for the registration of caries, restorations and bone loss from radiographs has been suggested by Kullman and Martinsson (1985). The precision of measuring a

radiolucent area using computer graphics was however not determined in the study and its potential use for assessing caries progression remains uninvestigated.

1.4. Use of xeroradiographs monitor carious lesions.

Stuart et al.(1984) compared xeroradiographs and film for the detection of proximal surface caries and found that Ektaspeed and xeroradiographs were superior to Ultraspeed film for detecting proximal surface carious lesions. They however warn that radiographic detection of proximal surface caries even with newest image receptors remains an inexact science. They suggest that the image receptors examined in the study offer essentially comparible diagnostic use, accordingly the system that offers the least exposure to the patient to radiation should be considered.

In a more recent clinical trial by Wilson and Grant (1986) the results indicate that xeroradiography is superior to conventional intra-oral(film) radiography for the assessment of intra-oral structures and the diagnosis of all hard tissue lesions. They suggest that xeroradiography may be of particular value when attempting to assess discrete changes in carious and bony lesions, the diagnostic sensitivity and specificity achieved being found to be higher than those generally considered possible with conventional film imaging.

1.5 Assessment of the methods used.

The selection of the criteria to be used in a study will to an extent influence the sensitivity of the data recorded as well as its reliability. Assessment of the criteria or the method used can thus be based on the on the level of sensitivity and the effect this has on the results, and on the level of reproducibility. The most appropriate method will then be the method which provides an acceptable balance between sensitivity and reproducibility. This topic is covered in detail in the later chapters and only part of the literature not covered fully there will be outlined here.

1.5.1 Discriminatory ability.

The FDI recommendations (1982) for controlled clinical trials while recognising the importance of examiner consistency stresses the importance of choosing a method that is sufficiently discriminatory to detect important treatment effect efficiently.

Howat and Brandt (1980) carried out a study to investigate the discriminatory ability of different radiological caries diagnostic levels to provide information on the criterion giving the highest discriminatory level. They found that reliability of the radiological prevalence and increment data was high, and that although preventive treatment effects was evident for all diagnostic levels the power to discriminate between test and control groups measured by the size of the Student t-value differed. Although the results showed a significant preventive effect at all four diagnostic levels, the criterion ,"involvement of the amelo-dentinal junction but not beyond

was the most discriminatory." The greatest benefits of the preventive agent was seen when caries was recorded at the highest level involving up to the amelo-dentinal junction and not beyond.

Howat and Brandt (1980) also cite an earlier study by Mitropoulos et al.(1978) in which an attempt was made to investigate the sensitivity of different diagnostic levels. The authors used two levels of diagnosis, lesions confined to the enamel and those involving dentine. When enamel lesions were included in the analysis, higher t-values were obtained than when they were omitted. The greatest sensitivities were obtained when all radiographic lesions were combined with the clinical diagnosis established dentinal cavities.

Such disparate results indicate the need for further investigations, and they suggest that radiological criteria in current use should be applied to radiographs collected from a number of trials undertaken in different areas.

As the pattern of dental caries changes and preventative regimes become increasingly more effective the evaluation of the behaviour of the caries lesion becomes increasingly more important. Lesions can and do remineralise, and many lesions remain confined to the enamel for long periods of time. If the natural history of such lesions is to be understood then sufficiently sensitive criteria must be used and the methodology employed must not prohibit reversals or regression of carious lesions (Pitts 1983).

1.5.2 Examiner reproducibility

Backer Dirks et al. (1951) commented on the fact that in many of the clinical caries studies the authors never prove the reproducibility of the method used. A reproducible method carried out more than once within a short time interval on the same study material should provide the same results. Without a measure of the reproducibility of the methods used it would be difficult to determine whether the statistical difference is due to the factor which was varied in the experiment or to a statistical difference in the diagnosis.

The other problems associated with examiner variation is dealt with in greater detail in the later chapters.

1.5.2.1 Errors related to the diagnosis of disease

1.5.2.1.1 Diagnostic errors

Two types of diagnostic errors can occur:

a. False positive - when a healthy individual is diagnosed as diseased,

b. False negative - when an individual who is affected by disease is considered to be healthy.

1.5.2.1.2. Observational errors

Currently radiographs are not sensitive enough to detect the earliest changes of the disease processes of dental diseases. The measurements made using radiographs are thus rarely accurate. The differences between the absolute and the observed value is known as the observational error and are of two types:

a. Systemic errors .

Errors inherent to the technique of measurement. These errors may occur between different examiners at the same time, or between the same examiner at different points in time.

b. Accidental or random errors

Errors inherent to the observer specifically when a subjective judgement is involved, as in the detection of caries on radiographs.

1.5.2.2. Causes of examiner variability

The examiner of a radiograph interprets the information in the image to arrive at a diagnosis , the diagnosis being the result of the interaction between the information content of the radiograph and the observer. Factors influencing the observer might therefor have a profound impact on the interpretation and subsequent diagnosis (Grondahl 1979).

Grondahl(1979) reviewed the literature on causes of examiner variability and cites evidence for the following factors as being causes of examiner variability :

1. Attitude of observer
2. The provision of information other than that of the image.
3. Inadequate search pattern.
4. Influence of other observers.
5. Independent multiple (dual) readings by two or more observers.
6. Film density
7. Choice of diagnostic criteria
8. Interpretation of the diagnostic criteria.

Grondahl (1979) asserts that of all the reasons for observer variation and error the ones with most serious effects in epidemiological studies are likely to be those brought about by a systematic change of the diagnostic criteria. The effects of observer errors of a non-systematic character may be minimised by careful planning of the investigation.

Mileman et al. (1982) carried out a study to measure the variation in radiographic caries diagnosis and treatment decisions among university teachers. They found large variations in caries diagnosis and treatment decisions among the teachers, and attributed the differences to differences in the diagnostic criteria and viewing ability.

Ekanayake (1986) points out that in a number of studies only lesions penetrating more than half way through enamel or amelo-dentinal junction had been scored as carious e.g. Murray and Majid(1978). The

authors probably thought that recording the more advanced lesions will be associated with lower method error. While this was clearly seen in the study by Holst et al.(1976), this view is not supported by the findings of the study by Haugejorden and Slack (1975 a). They found no marked increase in examiner error when using two scoring systems (one point and two point scale for enamel caries) and reading the same set of radiographs. These conflicting reports on the effect of the choice of criteria suggests that further investigation is required.

In order to minimise examiner error the Federation Dentaire Internasionale (FDI) recommended all examiners to undergo a period of training prior to the trial (FDI 1974). In a study measuring reliability Poulsen et al.(1980) however found that random error was responsible for the major part of the error-fraction of the total error. The findings of the study indicated that it would be difficult to obtain reduction in error by calibration programmes based on radiographs alone, as the major part of error variance is due to random error which is inherent to the observer.

1.5.2.3. Measuring examiner reproducibility.

Rugg-Gunn and Holloway (1974) used Fletcher's (1960) definition of repeatability as "the extent to which a test provides the same results on the same subjects on two or more occasions either in the hands of the same or different observers, the subject of the test

being in the same state of health or disease on the two occasions". The reproducibility used by some workers can be taken to be the equivalent to repeatability.

The main purpose of reliability measurements is to indicate the influence of error on the efficiency of a study, or in other words to inform the investigator what saving in sample size might be possible if error was eliminated, with no change in the precision of the final statistics (Rugg-Gunn and Holloway 1974).

Various formulae have been used to express diagnostic consistency estimates.

Shaw and Murray (1975) reviewed some of the methods used and are reproduced below.

Definitions :

a = no. of teeth or sites with disagreement as to sound or carious (cs or sc)

b = no. of teeth or sites consistently diagnosed as carious.(cc)

c = number of teeth or sites consistently diagnosed as sound.(ss)

Formulae :

1. Reproducibility ratio (FDI 1974)

More recent studies have expressed the reproducibility in terms of the reproducibility ratio put forward by the FDI (1974). This ratio is a measure of the ability of an examiner to diagnose carious surfaces in relation to an approximation of the prevalence dental caries in the population. It is expressed as :

$$r = \frac{a}{b}$$

2. Consistency ratio (Percentage reproducibility)

The consistency ratio (CR) introduced by Alman in 1965 was used to express an examiners diagnostic consistency by amongst other Haugejorden (1974) and Pliskin et al.(1984). It is also called the Percentage Reproducibility (Jackson 1966) and has been used by Shaw and Murray (1975).

$$CR = \frac{b}{a + b} \times 100$$

3. Diagnostic inconsistency ratio

He later proposed that it would be an advantage to change the consistency ratio to the diagnostic inconsistency ratio (DIR) so that it will not give the same false sense of satisfaction as the CR.

$$DIR = 100 - \frac{b}{a+b} \times 100$$

4. Modified Reproducibility Ratio (Murray and Shaw 1975)

Shaw and Murray (1975) suggest that the reproducibility ratio and the percentage reproducibility emphasise the diagnostic variability by focusing attention on the carious diagnosis. They suggest that the examiners decision in many instances to diagnose a surface as caries free is just as critical as a diagnosis of caries. In the above methods the reproducibility of sound decisions is not taken into consideration. They thus felt it justified to introduce the modified reproducibility and percentage ratios. The figures include all examiners diagnosis on sound and carious surfaces instead of taking into concentrating entirely on the diagnosis of caries.

$$r(1) = \frac{a}{(b+c)}$$

5. Modified percentage ratio (Murray and Shaw 1975)

$$P(1) = \frac{b+c}{(a+b+c)} \times 100$$

6. Coefficient of reliability

Haugejorden and Slack (1975) recognised the limitation of DIR and other conventional methods of expressing consistency in that the estimates cannot be used in the analysis of data. Rugg-Gunn and

Holloway (1974) also pointed out that many of the published methods of demonstrating reliability do not allow the influence of error to be quantified. They suggested that the reliability coefficient together with error variance should be used to express repeatability, since reliability is closely related to the efficiency of the study and allows the relative importance of error to be assessed .

They used Guilfords definition of reliability:

$$Rt = \frac{Sx^2}{St^2} = 1 - \frac{Se^2}{St^2}, \text{ where}$$

Sx^2 = true variance

Se^2 = error variance

St^2 = total variance, $(= Se^2 + Sx^2)$

Rt^2 = the coefficient of reliability.

The St^2 is usually known, and if Se or the Rt can be calculated, than the true variance can be calculated.

For incremental studies they recommend the use of the sum of the prevalence variances method. The prevalence error variance is calculated for each examination and the sum of the variances provide an estimate of the error variance of the corresponding incremental scores.

They advocate the use Dahlsberg method to calculate the prevalence error variance :

a. Dahlsberg method

The following formula may be used to determine the error variance:

$$Se = \frac{\sum(d)}{2N}$$ where

d= the differences between routine and reexamination scores,

N = the number of subjects examined.

b. Test retest correlations

The test retest correlation can be used in cases where duplicate assessments are carried out. The test retest reliability is a "measure of the proximity of the scores obtained by the same examiner, using the same test at two different occasions where the subject is assumed not to have altered between the two tests.

It would be applicable when all or a random sample of the subjects are re-examined after a short period of time. Guilford has stated that the reliability coefficient for a test is a self correlation of the test. It is convenient in dental research to correlate one test against its retest so that the correlation between these two examinations is an estimate of its reliability.

Having estimated the value for Rt and the total variance scores using Guilfords formulae the true variance and error variance can be estimated.

7. Analysis of variance

A number of researchers have used the analysis of variance (ANOVA) approach introduced by Guilford and Futcher (1973) to calculate reliability. The estimation of reliability coefficient Rt is made using the following formula :

$$Rt = \frac{MS_{\text{between Subj.}} - MS_{\text{within sets}}}{MS_{\text{between Subj.}} - \frac{(K-1)MS_{\text{within sets}}}{}}$$

MS : mean squares (used as estimates of variance)

K : number of repeat measurements.

8. Kappa values

Hunt (1986) points out that the use of percent agreement and Pearson's correlation coefficient to represent interexaminer reliability can be misleading. He suggests that the use of percent agreement to measure inter and intra agreement should be discouraged, because it does not take into account the agreement solely due to chance. Caution should be exercised in the interpretation of Pearson's Correlation coefficient, because it is unaffected by systematic biases. He advocates the use of correlation and Kappa together to uncover non random examiner error. The Kappa statistic is recommended as a useful measure for quantifying agreement beyond chance for dichotomous judgements as the presence or absence of diseases. Kappa (k) is defined as :

$$k = \frac{Po - Pe}{1 - Pe} \quad \text{where}$$

Po is the percent agreement observed

Pe is the percent agreement expected.

The numerator reflects the agreement observed beyond chance. The denominator reflects the maximum agreement beyond chance that would have been possible given the marginal distributions of the disease. Thus kappa is interpreted as the proportion of possible agreement beyond chance that was actually achieved.

9. Weighted Kappa.

The Weighted Kappa as a measure of examiner reproducibility is discussed fully in Chapter 4.

1.5.2.4 Reported reproducibility in studies on caries progression

A number of studies have reported the results in which either the consistency ratio has been reported or the results allow the ratio to be calculated. These are presented in a Table 1.3, reproduced with modifications from Pliskin et al.(1984). Some studies report reproducibility in manner which make it unsuitable for inclusion in the Table 1.3 above. These will be discussed individually.

Haugejorden and Slack (1975) in a study of intra-examiner error associated with recording caries at different diagnostic levels found that the DIR was always lower than 34% and usually below 20%.

Mertz -Fairhurst et al. (1979),in a study on clinical progress of sealed and unsealed occlusal lesions found that uncalibrated dentist evaluators can unanimously agree on a comparative ranking of depth changes of approximately 400 um or larger. The evaluators had difficulty in differentiating between small depth changes.

Poulsen et al. (1980) in calibration trial involving 18 dentists found the effect of the training programme on interexaminer variation limited. They calculated the reliability coefficient from two-way analysis of variance. The results are outlined below:

Reliability coefficients:

Lesion	Initial	Manifest	Secondary
Systematic Error between dentists:			
included	.33-.43	.55-.61	.61-.71
excluded	.43-.51	.63-.69	.67-.71

Relative proportion(%) of total variance due to error :

Lesion	Initial	Manifest	Secondary
Systematic error between dentists :			
included	57-67	39-46	24-39
excluded	49-57	31-37	22-33

They found no consistent changes in the reliability coefficients and in the coefficient of variation from one examination to another (i.e. before and after the calibration). They however show that only small errors were found between the reliability coefficient when computed with and without the inclusion of the systematic error. They conclude that the major part of error variance was due to the random error.

Craig et al. (1981) determined the reproducibility of assessment of lesion penetration for 55 unrestored lesions in 26 subjects. They report that identical assessments were made for 48 of the 55 lesions giving a reproducibility of 87.2%.

Powell et al. (1981) made an assessment for reproducibility on 104 lesions in 60 subjects. Identical diagnoses were made for 95 of the 104 lesions, giving a reproducibility of 91%. There was no statistically significant difference between the original and duplicate assessments in the distribution of lesions in each of the three progression stages.

Mileman et al. (1982) carried out a study in which 12 duplicated bitewing radiographs were viewed under controlled conditions by 42 dentists in a teaching department. The dentists noted surfaces with initial caries or with in need of treatment. The interexaminer variation between the dentists on the number of surfaces diagnosed as carious per dentist ranged from 160 to 54, with mean of 22.4 and s.d. of 16.2. The radiographs were re-examined by 20% of the dentists to determine inter and intra examiner variability. They suggest that the reproducibility of the overall judgement can be estimated from

the number of surfaces scored as sound at both viewings by the subgroups of teachers. This given as percentage of total possible sound surfaces per teacher was mean 70, s.d 7, min. 60, and max.80.

Pitts and Renson (1985) reported on the reproducibility of computer aided image analysis derived estimates of depth and area of radiolucencies in proximal enamel. They reported average values for the standard error of mean (SEM) of triple determinations of depth at between 2.0 and 3.5%, while the SEM for area was from .03 to .04 square mm. Average test retest correlations ranged from .963 to .871 for depth and from .963 to .884 for area. Average reliability coefficients ranged from .937 to .821 for depth and .963 to .886 for area. When compared with reproducibility of attempts to grade the radiolucency size visually they conclude that the image analysis method appears to offer considerable advantages, in that consistent estimates of radiolucency size was made possible by the use of image analysis.

Ekanayake (1986) reported a reproducibility ratio (FDI) for caries of .16 and .28 when score changes from carious to unreadible surfaces were included. She reported the following agreement ratios:

Depth of lesion	Agreement ratio (%)
Outer enamel	73
Inner enamel	58
Outer dentinal	72
Inner dentinal	100

1.6. Methods of analysing caries progression.

Various methods have been used to analyse caries progression data. The diversity of the methods make it difficult to make direct comparisons of the results of the different studies.

1.6.1 Calculating the percentage of lesions that progress/do not progress at a later date, of a given total of lesions present at the baseline examination.

Many of the investigators who have attempted to quantify the caries progression expressed their results in the following manner:
If p = the percentage of lesions in a specific state at the start of the study, which remain confined to that state after a specific period, a series of values for p can be derived. The implication of this would be that p% of the lesions in the state can be said not to have progressed over the time period (Pitts 1983).

Researchers who have reported their results in this manner include (Emslie 1959, Backer Dirks 1966, Hollander and Koch 1969, Berman and Slack 1973, Hyde 1973, Haugejorden and Slack 1975. Murray and Majid 1978, Grondahl and Hollander 1979, Granath et al. 1980, and Craig et al. 1981).

There are a number of limitations associated with this type of analysis. Most of these studies rarely provide sufficient data to estimate the probability distribution, and furthermore they tend to result in certain biases when used to estimate the rate of

progression (Schwartz et al. 1984). The topic is discussed in further detail under 6.5.2. The manner of handling data in progression studies in which attempts are made to evaluate pooled data and to apply the results to individual teeth or a person also makes interpretation and drawing of conclusions difficult (Berman and Slack 1973).

1.6.2 Using caries progression scores.

A number of authors have used and/or proposed progression scores. In this system a progression score is calculated from the score transitions that each surface undergoes between examinations. The analysis is based upon the changes in the individual lesion monitored over certain length in time, rather than pooled data from the baseline and subsequent examination.

Wagg (1974) devised a complex measure of caries progression which took into account the enlargement of existing lesions as well as the initiating of new ones. The failure to subdivide the enamel cap however meant that only relatively gross assessments of progression could be made (Pitts 1985).

Hollander and Koch (1969) also employed a score system (without enamel subdivision) in a radiological study of caries progression. They obtained estimates of the caries progression rates of particular groups in the following manner: By adding all the combinations of consecutive gradings (1-1,1-2,and 1-3) the total number of combinations where grade one was involved was obtained. The number of

combinations of each type was then expressed as a percentage of the total number of combinations involving grade 1. They used the figures thus obtained as mean values for the test and control groups in order to make comparisons between the groups.

Grondahl et al.(1977) proposed an index and score system which use more sensitive scoring codes (with subdivision of enamel and dentine into two halves). In their system a progression score was calculated from the score transitions which each surface underwent in a manner analogous to that of Hollander and Koch (1969). In comparing the score system with DF surface system they found that the score system revealed greater differences between groups of individuals than DFS increments. In a later report the same workers suggest that score system would provide a better basis for prediction of caries progression than the difference in DF surfaces observed within a certain time interval.

1.6.3 The average duration of time in a carious state.

The average duration of time in a particular state as a prediction of the rate of caries progression was first used by Marthaler and Wiesner (1973), and later by Zamir et al.(1976), and Shwartz et al.(1984).

Marthaler and Wiesner (1973) worked out all the possible categories of the appearance of grade 1 lesions (radiolucency in the outer half of enamel) and their passage into higher grades. The penetration times for each of these categories was worked out and the frequency distribution and cumulative percentages of the surfaces falling into

the various categories were calculated. The penetration times showed a lognormal distribution. From these they were able to calculate the average time required for a lesion to reach the inner half of enamel, and also the quantiles for lesions to reach the outer and inner half of enamel.

Zamir et al.(1976) worked out the average time required for a given enamel lesion to progress to a deeper layer, and also the Life Table of the enamel lesion, where at each specific consecutive time the distribution according to depth was recorded. This distribution was plotted as a semilogrithmic curve and the average survival time for a lesion was interpreted from the 50% survival time.

Shwartz et al. (1984) used survival analysis to determine the average duration of time in carious state. The method is described in detail in 1.6.4 below.

A striking feature of the studies carried out to estimate caries progression rates is the diversity of the populations studied, the radiographic techniques and diagnostic criteria used, and the methods of analysing the data obtained. In order to derive meaningful conclusions some authors have derived mathematical models and applied it to reported data in the literature.

Pitts (1983) and Shwartz et al. (1984) derived similar exponential models and applied it to existing data from previous studies. Using the model they were able to estimate average duration in a particular state for the various studies and in this way compare the findings of the studies.

The assumption of the model was that the duration of time in carious state follows an exponential distribution. The parameter of the exponential distribution was obtained from the reported percentage of lesions that remain in the state of interest between the first and the last examination, and the average time in the state was then calculated as the reciprocal of exponential parameter. These approaches have to be interpreted with caution in view of the intrinsic interstudy differences. In a later report (Darvell and Pitts 1983) a more complex mathematical is presented in which account is taken of the age of the subjects as well as the observation periods in predicting the proportion of lesions remaining in enamel. This model also had a form of a negative exponential, second order in age.

1.6.4 Survival analysis

1.6.4.1 Use of survival analysis in dental research

Survival analysis especially the Life Table method has been used to present death rates in the population has been used under different circumstances in dental research (Ekanayake 1986). The method can be used in general to determine the survival rates after an event has occurred. It is important that the event occurs at one point in time,

and that, at that time it can be clearly defined as being present or not present. (well defined starting and ending point). One complication of the use of survival analysis is the problem of censored data. The problems and type of censored data are described in further detail under 4.5.1. Elimination of censored data with the use of only uncensored data will bias the survival times (Schwartz et al. 1984). However two methods of survival analysis namely the Life Table method and the product limit estimate (Kaplan and Meier (1958) allow the incorporation of both censored and uncensored observations in the estimation of survival times. The two methods are similar except that in the Life Table method there is an arbitrary grouping of the survival times (Ekanayake 1986).

1.6.4.2 Application of survival analysis to caries progression data

The application of Survival analysis to caries progression data was introduced by Shwartz et al.(1984), and has also been used by Ekanayake (1986).

The Life Table method and the Product Limit estimate are appropriate to determine the probability distribution of survival times of a lesion in a carious state, as they can be used to include non progressing lesions, and restored lesions (right centered data) in the estimation of the survival times in carious state. In this way the biases that are introduced by the exclusion of censored data are eliminated Shwartz et al.(1984).

Shwartz et al. (1984) apply and advocate the use of survival anlysis to caries progression data in order to include censored data. The approach is based on the on the estimation of hazard rates , i.e. the probability that a lesion progresses from a certain state in some small time interval (e.g. a month) given that the lesion was in that state at the start of the interval. Right centered data were incorporated in the denominator of the ratio and used to estimate the hazard rate for all time periods prior to the censored period. Assuming for example that it was necessary to estimate the hazard rate for state 1 for 18 months the ratio would be:

$$\frac{\text{No. of lesions progressing from state 1 between months 18 and 19}}{\text{No. lesions in state 1 at the start of month 18}}$$

Only lesions censored at times after month 18 would be included in the denominator. Once hazard rates had been calculated for each time period, the survivor function S(t), which is the probability that a lesion had not progressed from the state by the time t, is determined by multiplying together one minus the hazard rate for the time period with the S(t)of the previous time period. From the survivorship function the average time in a state can easily calculated.

Shwartz et al. (1984) suggest that the duration of enamel lesions is extremely variable between individuals and between lesions in any one individual. They suggest that it might be more useful to focus on the distribution of time for which lesions remain in the enamel rather than on the average duration. This could be calculated if we assume that the distribution of time for which a lesion remains in each

half of the enamel is exponential. If the mean is known, the percentage of new lesion still in enamel after a time period can be calculated.

1.6.5 Monitoring progression using image analysis

Pitt and Renson (1987) proposed a system of measuring caries progression using image analysis. The technique allows computer aided estimates of depth and area of the lesion to be made, the results being provided in terms of percentage depth of the enamel and scaled measures of the area.

A linear regression method is employed to find whether a linear trend would adequately describe the relationship between the radiolucency size, and time. A straight line is fitted to minimise the square deviations about the line. The percentages for depth were given arc sine transformations as the transformed values were more likely to be normal and homoscedastic(two or more distributions whose variances are equal) than percentages. They determined the critical values for r(which had to be exceeded if P >.05 was to be attained) for the groups under examination. Positive values exceeding the limits ($p > .05$) were regarded as indicating a trend of linear progression, whole negative values exceeding them were classified as regression. Those values that failed to reach the critical values were regarded as arrested or providing no evidence of progression or regression.

1.6.6. Sources of error in the analysis of data.

1.6.6.1 Censored data

In order to estimate the duration of time a lesion spends in a particular state the start point and the end point for the lesion in that particular state must be known. Uncensored observations are those lesions in which it is known at least within a range, when the lesion entered the state and when it left it.

Censored observations are those lesions for which either the start point or the end point (or both) is unknown. Right censored observations are those in which the start point of the lesion at a particular state is known, but the end point for the lesion in the state is unknown, it is censored. Lesions that were filled during the course of the study and lesions that did not progress from the particular state by the end of the last examination constitute right censored lesions. Left censored lesions are those in which the start point of the lesion for a particular state is unknown.

Shwartz et al. (1983, 1984) showed that if either censored data is excluded and only censored data are used to make the estimate of caries progression , or if the censored data is treated like uncensored data valuable information is discarded and a bias is introduced.

An uncensored observation, in order for the start and end points to be known, has to make two transitions during the observation period, that is into the state and out of the state. On the basis of this one can conclude that the uncensored observation must be a fairly rapidly progressing lesion. Both right and left censored data make only one transition during the same period of time and hence, on the average would be the slower progressing lesions. By ignoring the censored data, i.e. the more slowly progressing lesions, a bias towards underestimating the duration of time a lesion spends in a state will result (Shwartz et al. 1984).

In the study by Marthaler and Wiesner (1973) lesions that did not progress from the outer half of enamel were excluded from the analysis. Lesions that were restored after having been in the outer half of enamel on the preceding radiograph were assumed to have progressed before they were restored. In the study by Zamir et al.(1976) it appears that non progressing lesions and restored lesion are ignored in the analysis. As a result of the biases introduced by these methods of analysis these studies have overestimated the rate of progression of caries (Shwartz et al. (1984).

Shwartz et al. (1984) also discuss the problem of left censored data in their discussion. Left censored data is data in which the starting point of a particular state is unknown. Since the period in the life of the lesion being observed is unknown, there is no way to determine for which periods hazard rate the observation should contribute. If the hazard rate is assumed to be the same for each period, then it does not matter that it is not known which period in

the life of the lesion is being observed. The observation can be treated similarly to a right censored lesion. However if the hazard rate is not constant, use of the left censored data in estimating the distribution of time in a certain state becomes difficult.

1.6.6.2 Two and three examination protocols

Shwartz et al. (1984) point out that many of the studies from which the available information on rates of caries progression has come, have been of the type in which two examinations were carried out. Furthermore, in these studies the percentage of lesions that did not progress from a particular carious state between the two examinations were recorded. They suggest that extrapolation from this type of study is subject to two offsetting biases:

a. Slow progressing lesions in a particular state long before the first examination may progress between the first and second examination, resulting in underestimation of non progressing lesions.

b. Screening examinations of which dental radiography is one, detect sample of lesions that are not necessarily representative of the entire population of lesions. Length bias sampling is the second type of bias which occurs. Slow progressing lesions are overrepresented in the sample of lesions detected at the first examination, and result in the overestimation of non progressing lesions.

In order to minimise these biases the authors recommend a three examination protocol.

1.6.6.3 The use of the lesion as the sampling unit

Most of the studies on caries progression have considered the lesion as the sampling unit. The number of subjects who show/ do not show progression has seldom been reported in terms of progression of lesions per subject. There are a number of problems associated with the use of the lesion as the sampling unit. These problems and the alternative approaches that may be used are discussed in detail in Chapter 5.

1.7. Rates of caries progression in permanent teeth.

The rates of caries progression in permanent teeth reported in the various studies have been summarised in Table 1.4 (reproduced from Ekanayake (1986).A number of the studies have been excluded from the table above as their results do not allow comparisons by the above method for either one or more of the following reasons:

1. The methodology employed (diagnostic criteria; or the method of analysis) would make it unsuitable for comparison with studies reported in the table.
2. The results were reported in formats incompatible with studies reported in the table.
3. The studies were carried out on sample populations in whom faster or slower progression rates are expected.

The findings of these studies are discussed individually.

Boyd et al. (1950) in a study on institutionalised teenagers who received minimal treatment, reported that without reparative or other dental therapy cavities tend to remain almost static for periods of many months, that progression toward more severe caries involvement was not rapid in the great majority of cavities observed. For consecutive periods of at least one year "dental caries did not advance to a detectable degree" in one third of the group. Of this group 80% had periods of six months or more with no detected lesion advance during the two year study.

Parfitt (1956) reported that caries on the occlusal surfaces of teeth takes from less than three months to over six months to progress through the stage of incipient caries. Up to 28% were less than six months and between 9 and 47% were less then 12 months in this stage. He concluded that when yearly examinations are made only a small number of teeth would be lost through advanced occlusal caries.

Backer-Dirks (1961) in a longitudinal study of monitored 100 nine year children over six years. H^ stated that in proximal surfaces "dental caries developed slowly as it took a mean of two to three years for an incipient lesion to develop to a lesion affecting dentine.

Muhler et al. (1967) measured caries progression as part of a study to measure the effect of Stannous Fluoride therapy. They measured caries progression in terms of the increase in size of the lesion after projection of the radiographic image onto paper. They found that incipient lesions in the control group progressed on average by

size after six, twelve and thirty months by 49.5%, 83.19% and 98.22% respectively, and in the experimental group only by 14.09%, 16.41% and 18.22%.

Hyde (1973) selected a group of caries active children who required restorations of primary molars adjacent to mesial lesions in newly erupted first permanent molars. In the control group only 18% of the lesions failed to reach the ADJ during the two year study, whereas in the APF group 49% of the lesions remained superficial to the ADJ.

Marthaler and Wiesner (1973) monitored 133 caries active children aged 7.5 to 14.5 years, and found that the average time taken for a lesion to penetrate the outer half of enamel to be 1.71 year. The accuracy of these findings is however questionable as the authors excluded all arrested lesions and admit that unsupervised restorations of enamel lesions often occurred.

Murray and Shaw (1975) reviewed the radiographs of 1162 children aged 11 to 12 years taken during a 3 year clinical trial of two MFP toothpastes against a placebo . Lesions were diagnosed as carious only if the radiolucency reached the inner half of the enamel. They found that of those lesions confined to the inner half of enamel at base line only 10.9 % had not progressed or been restored over the same period. Approximately half of the inner half lesions that were regarded as having progressed were as a result of being restored. They concede that ' it cannot be proven that these lesions had indeed progressed. Over 40 % of the surfaces which were restored during the trial period had not been recorded as carious by the diagnostic

criteria used in the study at any preceding examination. In view of these uncertainties the findings of the study have to regarded with caution.

In order to make comparisons between the findings of the studies in spite of the inconsistencies inherent in them some authors derived mathematical models. Pitts (1983) applied the negative exponential to existing data. When only the observation period was taken into account to predict the proportion of lesions surviving, he found the mean survival time of all enamel lesions to be 3-4 years, and for outer enamel lesions only to be 5-6 years. In a later report (Darvell and Pitts 1984) observation periods as well as the age of the subject were taken into consideration in the mathematical model, the "peak rate" of progression was found to be around 11-13 years of age with an established peak half life of about 2.7 years. In the first report data from both fluoride supplementation studies and non-fluoride studies were included, while in the second report all fluoride supplementation studies were excluded.

Shwartz et al. (1984) derived a similar negative exponential model. They concluded that it took at least on average of four years for a lesion to progress through the enamel of permanent teeth, and that progression was slower in older individuals particularly those with long term exposure to fluorides. These approaches have to be interpreted with caution in view of the intrinsic interstudy differences.

Cook (1984) in a study to assess progression rates in group of dental students (95 students with 2 bitewings), examined at intervals of 8.5, 19 and 32 months found that for small initial lesions 79.2%, 79.6% and 68.4% of the lesions respectively remained unchanged at each time interval. For larger enamel lesions 90.9%, 57.7%,and 58.3% of the lesions remained unchanged.

Shwartz et al.(1984) used the Kaplan-Meier estimate to incorporate information on filled and non progressing lesions to minimise the biases in estimating progression rates. They monitored more than 700 children divided into five groups, three from Sweden and two from the USA and determined the average time a lesion spends in the outer and inner half of enamel. They reported the following findings:

The average time taken for a lesion to progress through the outer enamel in newly erupted first molars were 21(the Swedish group) and 23 (USA group) months. The time for the lesion to progress through the inner half of enamel was 28(Swedish group) and 19(USA group) months. For older adolescents there were two subgroups for the Swedish group and the progression rates were slower overall when compared to USA group. The progression rate in the Swedish subgroups were 37.6 and 41.2 months for the outer half of enamel and 47.4 and 56.4 months for the inner half of the enamel. The USA adolescent group had four subgroups who had different degrees of exposure to topical fluoride. It took 15.5 to progress through the outer half of enamel and 26.5 months to progress through the inner half of enamel. Progression was fastest in the control group, taking only 9.7 months for a lesion to

progress through the outer half of enamel. There were no consistent differences between upper and lower dentitions, premolars and molars, high and low risk individuals.

Ekanayake (86) carried out an investigation to assess whether progression rates had decreased with the decline in caries. The progression rates of 798 children who participated in a fluoride clinical trial between 1965-1968 were compared with the progression rates of 330 children who participated in a professional tooth cleaning study between 1978-1981. The findings indicated that a significantly higher percentage of outer enamel lesions progressed into dentine and to a filled state in the 1960's than in the 1970's (1960's 29% per subject, 1970's 11% per subject). The percentage of inner enamel lesions that did not progress par subject at the end of 36 months was significantly higher in the 1970's than in the 1960's (1960's 25% per subject, 1970's 39% per subject).Using the Product Limit estimate to analyse the data, she reported that there were statistically significant differences in the distributions of the survival times of inner enamel lesions between the 1960's and 1970's group. She also reported that progression varied according to the caries intensity of the subjects. There were differences in the percentage of outer enamel lesion that progression into dentine and to filled state, between children with 1-4 and >4 proximal carious and filled surfaces at baseline.

Pitt and Renson (87) using Image Analysis examined two groups :

1. 50 Surfaces monitored annually over a two year period in dentrifice trial of 11 to 13 year old children. They found that more than half the lesions showed a trend towards progression, one lesion when assessed by depth was regressing, while the remainder were arrested.

2. In the second group 50 surfaces of Hong Kong dental students were monitored 6 monthly for 18 months, mean age 20.4 years. In this group they found that the majority (76% by depth,68% by area) were arrested, 9 lesions (18%) progressed, and regression was seen for three lesions (14%).

They concluded that the lesion progression was a slow process, even for children (a time of during which there is peak caries susceptibility), but especially for older individuals with low dental severity.

1.8. Rates of caries progression in deciduous teeth

As the number of reports on caries progression in deciduous teeth is even more limited it is difficult to draw valid conclusions. A survey of the literature revealed only four studies in which caries progression is monitored.

Van Erp and Meyer Jansen (1970) in a study of 100 children aged 4.5 to 6.5 years determined the caries progression rates for preselected dental caries active sites in primary molars. They found the average time taken from the first appearance of the initial lesion to the time for the lesion to involve dentine to be 7 months.

Murray and Majid (1978) monitored 310 5 to 7 year children and reported the fastest progression. Of 71 new lesions in enamel only, 69 had progressed into dentine one year later. They suggested that the apparently more rapid progression in primary teeth may be due to the fact that the enamel in permanent teeth is thicker than in primary teeth. They however suggest that the use of different criteria in the study namely the convention of considering only lesions entering the inner half of dentine could be the reason for the findings of the study. Although the children in this study were participants of a fluoride varnish trial, the treatment was found to be ineffective in reducing the caries progression.

On the other hand Craig et al. (1981) found that caries progression was slow for deciduous teeth. They monitored 54 subjects (mean age 7 years)over a period of two years. At 24 months 74% of the proximal surface lesions and 90% of the occlusal surface lesions that were in the enamel at baseline remained unchanged. These children however received fluoride application immediately prior to the study which may have been effective in altering the progression of the caries.

Shwartz et al. (1984) found that for deciduous teeth it took an average of 12 months for a lesion to progress through the outer half of the enamel in both American and Swedish children , though the Swedish children were exposed to extensive fluoride programmes. Progress through the inner enamel was however slower in the Swedish children, taking 20.5 months for the Swedish children and 9.5 months for the American children.

Pitts (1983) in a review article suggested that no firm conclusion can be drawn from the studies that monitored caries progression in deciduous teeth but that it would be prudent to assume that progression rates may be faster through the thinner enamel cap. Ekanayake (1986) similarly stated that due to the contrasting evidence it is not justified to draw any conclusions regarding the progression of caries in deciduous teeth.

1.9. Summary and Conclusions.

A number of methods have been used in the past to monitor caries progression. While the use of bitewing radiographs to monitor progression has a number of limitations it appears to be the best available diagnostic aid. The reports on the use of Image Analysis appear to be very promising but further investigation is required in that field.

There has been a wide diversity in the choice of criteria and in the methods of analysis. This diversity makes the comparison of the results of the various studies difficult. It would then seem sensible for the adoption of a basic standardised set of criteria for future studies and which would allow comparison. The criteria should be evaluated for discriminatory ability and examiner reproducibility, and this testing should form the basis of the selection procedure.

Inter and intra examiner reproducibility should be reported in studies carried out and in a manner which would allow relative importance of error due to examiner variability to be assessed more accurately. The use of measures of reproducibility for caries progression data based solely agreement/disagreement on the presence/absence of a particular state, and the failure to take into account the relative magnitude of the disagreement into to the overall measure of disagreement has to be questioned.

The diversity of methods used in the analysis of data also makes comparison difficult. Greater standardisation of these methods would facilitate meaningful comparisons. In determining the duration of time a lesion remains in a particular state a method analysis which allows for the inclusion of censored data is preferable. As the duration of time in a carious state is extremely variable between individuals and between lesion in the same individual data should be presented in terms of the distribution of the duration of time in a carious state rather than the mean duration of time.

As a lesion in an individual is not mutually independent of other lesions in that particular individual, the individual rather than the lesion should be used as the unit of measurement in comparative analysis.

In spite of the wide variations in the degree of standardidisation achieved, in the composition of study groups and in the duration of the studies, the results indicate that for the permanent dentition proximal lesions progress slowly and large numbers remain unchanged for long periods. In a number of cases there is regression of the lesion, and lesion progression can no longer be regarded as inevitable. The evidence indicates that with the decline in the incidence of caries there has been a decrease in the progression rates.

For deciduous teeth there is a paucity of information. The contrasting nature of the methodologies employed makes comparisons difficult. Due to the conflicting results of the various reports it would be unjustified to draw any conclusions regarding the progression of caries in deciduous teeth.

Table 1.1 Studies using conventions with no subdivision of enamel.

Authors	0	1	2	3	4
Walker (1931)		Enamel caries only	Caries with dentine involvement	Pulp	
Emslie (1959)	Caries free	Caries in enamel	Caries with dentine just involved	Gross dentinal caries	
Moller (1965)	Caries free	Shadow in enamel	Shadow up to ADJ	Shadow up to half way through dentine	Pulp
Backer Dirks (1966)	Caries free	Radio-lucency in enamel	Radio-lucency also in dentine	Radio-lucency half way between ADJ and pulp	Pulp
Hollander and Koch (1969)	Caries free	Caries in enamel	Caries in both enamel and dentine	Restored surface	
Berman and Slack (1973)	Caries free	Caries not reaching ADJ	Caries in enamel and just into dentine	Caries half way through dentine	More than half way between dentine and pulp
Hauge-jorden (1974)	Caries free	Caries in enamel but not reaching Adj	Caries in enamel and dentine	Secondary caries	Filled surfaces
Van Erp & Meyer-Jansen (1970) (primary teeth)	Sound	Initial lesion	Dentine caries	Filling	Extrac-tion

Table 1.2 Description of scoring codes for recording degree of radiographic proximal caries- studies where the enamel has been subdivided into two categories.

Author	0	1	2	3	4
Raper (1931)		nick in the enamel	nick in the enamel and a radiolucent zone at the DEJ	nick in the with the the zone in dentine now bellying into the dentine towards the the pulp	nick in the enamel,the perforation through the enamel and the carious process bellying well into dentine
Marthaler (1966)	No radio-lucency	Radio-lucency in in outer of enamel	Radio-lucency in inner half of enamel	Radiolucency in dentine	R/lucency in inner half of dentine
Moller & Poulsen (1973)	Enamel contour intact	Enamel contour broken, shadow less than quarter through enamel	Shadow reaching ADJ	Shadow between ADJ,not more than half dentine	Shadow more than half way through dentine
Zamir et al. (1976)		I= enamel lesion less half in enamel	E= more than half way through enamel but not in DEJ	DEJ-extending into DEJ	More than half way through dentine and pulp
Grondahl et al. (1977)(a)	Intact surface	Lesion in outer half enamel	More than half way in enamel but not ADJ	Dentine and less than half way to pulp	More than half way through pulp
Marthaler and Wiesner (1973)	No radio-lucency	Radio-lucency in in outer of enamel	Radio-lucency in inner half of enamel	Radiolucency in dentine	R/lucency in inner half of dentine
Hauge-jorden and Slack (1973)	Caries free	Less than outer half of enamel	More than half way through enamel but in ADJ	More than half way through dentine	More than half way through dentine and pulp

Table 1.2 (CONT) Description of scoring codes for recording degree of radiographic proximal caries- studies where the enamel has been subdivided into two categories.

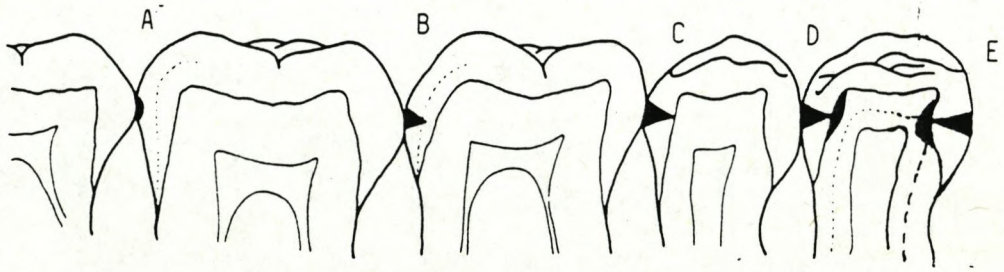
Author	0	1	2	3	4
Murray & Majid (1978)(b) (prim teeth)	No radio-lucency	Radio-lucency at least half way through enamel	Radio-lucency up to ADJ but not beyond ADJ	Radio-lucency less than half thick-dentine	Radio-lucenc more than half dentin
Granath et al. (1980)		Less than outer half enamel	More than half way through enamel but not in ADJ	Less than half way through dentine	More than half way through dentine and pulp
Powell et al. (1981)		Less than half way through enamel	More than half way through enamel but not in dentine	In dentine or and restored	
Shwartz et al. (1984)	Intact surface	Lesion outer half enamel	Lesion more than halfway enamel but not past ADJ	Lesion less than halfway through dentine	Lesion more half-way through dentine
Mejare et al. (1985)	No radio-lucency	Radio-lucency less than two-thirds enamel	Radio-lucency more than two-thirds enamel	Radio-lucency in dentine	
Ekana-yake (1986)	Intact surface	Lesion outer half enamel	Lesion more than halfway enamel but not past ADJ	Lesion less than halfway through dentine	Lesion 5 more pulp half-way through dentine
* Pitts (1984)					

Key:
* Pitts (1984) has proposed a comprehensive standardised system for grading and scoring radiographic diagnoses which is compatible with WHO recommendation for grading clinically diagnosed caries. The system makes provision for scoring surfaces which are overlapped, thus avoiding the loss of valuable data. The criteria are outlined in detail in Chapter 2.

(a) Hollander and Ronnerman(1978), Cook S.R (1984), Grondahl and Hollander (1979) same criteria as Grondahl et al.
(b) Shaw and Murray (1975 and 1986) same as Shaw and Murray(1978)

Fig 1.1

Summary of Different diagnostic criteria for grading lesion depth from bitewing radiographs. (Modified from Pitts (1983)



GRADES

A.	B.	C.	D.	E.
SMALL RADIOGRAPHIC LESION CONFINED TO OUTER HALF OF THE ENAMEL CAP	RADIOGRAPHIC LESION EXTENDING TO INNER HALF OF THE ENAMEL CAP	RADIOGRAPHIC LESION EXTENDING TO THE ADJ NO RADIOLUCENCY IN DENTINE	RADIOGRAPHIC LESION EXTENDING BEYOND THE ADJ BUT LESS THAN HALF DENTINE	RADIOGRAPHIC LESION EXTENDINC BEYOND HALF THICKNESS OF DENTINE

Conventions

Method 1:	Enamel caries = A, B, C		Dentine caries =D,E
Method 2:	Enamel caries = A, B,	ADJ= C	Dentine caries =D,E
Method 3:	Enamel caries = A, B		Dentine caries =C, D
Method 4:	Outer enamel= A Inner enamel= B, C		Outer dentine =D Inner dentine =E
Method 5:	Outer enamel= A Inner enamel= B, C	ADJ= C	Outer dentine =D Inner dentine =E
Method 6:	Outer enamel= A Inner enamel= B, C		Outer dentine =D Inner dentine =E

Note : in some studies the categories D and E in methods 4, 5, and 6 are regarded as single category (dentine caries).

Table 1.3

Published studies of inter and intra-examiner variability(*) Reproduced from Pliskin et al. (1984) with modifications.

Author(s)	Intra examiner agreement (%)	Interexaminer agreement (%)
Backer-Dirks (1951)	89 ($)	
Hollander and Koch(1969)	90	
De Paola & Alman (1972)	64-70	
Murray & Shaw (1975)	82-90	90-94
Haugejorden and Slack (1975)	83-90	
Marthaler & German (1975)		71
Murray & Majid (1978)	82	
Grondahl (1979 a)	79-80	76
Grondahl (1979 b)	70-93	
Granath et al.(1980)	86 ($)	

* Expressed as consistency ratios. Calculation of consistency ratio.

$$CR = \frac{CC}{CC+CS+SC} * 100$$

($) : Radiographic codes at each reading were determined by consultation between two dentists. Thus it is only possible to determine initial "reading group" agreement.

Table 1.4 (a) Rates of caries progression in permanent teeth. Studies with no apparent fluoride supplementation. (Reproduced from Pitts (1983) with modifications)

Author	Age at start	n	Results:1(p)* %,	S.d	interval (years)	Results:2(pl/2)+ %	S.D	interval (years)
A. No apparent fluoride supplementation								
Emslie(59)	20	50	80	2.4.	2		ND	
Backer-Dirks(66)	7	100	m. surf of perm 6's				ND	
			50	7.6	4			
			33	7.2	6			
			26	6.7	8			
Hollander & Koch (69)(++)			non-F^- control group				ND	
	10	123	49.3	2.8	3			
	10	83	50.4	3.7	3			
Berman & Slack(73)	11-13	353	52.6	2.5	3		ND	
Haugejorden & Slack (75) ($)	13-14	40	77.4	4.5	1	79.5	5.1	1
Zamir et al. (**) (1976)	20-24 & 14-15	51	77.9	4.2	2	81	4.7	2
Grondahl& Hollander (76)(L)	19	100	72.1	1.7	3	82.2	1.9	3
	16	100	35.6	1.8	6	48.5	2.3	6
Grondahl et al.(77) (L)	16	158	46.9	1.4	3	64.4	1.7	3
Granath et al.(80)	12-13	126	71.8	1.5	1	86.4	1.5	1
	12-13	126	56.8	2.5	2	71.6	2.9	2
Powell et al. (81)	12-14	102	non F^- control group 41	3.5	4		ND	

Key:
* %(+/- SD) of lesions in the enamel at the start , still confined to the enamel.
+ %(+/- SD) of lesions in the outer half enamel at the start, still confined to the enamel.
$ results form 2nd reading of radiographs.
** scoring code "dej" category added to "enamel" category.
L results from all proximal surfaces.

Table 1.4 (b) Rates of caries progression in permanent teeth. Studies with no apparent fluoride supplementation. Studies with fluoride supplementation. (Reproduced from Pitts (1983) with modifications)

Author	Age at start	n	Results:1(p)* %, S.d	interval (years)	Results:2(p1/2)+ %	S.D	interval (years)
Hollander & Koch (69) (++)	10	122	NaF dentrifice group 57.3	3.7 3		ND	
Kolehmainen Rytoma (77)(++)	10	87	NAF rinse group 61.1	3.9 3		ND	
Hollander Ronnerman(78)	21-26	59	94.3	1.8 20(mths)		ND	
Powell	10-17	109	78.5	2.9 2y2m	83.9	2.0	2y2m
	12-14	76	dentrifice alone 51	4.4 4		ND	
	12-14		dentrifice and topical 71	3.7 4		ND	
Craig et al.	7	54	primary teeth 74	5.3 2		ND	

KEY:
+ %(+/- SD) of lesions in the outer half enamel at the start, still confined to the enamel.
++ SEM calculated by the authors.

CHAPTER 2

GENERAL INTRODUCTION: EVALUATION OF DIAGNOSTIC CRITERIA USED TO MONITOR CARIES PROGRESSION

2.1 Introduction

This chapter has been written as a general introduction to the investigation described in Chapters 4 and 5. The discussion in the chapter has been subdivided into three sections, the first part will focus on outlining why there is a need to evaluate the diagnostic criteria of the scoring systems, the second part will examine the criteria that may be used to evaluate such systems and review some of the factors that appear to have been influential in the selection of the criteria, the third part will give an overview of the investigation in the following chapters.

2.2 The need for evaluation of scoring systems

The importance of information on caries progression data has been outlined in Chapter 1. Unfortunately very few studies have been carried out to monitor progression. This is understandable when one considers that caries progression studies are difficult to carry out. The difficulties stem from the fact that they are of long duration, costly, are associated with high drop out rates and there are ethical problems involved in repeated exposure of the subjects to radiation. There is therefor generally very little data available, and the problem is compounded by the diversity of methodologies

used in the various studies (discussed in detail in Chapter 1). These problems are even more acute with regard to deciduous teeth. Only 4 studies have reported progression rates for deciduous teeth. There were considerable differences in the diagnostic criteria used in the various studies, making it difficult to draw any conclusions from the data available (Pitts 1983, Ekanayake 1986).

Pitts (1984) pointed out the need to adopt standardised techniques, diagnostic criteria, and scoring systems in order to facilitate better comparability between studies of caries progression. To maximise the information that can be derived from the available data there must be greater standardisation of the methodologies, and in any such move towards standardisation evaluation of the various methodologies should play a major role. Considered in this light it is surprising that more effort has not been placed into evaluating the scoring systems that have been used.

2.3 The approaches to evaluation.

The most common parameters used and advocated to evaluate the scoring systems appears to be the level of reproducibility, the discriminatory ability of the system, and the effect this has on the results.

The importance of the use of consistent, reproducible methods in surveys of oral health of populations and in clinical trials is clearly recognised (WHO 1977, FDI 1982). In studies of caries

progression reproducibility takes on added importance as serial radiographs of individuals are examined. The inter and intra examiner reproducibility of radiological diagnosis is suspect (Pitts 1985). Errors in examiner observation can give a distorted picture of the true progression rates. Examiner variation increases the total variance, and reduces the efficiency of an epidemiological trial (Poulsen et al. 1980). Error due to examiner differences attenuates the power of the study, making the treatment effects more difficult to detect and making the population parameters more difficult to determine. The most desirable unit of measurement for a particular examiner to use has been cited by the FDI (1974) to be that which is associated with least diagnostic variability.

It has to be recognised however that while reproducibility is perhaps the major consideration in the selection of a set of diagnostic criteria it not the only consideration. Diagnostic criteria influences other parameters such as the discriminatory ability which also constitutes an important consideration. The FDI(1982) recommendations for controlled clinical trials while recognising the importance of examiner consistency stresses the importance of choosing a method that is sufficiently discriminatory to detect important treatment effects efficiently. The selection of criteria and their discriminatory ability will have a considerable impact on the results in studies of progression rates. If only broad criteria are used, information is lost and comparisons become suspect. Smaller divisions allow for further manipulation and comparison of data Pitts(1983).

The effect of the use of different scoring systems on permanent teeth was clearly demonstrated by Haugejorden and Slack (1975). Their findings indicated that on permanent teeth the use of scoring system with one degree of enamel caries, instead of two reduced by about half the percentage of lesions which appeared to have progressed during one year. It was concluded that the radiographic scoring codes with two degrees of enamel caries gave a better picture of caries progression than those with only one. Pitts (1984) in an extensive review concluded that the approach with enamel subdivision would seem to be preferable as it appears to offer the more accurate evidence of progression. It is however important to recognise that there are limits to the number of divisions, the limiting factors being examiner reproducibility and the introduction of spurious score transitions with lesions apparently progressing or regressing to different grades.

In recognising that there is a trade off between the two, a rational basis for selecting a scoring system should be to evaluate the reproducibility/discriminatory ability of different systems and on the basis of the findings select the system which would provide the most acceptable balance. While most of the studies on caries progression have reported the examiner reproducibility (reported in detail in Chapter 1) few studies have been carried out to compare the reproducibilities of different scoring systems. Furthermore studies that have been carried out to compare the reproducibilities and/discriminatory ability of different scoring systems, have been limited to permanent teeth (Haugejorden and Slack 1975, Mitropoulos et al. 1978, Howat and Brandt 1980). The

applicibility of the findings on permanent teeth to deciduous teeth (with regard to the effect on reproducibility/discriminatory ability of the use of different scales of measurement) have to be regarded with caution because of the inherent differences in the anatomical structure and radiographic appearance of the two.

Concern with regard to the effect on reproducibility appears to be the major factor in the selection of the scoring systems used in deciduous teeth. The diagnostic criteria in most of the investigations monitoring progression in deciduous teeth have considered only one category of enamel lesions (discussed in detail in Chapter 1). Only Schwartz et al.(1984) recorded two categories of enamel lesions. In the study reported by Murray and Majid (1978) although subdividing enamel into outer and inner halves, they recorded the earliest lesion as one in which the radiolucency extended at least half way across the thickness of enamel. Craig et al.(1981) cited the thinness of enamel in deciduous teeth as the reason for the not using a measurement scale for lesion penetration through enamel. As yet,however none of the scoring systems have been evaluated with regard to their use in deciduous teeth. This overriding concern with reproducibility of the scoring system when used on deciduous teeth, which while legitimate on theoretical grounds remains untested, and the findings of investigations on permanent teeth have to regarded with caution for the reasons stated above. There is therefor a need to evaluate the scoring systems with regard to their use on deciduous teeth.

2.4 Outline of the investigation.

The present investigation was designed to evaluate two scoring systems, a system proposed by Pitts (1983) (Method 1) and system based on the one used by Murray and Majid(1978)(Method 2) when used in monitoring caries progression in deciduous teeth. Pitts (1983) proposed a comprehensive standardised system for grading and scoring radiographic diagnoses which is compatible with the WHO recommendations for clinically grading caries. The system subdivides enamel, and makes provision for scoring surfaces which are overlapped, thus avoiding the loss of valuable data.

The fundamental differences between the two scoring systems is in the handling of enamel lesions and in the handling of overlapped surfaces. Method 1 allows outer and inner enamel lesions to be recorded and considered in the analysis as enamel lesions, while with Method 2 only lesions that are greater than half the depth of enamel are considered carious: lesions in the outer half of enamel being regarded as sound. With regard to the recording of overlapped surfaces with Method 1 surfaces that are overlapped up to but not beyond the amelo dentinal junction are coded as sound (provided there is no obvious dentinal caries), and there is provision for the recording of obvious caries even in the presence of overlap. With Method 2 all surfaces that are overlapped beyond half the depth of enamel are coded as unreadable due to overlap.

The evaluation of the two systems was carried out in two parts. The first part of the investigation designed to compare reproducibility, will be discussed in Chapter 4. The second part designed to compare the effect on discriminatory ability (in terms of the overall picture provided, the effect on the rate of progression and the amount of data lost) will be discussed in Chapter 5.

CHAPTER 3

MATERIALS AND METHODS

3.1 Introduction

The investigation consisted of two parts. The first part was designed to compare the reproducibility of two grading systems used in assessing caries progression. For the rest of the discussion this part of the study will be referred to as the reproducibility study (RS).

Part two was designed to compare the effect on discriminatory ability (in terms of the overall picture provided, the effect on the progression rates and the amount of data lost), using on the same material different grading systems. In the rest of the discussion this part of the study will be referred to as the progression study (PS).

3.2. Materials

3.2.1 Source of sample

The material used for the study was obtained from a 2-year investigation of the effect of Duraphat fluoride varnish on the deciduous dentition. In the trial 301 children from Chelsham, Buckinghamshire initially aged 5 years were clinically examined at 6 month intervals and bitewing radiographs were taken for each child at baseline, at the end of the first year and at the end of the second year. A half mouth technique was used , Duraphat (containing 22 ,600

ppm F) was applied to deciduous molars on one side whilst a placebo was applied to opposite side. Findings on the trials were reported by Murray et al.(1977) and Murray and Majid (1978).

For the purpose of the present study only the bitewing radiographs of a sub-sample (sampling methods outlined below) were re-examined. In the discussion below the word radiograph refers to a set (left and right) taken for a child at one of the examinations. The decision on the size of the samples for each part of the study was made on practical grounds, i.e. what was possible in the time available. The objective of the investigation was to compare two scoring systems using the same material for both systems, the effect of Duraphat was therefor of little consequence to the results of the study.

3.3. Methods

3.3.1 Sampling methods

3.3.1.1 Reproducibility study (RS)

The radiographs were selected from a sampling frame of 301 radiographs. A stratified sampling technique was used. The radiographs of each child were first divided into groups based on the time that the radiograph was taken i.e. baseline, first, or second year. The radiographs were numbered and then 50 were randomly selected from each group using random number tables and included in the sample if the radiograph was present and of reasonable quality. A total of 150 radiographs were thus examined.

3.3.1.2 Progression study

In the progression study three serial radiographs of 50 children were examined. The children were numbered and selected randomly using random number tables and included in the sample if:

1. There were three sequential radiographs.
2. The radiographs were of reasonable quality.

3.3.2 Radiographic equipment, materials and procedures.

A modified Rinn long cone attachment was used (Murray et al. 1977). The film is slotted into a plastic film holder , which slides into a groove at the front of the long cone attachment. The plastic film holder is provided with a thin wafer which extends at right angles to the film. When the Rinn long attachment is fixed to the x-ray set, and the apparatus is placed in front of the child, the film is automatically in the right position. The child then closes on the plastic wafer and the radiograph is taken (Murray and Majid 1978). The radiographs were processed under standardised conditions using a Pantomat automatic dental processor (Siemens Ltd.).

3.3.3 Aids to radiographic interpretation.

A "Magni Viewer" (x3) with an opal glass illuminated working surface of 6" x 12" was used for the interpretation of the radiographs throughout the study.

3.3.4 Conduct of the examination.

3.3.4.1 Reproducibility study.

In first part of the study 150 radiographs selected as described in 1.2.1. were examined a total of four times. Duplicate examinations were carried out for each grading system. In order to minimise the biases introduced as a result of familiarity with repeated examinations the following procedure was used.

1. The radiographs were divided into ten groups of fifteen each. Examination of the fifteen radiographs of particular group constituted one examination session.
2. The order of the examinations of the groups was carried out on random basis. Each group was allocated a number. Using random number tables a sequence of examination for the groups was established.
3. The examination of a particular group was not repeated within a period of seven days. Ideally this period should have been longer but the time constraints (in terms of the due date for the project) did not permit such an extension.
4. Alternate scoring systems were used at each session.
5. The radiographs in a particular group at each session were selected randomly using random number tables.

3.3.4.2 Progression study.

In the second part of the study fifty children with three serial radiographs were selected as described in 1.2.2. The children were numbered in the selection process, the radiographs of a particular child were labelled by the number allocated to the child followed by the suffix R1(baseline), R2(first year), or R3(second year).

Each radiograph was examined a total of two times, using the two scoring systems. In order to minimise the biases introduced as a result of familiarity with repeated examinations, and awareness of the preceding or subsequent radiographs of the same subject the following procedure was used.

1. The radiographs were first separated into six groups two groups each for baseline, first year or second year radiographs. Examination of the radiographs of a group (25 radiographs) constituted a session.
2. The baseline radiographs groups were examined first. One group was examined using the Pitt scoring system and the other group was examined using the system based on the Murray and Majid system. The groups in the first year radiographs, and the second year were similarly interpreted thereafter.
3. Once the entire set had been examined the procedure was repeated but using the alternate scoring system for each group e.g. if the Pitt system was used to examine a group the first time the Murray and Majid system was used the second time. In this way the entire set was examined using both scoring systems.
4. The radiographs in a particular group at each session were selected randomly using random number tables.

5. The examination of a particular group was not repeated within a period of seven days. Ideally this period should have been longer but the time constraints (in terms of the due date for the project) did not permit such an extension.

3.3.5 Diagnostic criteria.

One of the objectives of the study was to compare two grading systems, a system proposed by Pitts (1984), and a system based on the used by Murray and Majid (1978). The present study was based on a sub-sample of the material used in the latter report.

A score was assigned to each proximal surface of the deciduous molars according to the criteria stipulated by each scoring system. The criteria of the two scoring systems are described in further detail below:

3.3.5.1 Grading system proposed by Pitts(1984).(Method 1)

Pitts (1984) has proposed a grading system which would be compatible with WHO clinical codes. The system attempts to eradicate as many of the unspecified or ambiguous areas as possible, too minimise the loss of diagnostic information due to overlaps, and to logically subdivide the tooth surfaces so that studies of caries activity (and lesion regression) can be facilitated. The codes and the criteria are

outlined in Table 3.1 (reproduced from Pitts 1984) and the interpretation of some of the criteria is discussed in further detail below.

Recording caries .

1. R1 the outer half enamel grade has no minimum limit of lesion size.

2. The midpoint of the enamel is taken as being an imaginary line equidistant from tooth edge and the ADJ.

3. In all categories of this proposed system, where doubt exists the lower grade was assigned.

4. R1 lesions include at, but not beyond the ADJ, only those lesions which radiographically involve the dentine are scored as "dentine lesions ".

Recording overlapped and unreadable surfaces.

1. Grades R3(0) and R4(0) represent distinct dentine caries which can still be scored as such even if the enamel is overlapped .

2. The suffix (0) after the appropriate scoring code (and codes R5,R9 and R10) allows the total number of overlaps to be calculated where appropriate.

3. If the overlap is greater than half the enamel thickness, but is still confined to the enamel, and no caries is seen in dentine, grade R5 is recorded.

4. Where overlaps extend beyond the ADJ reliable diagnosis becomes more difficult and the surface is graded as R8(0) unreadable overlap.

5. Where there is a partial overlap of less than half the enamel width the inner half of enamel can still be graded. If it is carious up to but not beyond the ADJ grade R9 is awarded, if sound grade, R10 is given.

6. R6(0) and R7(0) allow filled overlapped surfaces to contribute to the overall number of overlaps.

3.3.5.2 Scoring system used by Murray and Majid.(Method 2)

The progression rate reported by Murray and Majid(1978) was more rapid than that reported by other studies carried out on deciduous teeth. An important difference in the methodologies of the studies was the use of different diagnostic criteria. Murray and Majid although subdividing enamel into two halves, recorded the earliest lesion as one in which the radiolucency extended at least half across the thickness of enamel. The report did not indicate how overlapped lesions were treated. A scoring system based on the criteria used by Murray and Majid is outlined Table 3.2.

3.3.6 Recording the data.

Scores of each radiographic examination were recorded directly onto the computer using the Psion Organiser XP, and the Numbase Version 2 statistical package. The scoring of the surfaces of the teeth was carried out in the following sequence:

1. Distal 5e.
2. Mesial 5e.
3. Distal 5d.

4. Mesial 5d.

5. Mesial 8d.

6. Distal 8d.

7. Mesial 8e.

8. Distal 8e.

9. Distal 6e.

10. Mesial 6e.

11. Distal 6d.

12. Mesial 6d.

13. Mesial 7d.

14. Distal 7d.

15. Mesial 7e.

16. Distal 7e.

Each surface was assigned a score according to the criteria outlined in 3.3.5.

3.3.7 Examiners diagnostic reproducibility.

A close check on the examiners diagnostic consistency was carried out throughout the study. This was done by randomly selecting 10% of the radiographs interpreted on one day and placing them at random among the radiographs to be examined on the next working day. As only one examiner participated only intra-examiner is relevant to the study. The methods and the findings are discussed in detail in Appendix A.

3.3.8 Analysis of the data.

The data were analysed using the computer facilities at the University of London Computer Center. The SAS statistical package was used for the data analysis.

3.3.8.1 Reproducibility Study

In order to use the individual as the unit of measurement in the calculation of reproducibility only one observation per subject should contribute to the analysis. For each individual however there were sixteen observations. By analysing results for each surface type using the individual as the unit of measurement, data from all the surfaces can be used in the analysis.

It was intended to derive Weighted Kappa values as a measure of reliability. At the present time there is no programme available to carry out such calculations, nor was there sufficient time available to write out such a programme. Following consultation with statisticians it was decided to use Kendall's Tau-b values as approximations for the Weighted Kappa as a measure of reproducibility. Kendall's Tau-b Values for the two scoring systems were estimated for each tooth surface type using the individual as the unit of measurement. A mean of all the values obtained for each surface type was taken as the indicator of the overall measure of reproducibility of the system.

The Students t test, applied to the values obtained for each surface type, was used to test for the significance of differences in reproducibility between the two systems.

3.3.8.2 Progression Study.

The data was analysed using two approaches: the surface as the sampling unit and the subject as the sampling unit.

3.3.8.2.1 Use of the surface as the sampling unit.

For Method 1 and Method 2 the following calculations were carried out:

1. Frequency matrices score transitions from:
   1.1 baseline (T1) to 12 months (T2)
   1.2 from(T1) to 24 months (T3)
   1.3 from (T2) to (T3)
   1.4 total over a 12 month period (T1 to T2 and T2 to T3)
2. The frequency distributions of score categories at T1, T2, and T3.
3. The progression of outer and enamel lesions to other score categories in terms of numbers and percentages.

3.3.8.2.2 Use of the subject as the sampling unit.

Caries progression using the subject as the sampling unit was expressed by calculating the number or the percentage of lesions that did/did not progress per subject. First subjects with enamel lesions (outer enamel and inner enamel separately) were selected. For each subject the number of of enamel lesions (outer and inner enamel

separately) present at the start of the time interval of interest were determined. Of these, the percentage per individual that progressed into various other states were determined. The mean percentage of lesions that progressed into the various states for the group was then calculated. Inner and outer enamel lesions (for Method 1) were then combined to determine the behaviour of enamel lesions on the whole.

Using the above method the analysis was carried out for the following time intervals:

1.1 baseline (T1) to 12 months (T2)

1.2 from (T1) to 24 months (T3)

1.3 from (T2) to (T3)

1.4 total over a 12 month period (T1 to T2 and T2 to T3)

3.3.8.2.3 Comparison of Method 1 and Method 2

With Method 1 outer enamel and inner enamel lesions were reported separately. In order to compare the behaviour enamel lesions when recorded in this way to the that with Method 2 the data for the outer and inner enamel lesions were combined. Statistical test were not applied to test for the significance of the differences as the number of subjects having surfaces in a particular state using the two scoring systems were different.

Table 3.1. Grading system proposed by Pitts (1983)

Code	Category	Diagnostic Criteria
R0	Sound	No radiolucency or restoration visible.
R1	Outer half enamel lesion	Zone of increased radiolucency confined to outer half of enamel.
R2	Inner half enamel lesion	Zone of increased radiolucency involving both inner and outer halves of the enamel,including lesions extending up to but not beyond the ADJ.
R3+/-(0)	Outer half dentine lesion	Zone of increased radiolucency penetrating enamel and ADJ but confined to the outer half of the dentine .(suffix 0 where surface has enamel overlapped provided radiolucency in dentine is distinct).
R4+/-(0)	Inner half dentine lesion	Zone of increased radiolucency penetrating into the inner of dentine with or without apparent pulpal involvement (suffix 0 where surface has enamel overlapped provided radiolucency in dentine is distinct).
R5	Enamel overlap (no lesion in dentine)	Overlapped surface .Overlap of more than half the thickness of the enamel but not beyond the ADJ. No zone increased radiolucency in dentine.
R6+/-(0)	Secondary caries	Zone of increased radiolucency associated with a filled surface (suffix 0 where obviously overlapped).
R7+/-(0)	Filled surface	Radiographic appearance consistent with a restoration. (suffix 0 where obviously overlapped).

Note: Table continued overleaf

Table 3.1(cont). Grading system proposed by Pitts (1983)

Code	Category	Diagnostic Criteria
R8+/-(0)	Excluded surface	Unerupted (extracted,or missing from film,(suffix 0 if unreadable overlap extending into dentine .
R9	Partial overlap: carious	Overlap of less than half the the enamel,zone of increased radiolucency in inner half of enamel including lesions extending up to but not beyond the ADJ.
R10	Partial overlap: sound	Partial overlap of less than half than half enamel thickness,no zones of increased radiolucency.

Table 3.2 Scoring system based on the one used by Murray and Majid.

Code	Category	Diagnostic Criteria
0	Sound	No radiolucency or radiolucency extending to less then half enamel width.
1	Early caries	Radiolucency extending to at least half-way across the enamel depth but not extending beyond the amelo-dentinal junction
2	Early dentine	Radiolucency extending beyond the amelo-dentinal junction up to less than half the width of dentine.
3	Gross lesion	Radiolucency extending beyond half the thickness of dentine.
5	Filled surface	
6	Excluded	Missing, unerupted, extracted or congenitally missing.
7	Overlapped	Overlap of more than half the the enamel width -unreadable.
8	Unreadible	Presumed present but not on radiograph, unreadible.
9	Sound (overlap)	Not completely readable, but presumed to be sound. Less than half of the enamel overlapped.

CHAPTER 4

COMPARISON OF THE EXAMINER REPRODUCIBILITIES OF TWO SCORING SYSTEMS.

4.1 Introduction

In Chapter 3 the criteria for evaluating scoring systems used to monitor caries progression were outlined and discussed. The first part of the investigation, designed to compare the reproducibilities of two scoring systems will be discussed in this chapter. The findings of the investigation will be preceded by a brief discussion on the shortcomings associated with traditional methods used to measure reproducibility in studies monitoring caries progression. In addition to the findings on reproducibility of the two systems, the investigation will be used to illustrate, firstly the use of the subject as the sampling unit in measuring reproducibility, and secondly, a more sensitive method of measuring reproducibility when analysing caries progression data.

4.2 Use of the individual as the sampling unit when measuring reproducibility.

Various formulae and methods have been used to report reproducibility (discussed in detail in Chapter 1). There are a number of shortcomings associated with use of these methods.

An underlying shortcoming of all the methods used has been the use of the tooth surface as an independent unit of measurement. The surface cannot be regarded as independent unit in the statistical analyses as the observer is influenced by the status of the adjacent surface. A method based on measuring reproducibility using the individual " as the unit of measurement is illustrated in this study.

4.3 Use of the Weighted Kappa as a measure of reproducibility.

Fleiss and Chilton (1983) and Hunt (1986) amongst others pointed out that the use of percent agreement and Pearson's correlation coefficient can be misleading, because they do not take into account the agreement solely due to chance. A measure of reproducibility should indicate the level of agreement achieved beyond chance.

A further shortcoming arising from the use of methods such as percentage agreement in progression studies is that in progression studies unlike prevalence studies a measure of reproducibility of a system should take into account not only disagreement but the level or magnitude of disagreement. In progression studies scores are assigned to each surface depending on the observed status. The scoring system represents multinomial categorical data. The concern in progression studies unlike that of prevalence studies is not only the absence or presence of a particular state but also severity in terms of the depth of the lesion. The measure of reproducibility should reflect the accuracy of this measurement of severity. It should thus be sensitive to consistency with regard to the status of the surface for all categories not merely the consistency in recording presence

or absence of one category. Furthermore it should incorporate certain adjustments to take into account the relative magnitude of the disagreements. Pliskin et al.(1984) reported reliability with regard to presence of a lesion as well as agreement on depth . They however used agreement ratios and reported the reliabilities of presence and depth as separate measurements making no attempt to present an overall index of reliability for the scoring system.

It is proposed that for caries progression studies in which nominal data are used the Weighted Kappa (Cohen 1968) would be a more appropriate measure of reproducibility since it allows "weights" to be assigned to varying levels of disagreement, as well as incorporating an adjustment for the degree of agreement to be expected purely on the basis of chance.

4.4 Objectives.

The objectives of the present investigation are to:

1. compare the reproducibility of Methods 1 and 2.
2. illustrate the use of the subject as unit of measurement in estimating reproducibility.
3. illustrate the use of more sensitive methods of measuring reproducibility when analysing caries progression data.

4.5 Methods

A total of 150 sets of radiographs were examined by one examiner a total of four times (duplicate examinations for each scoring system). On the basis of the duplicate examinations Kendall's Tau-B values for each surface type was derived. Students T test were applied to test for the significance of the differences between the two systems. An overall index of reproducibility for the system was derived by taking an average of the values obtained for each surface type. A more detailed account of the methods and materials used are presented in Chapter 2.

4.6 Results

The Kendall's Tau-B values and their standard errors for the individual surfaces for Method 1 and Method 2 are presented in Table 4.1. The frequency distribution of the values (rounded off to two decimal figures) is presented in the stem and feather diagram in Fig 4.1.

For Method 1 the values ranged from 1 (perfect score) to 0.85. Five surfaces had scores from .99 to 1, three surfaces had values ranging from .95 to .99, six surfaces had values ranging from .90 to .94, and three surfaces between .85 to .89.

For Method 2 the values ranged from 1 to .71. Two surfaces were in the range .99 to 1, one surface from .95 to .99, six values ranging from .90 to .94, two values ranging from .85 to .89, and one surface each for the ranges .80 to .84, .75 to .79 and .70 to .74.

The Students T test was applied to the values obtained for each surface using the two scoring systems (Table 4.2). The t value obtained was 2.06. The critical value (.05,15) is 2.13. The results thus indicated there was no significant difference at the 5% confidence ($p > 0.5$) between the two methods used. While the t test revealed no significant difference the frequency distribution of the values for each surface suggests a tendency for Method 1 to be more reproducible than Method 2.

4.7 Discussion

4.7.1 Comparison of the reproducibilities.

As outlined in Chapter 3, the selection of particular scoring system should be on the basis of an acceptable balance between discriminatory ability and reproducibility.

Method 1 by virtue of the greater number of divisions (including enamel subdivision) can be considered have the greater discriminatory ability. Haugejorden and Slack (1975) demonstrated that radiographic scoring codes with two degrees of enamel caries gave a better picture of caries progression than those with only one. Pitts (1984) in an extensive review of studies measuring caries progression concluded

that, as there appeared to be no penalty in terms of reproducibility by subdividing the enamel, this approach would seem preferable as it appears to offer more accurate evidence of progression. These observations were based mainly on the findings from studies carried out on permanent teeth. The question that needs to be answered is whether the advantages gained from the use of such a system on deciduous teeth would negated by loss of reproducibility.

The results of the present study suggests that the reproducibility of Method 1 is comparable to Method 2. The difference between the two systems was not significant at the 95% confidence level. The results in fact indicated a tendency for Method 1 to be the more reproducible. This could be explained by the fact that in calculating Kendall's Tau-B values weight is attached to the magnitude of the differences between the observations in terms of the difference in number of categories between them. With Method 1 there were a greater number of categories with result that overall weight given to consecutive categories was less.

It would in the light of the findings of the survey be reasonable to advocate the use of Method 1 for studies of progression rates in deciduous teeth. There appears to be no significant loss in terms of reproducibility and there are a number of advantages to be gained. Firstly it would allow for more meaningful comparisons to be made between different studies and secondly the use of smaller divisions allow for greater manipulation of the data and gives a better picture of the progression rates.

The methods used to measure reproducibility in this study have not been used elsewhere and thus it is not possible to compare the findings of this study with that of others. Ideally for the purpose of comparison the data would have been analysed using both the method used in this study and the more traditional methods. Unfortunately the already lengthy nature of this dissertation made this unfeasible.

4.7.2 Use of the individual as the unit measurement.

Various formula and methods have been advocated to measure reproducibility. An underlying shortcoming in the methodologies has been the use of the surface as the unit of measurement. The basic assumption of the statistical analyses applied to these measurements is that the observations are independent. The surface cannot be regarded as an independent unit of observation as the observer is invariably influenced by the status of the other surfaces on the particular individuals radiograph.

In this study reproducibility was measured using the individual as the unit of measurement. The analysis was carried out by measuring the reproducibility for each surface type, using the individual as the unit of measurement. The observations used in this way can be considered to be independent measurements, with the added advantage of being able to compare the reproducibility for each surface type. From the results it can be seen that the different surface type exhibited different reproducibilities. This is understandable when one takes into account the subtle variations in anatomical structure, the

presence/absence of adjacent surfaces and the influence of position of surface in the mouth in terms of the clarity of its radiographic appearance.

4.7.3 Use of Weighted Kappa

The methods used to measure reproducibility in caries progression studies have been outlined in Chapter 1. Their limitations were outlined in the introduction to Chapter 4.

Weighted Kappa (Cohen 1968) would appear to a more appropriate measure of reproducibility in caries progression trials. The Weighted Kappa provides for the incorporation of ratio-scaled degrees of disagreement to each of the cells of the k*k table of joint nominal scale assignments such that disagreements of varying gravity are weighted accordingly. Although providing for partial credit, Weighted Kappa is fully chance corrected. Further research is required on determining the correct weighting for the possible combinations of disagreements that may arise in a caries progression study, and on a programme which would perform the necessary calculations quickly.

It was intended to use (to) Weighted Kappa to measure reliability in the study. There is however no computer programme available at present to carry out such calculations nor was there sufficient time available to write a suitable programme. It was, following consultation with statisticians, decided to use Kendall's Tau-B values as an approximation. Kendall's Tau-b has been used for measuring association of ordinal-level data, and was recommended as being a reasonably good

approximation of Weighted Kappa. The precise methodology used in deriving, is beyond the scope of this dissertation and is therefor not discussed here.

4.8 Summary and Conclusions

The reproducibilities of two scoring systems, (one proposed by Pitts(1983) and one based on the system used by Murray and Majid (1978)) when used on deciduous teeth was measured. The analysis was carried out using the subject as the sampling unit and Kendall's Tau-B was used as an approximation of the Weighted Kappa as measure of reproducibility. The results indicated that while the Pitts method appeared to be more reliable, the difference between the two methods was not significant($p>.05$). In the light of the comparability of the two systems in terms of reproducibility the greater discriminatory ability of the Pitts scoring would suggest that it would be the more useful scoring system to use for future studies monitoring caries progression in deciduous teeth.

The shortcomings in taking the surface as the independent sampling unit in measuring reproducibility have been highlighted, and a method using the individual as the sampling unit has been illustrated. Attention has been drawn to the need to develop a measure of reproducibility for progression studies which would take into account the magnitude of the disagreement (instead of just disagreement) into the overall index of reproducibility. The use of Weighted Kappa is suggested as being perhaps a more appropriate measure of reproducibility since it allows 'weights' to be attached to various

levels of disagreements. More research is required to develop a programme that would be able to carry out such analysis and the designation of appropriate weights to the various disagreements that may arise in studies monitoring caries progression.

FIG 4.1 STEM AND FEATHER DIAGRAMME FOR KENDALL'S TAU-B VALUES FOR METHOD 1 AND METHOD 2.

METHOD 2		METHOD 1
0 0	1.	0 0 0 0 0
5	.9	6 7 7
4 4 4 2 2 0	.9	0 1 2 2 4 4
8 7	.8	5 6 8
4	.8	
9	.7	
1 1	.7	

TABLE 4.1 KENDALL'S TAU-B VALUES FOR INDIVIDUAL SURFACES

Kendall's Tau-b

SURFACE	METHOD 1	SE	METHOD 2	SE
D5E	1.00	.000	1.000	.000
M5E	.883	.033	.942	.025
D5D	.956	.018	.935	.027
M5D	.858	.079	.839	.088
D6E	1.000	.000	.708	.249
M6E	.908	.028	.923	.030
D6D	.969	.010	.958	.019
M6D	.937	.061	.708	.136
M8D	.998	.002	.875	.087
D8D	.974	.009	.919	.023
M8E	.924	.030	.903	.037
D8E	.912	.082	.866	.125
M7D	.847	.037	.786	.130
D7D	.937	.036	.942	.020
M7E	.924	.029	.954	.025
D7E	1.000	.000	1.000	.000
AVERAGE	.939		.891	
SD	.050		.091	

TABLE 4.2 STUDENTS T TEST FOR METHOD 1 AND METHOD 2

Kendall's Tau-b

SURFACE	METHOD 1	METHOD 2	DIFFERENCE
D5E	1.00	1.00	1.00
M5E	.883	.942	-.059
D5D	.956	.935	.021
M5D	.858	.839	.019
D6E	1.00	.708	.292
M6E	.908	.923	-.015
D6D	.969	.958	.011
M6D	.937	.708	.229
M8D	.998	.875	.123
D8D	.974	.919	.055
M8E	.924	.903	.021
D8E	.912	.866	.046
M7D	.847	.786	.061
D7D	.937	.942	-.005
M7E	.924	.954	-.030
D7E	1.00	1.00	0.00
AVERAGE	.939	.891	.048
SD	.050	.091	.093
SE			.023
T VALUE			2.059

t(.05,15=)2.13 t(.001,15)=4.07

CHAPTER 5

COMPARISON OF THE DISCRIMINATORY ABILITY OF TWO SCORING SYSTEMS

5.1 Introduction

The criteria for evaluating a scoring system, namely reproducibility and discriminatory ability were outlined in Chapter 3. The findings of Chapter 4 indicated the two scoring systems were comparable in terms of reproducibilities. In this chapter an investigation designed to compare the discriminatory ability of the two systems when used on deciduous teeth will be discussed. The discriminatory ability of the systems will be considered on the basis of the overall picture they provide, the effect on progression rates, and the amount of data lost as a result of recording surfaces as overlapped. The effect on progression rates and the overall picture provided by the use of different scales of measurement has been discussed in detail in Chapter 3. The effect on the amount of data lost and the consequences of such loss in terms of the findings of the study will be outlined below. In addition the use of the subject as the sampling unit in monitoring caries progression will be discussed and illustrated in the analysis of this part of the investigation.

5.2 Loss of data due to unreadibility.

In radiographic studies there would always be a loss of information due to overlapping of proximal surfaces and surfaces missing from the film. The criteria used in recording overlap, the reports on

unreadibility of the various studies, and the problems associated with loss of data due to overlap has been dealt with in detail in Chapter 1. The major problem with exclusion of overlapped surfaces is that if a proportion of data is lost at each survey of a trial the data loss is likely to be compounded as the overlapped surfaces are not the same on all occasions (McDonald 1983).

In the comparison of the methods there were two major differences between the methods with regard to the recording of overlapped surfaces. Method 1 allowed surfaces that had more than half the enamel overlapped but no radiolucency in dentine to be recorded as sound, while with Method 2 surfaces with more than half the enamel overlapped were recorded as overlapped. Method 1 also included scoring codes for quantifying the degree of overlap and which allowed the recognition of obvious caries in the presence of an overlap. In this investigation an effort will be made to assess the amount of data lost due to overlap using the two systems.

5.3 Use of the subject as the unit of analysis.

The methods used to analyse caries progression data have been reviewed in detail in Chapter 1. Most of the studies on caries progression have considered the lesion as the sampling unit. Ekanayake (1986) pointed out the inappropriateness of the use of the lesion as independent sampling units. The oral environment and other influences to which the surfaces in the mouth of a particular individual are exposed means that the lesions in the mouth are related and cannot be regarded as independent units of measurements.

The number of subjects who show/do not show progression has seldom been reported in terms of progression of lesions per subject. Subjects may differ in their tendency to develop caries. There is evidence that caries progression may be related to the intensity of caries attack in an individual. Granath et al.(1980), Grondahl et al.(1984), and Ekanayake (1986) found that the progression of caries is significantly higher in subjects with high caries intensity than in subjects with low caries intensity. Individual surfaces in any one subject cannot be considered as providing independent pieces of information. The error of using the wrong sampling unit (i.e. in dental research counting each tooth as if it gave an independent piece of information) was called "spurious enlargement of samples ", or "counting the same thing over again" by Mainland (1963).

Many of the statistical analyses are based on the assumption that the underlying observations are independent. The application of these analyses using the surface as the sampling unit has to be considered as incorrect. Ekanayake(1986) used Mainlands argument that since individual teeth in a mouth do not provide individual pieces of information in dental caries studies the proper sampling units should be children and not the teeth or the lesions. Data should thus be presented according to the number of children with/ without caries or a finer measurement could be the number of teeth or lesions per subject. In this investigation the data was analysed using both approaches, the surface and the subject as the sampling unit.

5.4 Objectives

The objective of the present investigation are to:

1. Compare the scoring system proposed by Pitts and a system based on the one used by Murray and Majid in terms of the following parameters:

1.1 The overall picture they provide on the development of carious lesions in deciduous teeth.

1.2 The effect on progression rates of deciduous teeth.

1.3 The amount of data lost as a result of being recorded as unreadable.

2. Illustrate the use of the subject as the sampling unit in the analysis of caries progression data.

5.5 Methods

The methods and materials used in this part of the study are described in detail in Chapter 2.

5.6 Results

The results were analysed for time intervals baseline(T1) to 12 months(T2), from baseline to 24 months (T3), and from 12 months to 24 months. The data for T1-T2 and T2-T3 were pooled as representative for 12 month period and references to "12 month period" below refers to this pooled data. The data for T1-T3 represented the 24 month period.

5.6.1 Using the surface as the sampling unit

On close examination it was found that the patterns that emerged using the two methods (using the surface and subject as the sampling unit) were similar. In order to avoid duplication only the results of analysis using the subject as the sampling unit will be discussed as statistically it represents the more acceptable method. An outline of the analysis carried out using the surface as the sampling unit is given below and the results are presented in Appendix B.

5.6.1.1. The distribution of score categories at baseline, 12 months and 24 months are presented in Table B.1 for Method 1, Table B.2 for Method 2, and Table B.3 for a comparison of the two methods.

5.6.1.2. The numbers of the tables presenting the frequencies for the transitions of the surface scores for the various time intervals are indicated below. The time interval under consideration is in the first column, the number of the table for Method 1 in the second column, and the number of the table for Method 2 in the third column.

Time interval	Method 1 Table	Method 2 Table
T1-T2	B.4	B.8
T2-T3	B.5	B.9
12 months(a)	B.6	B.10
T1-T3	B.7	B.11

(a) Data for T1-T2 and T2-T3 combined.

5.6.1.3. The numbers of the tables presenting data on the progression of surface categories, sound, outer enamel, inner enamel and all enamel (outer and inner combined) is indicated below. The surface category is indicated in the first column, the table containing the data for Method 1 in the second column, for Method 2 in the third column, and the comparison of the two methods in the fourth column.

Surface category	Method 1 Table	Method 2 Table	Comparison (Method 1 and 2) Table
Sound	B.12	B.13	B.14
Outer enamel	B.15		
Inner enamel	B.16		
All enamel	B.17	B.18	B.19

5.6.2. Analysis using the subject as the sampling unit.

The method used to analyse the data using the individual as the sampling unit has been discussed in detail in Chapter 2. Basically the subjects having surfaces in the state of interest at the start of a particular time interval were selected. For each subject the number of surfaces in the state of interest were calculated. The percentages for transitions to other states at the end of the interval were calculated, and the average percentage for the transitions were determined for the group.

5.6.2.1 Comparison of the distribution of surface score categories per subject at baseline, 12 months and 24 months.(Table 5.1)

A large proportion of the surfaces were sound 75% (Method 1) and 72% (Method 2) at T1. The proportion of sound surfaces decreased to 67% and 67% at T2, and 57% and 52% at T3 for Method 1 and 2 respectively.

The main difference between the two methods was in the proportion of surfaces per subject recorded as being having enamel lesions and the number of surfaces recorded as being unreadable due to overlap . For Method 1 the percentage of enamel lesions per subject were 8% (T1 and T2), 3% (T3). For Method 2 the value was 3% at T1, T2 and T3. The overall percentage of enamel lesions recorded with Method 1 was much higher. A similar situation was found with regard to overlapped surfaces. For Method 1 the percentage of surfaces per subject recorded as being unreadable due to overlap were 7%(T1),

and 8% for T2 and T3. The corresponding percentages for Method 2 were 13%, 13% and 22%. In general a greater percentage of surfaces were recorded as being unreadable using Method 2.

(A more detailed breakdown of the data for distribution of surface score categories at baseline, 12 months and 24 months is presented in Table 5.2 (Method 1) and 5.3 (Method 2)).

5.6.2.2 Comparison of the transitions in sound surfaces.

Comparisons of the progression of sound surfaces for the two methods are presented in Table 5.4. There were 50 subjects with at least 1 sound surface for both methods at 12 and 24 month intervals. The mean percentage of surfaces per subject which remained sound 12 months later were 76% for Method 1, 69% for Method 2. The percentages were lower after 24 months, 69%for Method 1 and 61% for Method 2. For both intervals Method 1 showed the greater proportion of surfaces as having remained sound. The mean percent per subject of surfaces that progressed form sound to decayed after 12 months was low: 4% for Method 1 and 2% for Method 2 progressed to enamel, 2% and 3% to outer dentine correspondingly. After 24 months 5% and 3% progressed to enamel, and 5% for Method 1 and 2 progressed to dentine.

The frequency distribution of the subjects according to the number the percentage of sound surfaces that remained confined to enamel is presented in Table 5.12. For Method 1 in 50% of the subjects more than 80% of the sound surfaces remained confined to enamel 12 months

later and in 98% of the subjects more than 60% of the surfaces that were sound remained confined to enamel. For Method 2 the corresponding figures were 30% and 80%.

The frequency distribution of the subjects according to the percentage of sound surfaces that progressed to dentine or were filled 12 months later is presented in Table 5.13. In 98% of the subjects for Method 1 and 96% with Method 2 less than 21% of the surfaces had progressed to dentine or been filled within a 12 month period.
(A more detailed breakdown of the data on the progression of sound surfaces is presented in Table 5.5 for Method 1 and Table 5.6 for Method 2).

5.6.2.3 Comparison of the progression of enamel lesions.

The grading system with Method 1 allowed enamel lesions to be subdivided into those being less then half the depth of enamel and those greater than half the depth of enamel. The behaviour of the these lesions separately will be discussed first, and then combined to give an overall picture of the progression of enamel lesions.

5.6.2.3.1 Progression of outer enamel lesions. (Table 5.7)

Over a 12 month period, of subjects who had at least one outer enamel lesion at the start (N=32), an average of 25% of the lesions per subject regressed, 22% remained in enamel, 26% progressed to

inner enamel, 10% progressed to dentine, and 4% had been filled. An average of 73% of the lesions per subject had thus not progressed beyond dentine.

At the end of 24 months (N=25), an average of 28% per subject of the lesions present at the start had regressed, 16% remained in outer enamel, 10% progressed to inner enamel, 22% progressed to dentine and 15% had been filled. Overall 54% of the lesions did not progress beyond dentine, the proportion being lower than for the 12 month period. The proportion of lesions that had been filled increased from 4% after 12 months to 15% after 24 months.

5.6.2.3.2 Progression of inner enamel lesions (Table 5.8)

The progression of the inner enamel lesion appeared to be much faster. Twenty seven subjects had at least one inner enamel lesion at the start of the period. At the end of 12 months an average per subject of 7% had regressed to outer enamel, 27% remained in inner enamel, 39% progressed to outer dentine, 1% to inner dentine, and 15% had been filled. Overall 34% of the lesions per subject had not progressed to dentine over a 12 month period.

The corresponding figures for the 24 month interval were 11% having regressed to outer enamel, 18% remaining in inner enamel, 20% progressing to outer dentine, and 48% being filled. At the end of 24 months an average 29% of inner enamel lesions per subject remained confined to enamel.

5.6.2.3.3 Comparison of the progression of enamel lesions using Method 1 and Method 2. (Table 5.9)

In order to compare the results for progression of the enamel lesions using the two methods the outer enamel and inner enamel lesions of Method 1 were combined to form one category of enamel lesions. This gave an overall picture of the enamel lesions using this method.

For the 12 month period there were 38 (Method 1) and 29 (Method 2) subjects with enamel lesions at the start of the period. At the end of the period an average per subject of 16% and 18% of the lesions had regressed, 43% and 18% remained in enamel, 22% and 31% progressed to outer dentine, 8% and 19% had been filled for Method 1 and 2 respectively. An average of 60% (SE 7.43)of the lesions per subject (Method 1) remained confined to enamel while the figure for Method 2 was only 37% (SE 8.45). There was also a large difference in the mean proportion of lesions per subject that had progressed to dentine or been filled, 30.44% (SE 5.52) for Method 1, and 50% (SE 9.72) for Method 2.

For the 24 month period there were 30 (Method 1) and 20(Method 2) subjects with enamel lesions at the start of the interval. An average per subject of 19% and 24% had regressed, 24% and 15% remained in enamel, 24% and 13% progressed to dentine, and 25% and 38% had been filled for Method 1 and 2 respectively. An average per subject of 43%(SE 9.47) for Method 1, and 39% (SE 12.29) for Method 2 remained confined to enamel. The figure for the mean proportion that

progressed to dentine or had been filled was 49% (SE 8.85) for Method 1 and 51%(SE-12.5) for Method 2. There was therefor a closer correlation between the two methods for the 24 month data.

(A more detailed breakdown of the data on the progression of the enamel lesions is presented in Table 5.7 and 5.8 (Method 1), and 5.11(Method 2).

The frequency distribution of the subjects according to the percent of lesions per subject that remained confined to enamel is presented in Table 5.14 In 39% (Method 1) and 20% (Method 2) of the subject over 80% of the lesions had not progressed 12 months later, and in 50% (Method 1) and 34% (Method 2) of the subjects over 61% of the lesions had not progressed.

The frequency distribution of the subjects according to the percent of lesions per subject that had progressed over a 12 month period is presented in Table 5.15. In 50% (Method 1) and 34% (Method 2) of the subjects up to 20% of the lesions had progressed. Only in 11% of the subjects with Method 1 had more than 80% of the lesions progressed while the corresponding figure for Method 2 was 34%.

5.6.2.4 Comparison of the proportion of surfaces recorded as unreadable due to overlap.

The proportion of unreadable surfaces was consistently higher for Method 2 when compared to that with Method 1 . The average percent of surfaces per subject that were unreadable due to overlap were 7%

and 13% at baseline, 8% and 13% at 12 months, and 8% and 22% at 24 months for Method 1 and 2 respectively (Table 5.1). An average of 12% (Method 1) and 18%(Method 2) of lesions that were sound at the beginning of the 12 month interval could not be monitored because of overlap, and the corresponding figures for 24 month interval were 15% and 22% for Methods 1 and 2 respectively (Table 5.4).

5.7 Discussion

5.7.1 The use of the subject as the sampling unit

The results were analysed using both the surface as well as the subject as the unit of analysis. As the pattern of results obtained were similar for the two scoring systems only the results using the subject as the unit of analysis will be discussed.

While the patterns of results obtained were similar there are number of advantages with using the subject as the sampling unit. In using the subject as the unit of analysis the underlying observations are mutually independent and therefor satisfy the underlying assumptions of many of the statistical analyses. Secondly the use of the subject as the unit of analysis gives a better picture of the distribution of the subjects according to their progression rates (Tables 5.14 and 5.15). The results indicated that for Method 1 in 42% of the subjects none of the enamel lesions progressed, and in 40% of the subjects between 80-100% of the enamel lesions remained confined to enamel after 12 months. The presentation of such frequency distributions would be especially useful in identifying the size of the high risk population (i.e. those individuals in whom there is a high percentage

of lesions that progressed). In the investigation with Method 1 in only 11% of the subjects did 80-100% of the enamel lesions progress after 12 months. It would thus appear that the number of high risk individuals is small, and that the progression rates in the majority of the individuals was slow.

5.7.2 Comparison of the two the two scoring systems.

The difference between the two systems will be discussed in terms of the overall picture they provide of the development of carious lesions, their effect on caries progression rates, and the effect on amount of data lost on account of unreadibility due to overlap. Finally the implications of the findings of this study in terms of the findings of other studies reporting caries progression rates in deciduous teeth will be discussed.

5.7.2.1 Overall picture of the development of carious lesions.

Method 1 appeared to provide a much better overall picture of caries development than Method 2. By taking into consideration outer enamel and inner enamel lesions a greater number of subjects with enamel lesions were identified and also larger number of enamel lesions were detected. Thirty at T1, 32 at T2, subjects were identified as having at least one enamel lesion for Method 1 (Table 5.10), the corresponding figure for Method 2 were 20 and 22 (Table 5.11). The percentage of enamel lesions per subject at T1 and T2 were 8% and 3%, 6% and 3% at T3 (Table 5.1). The proportion of enamel lesions recorded were thus consistently higher using Method 1.

Method 1 allowed the progression of outer and inner enamel lesions to be considered separately. The results indicate that the progression rates of the two categories of lesions varies considerably and emphasises the need to make a distinction between the two. The progression rates of outer enamel lesions is much slower as would be expected, an average of 73% per subject having remained confined to enamel after 12 months, and only 14% having progressed to dentine or been filled. Over 24 months, 54% were still found to be confined to enamel, while 37% had progressed to dentine or been filled (Table 5.7). With inner enamel lesions an average of only 34% per subject had remained confined to enamel, 55% having progressed to dentine or been filled after 12 months and 29% remaining in enamel and 68% having progressed to dentine or been filled after 24 months (Table 5.8). The difference in the progression between the categories is logical when one considers that a greater proportion of inner enamel lesions would be expected to progress into dentine simply of the ground that they are closer to dentine.

From the above discussion it would be reasonable to conclude that Method 1 by virtue of the fact that it allows the recording of the disease process at an earlier stage, and is more sensitive to the various stages of the disease process provides a more complete overall picture of the of the carious process.

5.7.2.2 The effect on progression rates.

For the purpose of comparing the progression rates as determined by the two methods the outer and enamel lesions in Method 1 were combined to form one category of enamel lesion. The two major considerations in terms of dental public health planning and treatment planning of caries progression rates are the time it takes for caries to develop in a sound surface and progress to dentine, and the time taken for a lesion established in enamel to progress to dentine. The discussion will thus focus on these two parameters of caries progression. In terms of the analysis used in this investigation these parameters are expressed as the mean percentages per subject that remained in the same state or progressed to some other state of interest at the end of given period. Whilst the use of survival analysis and other methods used to analyse progression data offer certain advantages (discussed in detail in Chapter 1) the brief of this investigation was to compare two methods, and for that purpose the analytic methods used were considered to be adequate.

The development and progression of caries to dentine from sound surfaces appeared to be more rapid with Method 2, the percentage of surfaces remaining confined to enamel being lower and the percentage progressing to dentine or being filled was higher. The average percent per subject of surfaces that remained sound (or confined to enamel) after 12 months was 72% (SE 2.47), and after 24 months 63% (SE 2.83). The corresponding figures for Method 1 were 80% (SE 2.52) and 73% (SE 3.09). The average percent per subject that had progressed to dentine or been filled after 12 months for Method 2

was 5% (SE .83), and 9% (SE 1.53) after 24 months. The corresponding figures for Method 1 were 3% (SE .68) and 7.2% (SE 1.53) (Table 5.4). The difference in the progression rates using the two methods was also reflected in the frequency distributions of the subjects according to proportion of lesions that progressed/did not progress.

The difference in the results between the two methods was more striking when considering the progression of enamel lesions. The average percent per subject of lesions that had remained in enamel after 12 months was 60% (SE 6.08) for Method 1, and 36% (SE 7.63), for Method 2. The average percent per subject that progressed to dentine or were filled was 30% (SE 5.52) for Method 1 and 50% (SE 9.72) for Method 2. The differences between the two methods were less prominent when considering the figures for the 24 months interval. This could be due to the fact that there were a greater proportion of more advanced lesions at that stage and which could thus be recorded using the criteria of Method 2 ((Table 5.1). The frequency distribution of the subjects according to proportion of lesions that had progressed/not progressed showed similar patterns. Over the 12 month period in 39% using Method 1, and only 20% using Method 2, of the subjects more than 80% of the lesions per subject did not progress. Over the same time interval in 50% for Method 1, and only 34% for Method 2, of the subjects less then 20% of the lesions progressed to dentine or were filled.

The obvious explanation for the discrepancy in the proportions of surfaces/lesions found to have progressed or not using the two systems is the exclusion of the outer enamel lesions when using Method

2. The difference in the rate of progression of outer and enamel lesions is clearly demonstrated by the results and has been discussed above. A smaller proportion of outer enamel lesions would be expected to have progressed over a given time interval. In the analysis the percent of lesions progressing per subject were calculated and then the overall mean was calculated. By excluding the outer enamel lesions two biases are introduced: firstly the percent of lesions found to have progressed per subject will be higher, secondly the subjects that have only outer enamel lesions are excluded from the analysis. The combination of these biases favour overestimating the proportion of lesions deemed to have progressed.

5.7.2.3 Loss of data due to unreadibility.

The need to minimise the loss of data due to unreadibility and the consequences of losing data in this manner has been outlined in the introduction. The major difference between the two systems with regard to the recording of overlapped surfaces has also been outlined in the introduction.

In the comparison of the methods there were two major differences with regard to the recording of overlapped surfaces. Method 1 allowed for surfaces that had more than half the enamel overlapped but no radiolucency in dentine as sound to be recorded as sound , while with Method 2 surfaces with more than half the enamel overlapped were recorded as overlapped. Method 1 had the added advantage of including scoring codes that quantify the degree of overlap and which allowed the recognition of obvious caries in the presence of an overlap.

The effect of the two systems on the number of surfaces excluded because of overlap is clearly demonstrated by the results. The proportion of surfaces regarded as unreadable was consistently higher for Method 2 when compared to Method 1. The average proportion of surfaces per subject regarded as unreadable due to overlap was 7% for Method 1, and 13% for Method 2 at baseline, 8% and 13% at 12 months, and 8% and 22% at 24 months.

The amount of data lost as a result of exclusion due to overlap must be considered in the context of the effect of such exclusion on the overall results. Haugejorden (1974) showed that the exclusion of all overlapped surfaces can have a misleading effect on the results of a clinical trial, by demonstrating an apparently greater percentage reduction of caries in test group of between 2 and 12% solely due to restricting the calculations to non-overlapped surfaces. Pitts (1983) has pointed out that a dramatic reduction in the number of surfaces available for a study would affect the significance of the results.

From the findings of the study it would be reasonable to conclude that with regard to the recording of overlapped surfaces Method 1, by avoiding the unnecessary loss of valuable data offers some advantages over Method 2.

5.7.3 Implications of the findings of the study in terms of the findings of other studies.

Murray and Majid (1978) reported that of 71 newly initiated lesions diagnosed as 'enamel only' 69 had progressed into the dentine 1 year later, and this remains the fastest progression rate reported in the dental literature. They suggested that the apparently more rapid progression found in their study may be due to the fact that caries progresses faster in deciduous teeth than in permanent teeth because the enamel cap is thicker on permanent teeth. A further possible reason for the finding in the study of relatively fast rate of progression was ascribed to the use of slightly different criteria in the study.

The progression rates reported in the study are however faster than that reported by other studies monitoring progression in deciduous teeth. Craig et al.(1981) reported that after 24 months 74% of lesions remained in primary enamel. These children had however received fluoride applications immediately prior to the study which may have been effective in altering the progression of caries. Schwartz et al.(1984) reported that it took an average of 12 months for lesions to progress through outer enamel, in both American and Swedish children although the Swedish children were exposed to extensive fluoride programmes. Progression through the inner enamel was however slower in the Swedish children, taking 20.5 months for the Swedish children and 9.5 months for the American children. Whilst the findings of Van Erp and Meyer-Jansen (1970) also indicated fast progression rates, (94% of the incipient enamel lesions had

lesions had progressed into dentine in 12 months or less), their study was designed to determine the rate of progression for pre-selected caries active sites, and therefor a faster progression is expected. It is unlikely that the exceptionally fast progression rates reported in the study by Murray and Majid was due to anatomical differences of deciduous teeth.

The findings of the present investigation indicated that there were more surfaces/lesions that were deemed to have progressed in a given time interval when using the system used by Murray and Majid compared to when using the Pitts system. In the light of these findings it would appear that the latter explanation, namely the use of different diagnostic criteria, was the major factor for the fast progression rates determined in the study by Murray and Majid (1978).

As stated earlier the objective of the investigation was not to describe rates of progression for a defined population but to compare the effect on progression rates in deciduous teeth of the use of different scales of measurement. Conclusions cannot therefor be drawn with regard to progression rates for deciduous teeth. It can however be stated that Murray and Majid (1978), because of the methodologies used, may have overestimated the progression rates in deciduous teeth.

5.8 Summary and Conclusions

The investigation was designed, firstly, to compare two scoring systems, a system proposed by Pitts (Method 1) and a system based on the one used by Murray and Majid (Method 2), and secondly, to illustrate the use of the subject as the sampling unit.

The primary differences between the two systems were:

1. The recording of two categories of enamel caries with Method 1 while with Method 2 only lesions that were greater than half the depth of enamel were recorded as being carious.
2. The recording of overlapped surfaces. Method 1 allowed the surfaces that were overlapped up to but not beyond the amelo-dentinal junction (ADJ) to be recorded as sound. With Method 2 all surfaces overlapped beyond half the depth of enamel were recorded as unreadable. Method 1 also made provision for the recording of obvious caries even in the presence of overlap.

The findings of the investigation lead to the following conclusions:

1. Method 1 by virtue of the fact that it allows the recording of the disease process at an earlier stage, and is more sensitive to the various stages of the disease process, provides a more complete overall picture of the of the carious process. The behaviour of outer and inner enamel lesions were shown to differ considerably and Method 1 allowed the behaviour of these lesions to be considered separately.

2. The progression rates were found to be faster with the scoring system of Method 2. This was explained on the ground that Method 2 by excluding outer enamel lesions introduced two biases: firstly the percent of lesions found to have progressed per subject will be higher, secondly the subjects that have only outer enamel lesions are excluded from the analysis. The combination of these biases favour overestimating the proportion of lesions deemed to have progressed.

3. The reason for the exceptionally fast progression rates reported by Murray and Majid (1978) most probably due to the scoring system they used. The use of such a scoring system could have lead to an over-estimation of the progression rate in deciduous teeth.

4. The use of Method 2 may lead to the unnecessary loss of valuable data. More surfaces were excluded as being unreadable because of overlap with Method 2. In this regard Method 1 appears to offer some advantages.

5. The use of the subject as the unit of analysis offers a number of advantages when compared to the use of the surface as the unit of analysis. It satisfies the conditions of many statistical analyses in that the underlying observations are independent. Secondly it provides information on the distribution of subjects on the basis of their progression rates. The findings of the study indicate that the proportions of high risk subjects (subjects in whom a large proportion of lesions progressed in a given time period) was low.

TABLE 5.1 THE MEAN PERCENT OF SURFACE SCORES PER SUBJECT AT BASELINE(T1), 12 MONTHS(T2), AND 24 MONTHS (T3) FOR METHODS 1 AND 2.

	T1		T2		T3	
	M1	M2	M1	M2	M1	M2
S	74.50	71.50	67	66.75	57.13	52.13
E	8.25	3.25	7.63	3.25	6.13	2.63
OD	5.50	5.50	5.75	5.50	6.25	5.13
ID	0.75	0.75	0.88	0.75	1.25	1.00
F	1.50	1.50	6.51	6.50	2.50	10.00
O	7.00	13.38	8.00	13.38	7.50	22.13
X	2.50	2.88	4.25	0.62	5.13	7.00

KEY:

S SOUND, E ENAMEL, OD OUTER DENTINE, ID INNER DENTINE,

F FILLED, O OVERLAPPED, X EXCLUDED.

M1-METHOD 1, M2-METHOD 2.

TABLE 5.2 THE MEAN NUMBER OF SURFACE SCORES PER SUBJECT AT BASELINE (T1), 12 MONTHS (T2) AND 24 MONTHS (T3) (METHOD 1)

SURFACE	T1		T2		T3	
SCORE	N	%	N	%	N	%
S	11.92	74.50	10.72	67.00	9.14	57.13
OE	0.84	5.25	0.66	4.13	0.44	2.75
IE	0.48	3.00	0.56	3.50	0.54	3.38
OD	0.88	5.50	0.92	5.75	1.00	6.25
ID	0.12	0.75	0.14	0.88	0.20	1.25
SD	0.12	0.75	0.22	1.38	0.40	2.50
F	0.12	0.75	0.82	5.13	1.20	7.50
E	0.40	2.50	0.68	4.25	0.82	5.13
O	1.12	7.00	1.28	8.00	2.26	14.13

KEY:
S SOUND, OE OUTER ENAMEL, IE INNER ENAMEL, OD OUTER DENTINE,
ID INNER DENTINE, SD SECONDARY DECAY, F FILLED,
E EXCLUDED, O OVERLAPPED.
N NUMBER OF SUBJECTS.

TABLE 5.3 THE MEAN NUMBER OF SURFACE SCORES PER SUBJECT AT BASELINE (T1), 12 MONTHS (T2) AND 24 MONTHS (T3) (METHOD 2)

SURFACE	T1		T2		T3	
SCORE	N	%	N	%	N	%
S	11.44	71.50	10.68	66.75	8.34	52.13
EN	0.52	3.25	0.52	3.25	0.42	2.63
OD	0.88	5.50	0.96	5.50	0.82	5.13
ID	0.12	0.75	0.14	0.75	0.16	1.00
F	0.24	1.50	1.04	1.50	1.60	10.00
M	0.12	0.75	0.12	0.75	0.40	2.50
O	2.14	13.38	2.04	13.38	3.54	22.13
X	0.34	2.13	0.50	2.13	0.72	4.50

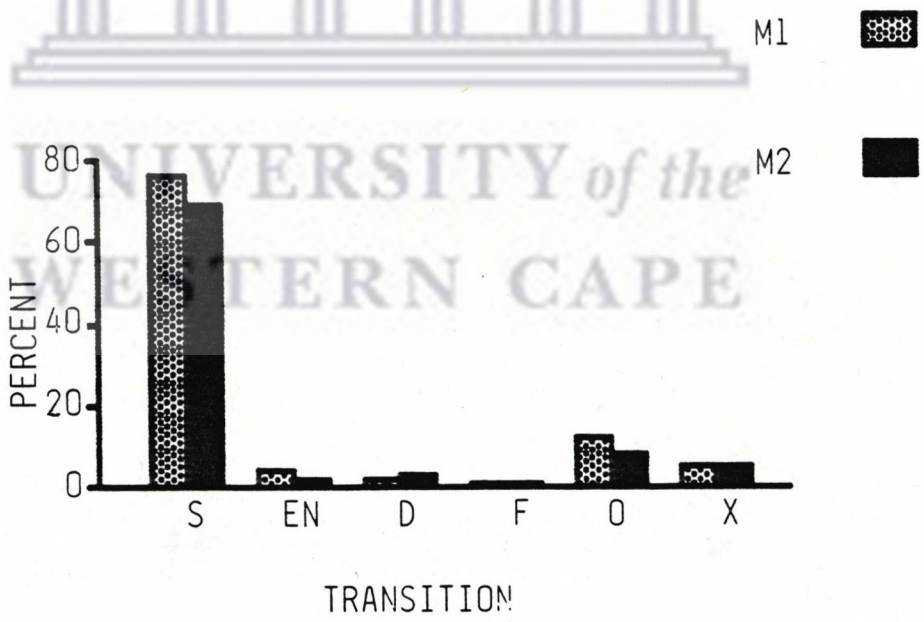
KEY: S SOUND, O ENAMEL, OD OUTER DENTINE, INNER DENTINE
F FILLED, MISSING, O OVERLAPPED, X EXCLUDED.

TABLE 5.4 THE MEAN PERCENT PER SUBJECT FOR TRANSITIONS OF SOUND SURFACES USING METHODS 1 AND 2.

	12 MONTHS				24 MONTHS			
	M1 N=50		M2 N=50		M1 N=50		M2 N=50	
	MEAN	SE	MEAN	SE	MEAN	SE	MEAN	SE
S	75.60	2.41	69.33	2.41	68.58	2.91	60.56	2.71
E	3.97	0.74	2.35	0.53	4.54	1.03	2.95	0.84
OD	2.04	0.47	3.13	0.71	4.60	1.01	4.55	1.08
ID	0.00	0 .5	0.21	0.14	0.13	0.13	0.42	0.30
F	1.22	1.47	1.52	0.41	2.47	0.88	4.01	1.06
O	11.92	2.08	17.83	1.89	14.57	2.31	21.69	2.31
X	5.21	2.09	5.61	2.08	4.92	1.36	5.67	1.14
RE	79.57	2.52	71.68	2.47	73.12	2.83	63.51	2.43
PD	3.26	0.68	4.85	0.83	7.20	1.35	8.98	1.53

KEY:
RE- SOUND SURFACES NOT HAVING PROGRESSED BEYOND ENAMEL,
PD- SOUND SURFACES HAVING PROGRESSED TO ENAMEL OR BEEN FILLED.
FOR OTHER CODES SEE TABLE 5.1

FIG. 5.1 THE PERCENT OF SOUND SURFACES PER SUBJECT THAT PROGRESSED/DID NOT PROGRESS OVER 12 MONTHS.



KEY: S Sound, EN Enamel, D Dentine,

O Overlapped, X Excuded.

TABLE 5.5 MEAN PERCENT PER SUBJECT FOR TRANSITIONS OF OF SOUND SURFACES (METHOD 1)

		12 MONTHS MEAN	SE	24 MONTHS MEAN	SE
S	(A)	79.60	2.96	68.57	2.91
	(B)	73.60	2.74		
	(C)	75.63	2.41		
OE	(A)	2.57	0.74	1.51	0.54
	(B)	1.30	0.52		
	(C)	2.06	0.53		
IE	(A)	1.40	0.49	3.03	0.87
	(B)	2.39	0.85		
	(C)	1.91	0.51		
OD	(A)	1.90	0.68	4.60	1.01
	(B)	2.30	0.70		
	(C)	2.04	0.46		
ID	(A)	0.00	0.00	0.13	0.13
	(B)	0.00	0.00		
	(C)	0.00	0.00		
SD	(A)	0.00	0.00	0.44	0.26
	(B)	0.26	0.25		
	(C)	0.11	0.11		
F	(A)	1.67	0.78	2.03	0.84
	(B)	0.34	0.34		
	(C)	1.11	0.51		
E	(A)	3.71	2.16	4.92	1.35
	(B)	4.92	1.41		
	(C)	5.21	2.09		
O	(A)	9.12	1.98	14.75	2.31
	(B)	14.87	2.30		
	(C)	11.93	1.46		

KEY:
S SOUND, OE OUTER ENAMEL, IE INNER ENAMEL,OD OUTER DENTINE, ID INNER DENTINE, SD SECONDARY DECAY, F FILLED, E EXCLUDED, O OVERLAPPED.
(A) T1-T2, (B) T2-T3 (C) T1-T2 AND T2-T3 COMBINED .
N=50 FOR ALL INTERVALS

TABLE 5.6 MEAN PERCENT PER SUBJECT FOR TRANSITIONS OF SOUND SURFACES (METHOD 2)

		12 MONTHS MEAN	12 MONTHS SE	24 MONTHS MEAN	24 MONTHS SE
S	(A)	75.42	3.27	60.56	2.70
	(B)	66.17	2.90		
	(C)	69.33	2.41		
EN	(A)	2.91	0.76	2.95	0.83
	(B)	1.86	0.80		
	(C)	2.35	0.53		
OD	(A)	3.72	0.93	4.55	1.08
	(B)	1.72	0.84		
	(C)	3.13	0.70		
ID	(A)	0.00	0.00	0.42	0.29
	(B)	0.43	0.30		
	(C)	0.21	0.14		
F	(A)	1.37	0.51	4.01	1.06
	(B)	1.54	0.65		
	(C)	1.52	0.41		
M	(A)	0.00	0.00	1.07	0.63
	(B)	1.20	0.73		
	(C)	0.52	0.35		
O	(A)	12.66	2.27	21.69	2.30
	(B)	22.28	2.61		
	(C)	1.83	0.89		
X	(A)	3.88	2.38	4.61	1.04
	(B)	4.78	1.06		
	(C)	5.09	2.05		

KEY:
S-SOUND, EN-ENAMEL, OD-OUTER DENTINE, ID-INNER DENTINE, F-FILLED, M-MISSING, O-OVERLAPPED, X-EXCLUDED.
(A) T1-T2 (B) T2-T3 (C) T1-T2 AND T2-T3 COMBINED
N=50 FOR ALL INTERVALS

TABLE 5.7 MEAN PERCENT PER SUBJECT FOR TRANSITIONS OF OUTER ENAMEL LESIONS (METHOD 1).

TRANSITION		12 MONTHS MEAN	12 MONTHS SE	24 MONTHS MEAN	24 MONTHS SE
S	(A)	26.80	8.65	28.00	8.70
	(B)	16.67	6.98		
	(C)	24.94	6.53		
OE	(A)	28.10	8.58	16.00	6.27
	(B)	31.57	9.61		
	(C)	21.61	5.83		
IE	(A)	24.10	7.57	10.00	5.77
	(B)	20.17	8.69		
	(C)	26.14	6.54		
OD	(A)	12.13	5.05	22.00	7.11
	(B)	5.26	3.61		
	(C)	10.00	3.87		
ID	(A)	0.00	0.00	0.00	0.00
	(B)	0.00	0.00		
	(C)	0.00	0.00		
SD	(A)	0.00	0.00	7.33	4.52
	(B)	0.00	0.00		
	(C)	0.00	0.00		
F	(A)	4.80	2.80	8.27	3.94
	(B)	2.63	2.63		
	(C)	4.27	2.27		
E	(A)	4.00	4.00	2.00	2.00
	(B)	5.26	5.26		
	(C)	6.25	4.35		
O	(A)	0.00	0.00	6.40	4.57
	(B)	18.42	8.27		
	(C)	6.77	3.97		

KEY: SEE TABLE 5.5
(A) T1-T2, N=25
(B) T2-T3, N=19
(C) T1-T2 AND T2-T3 COMBINED, N=32

TABLE 5.8 MEAN PERCENT PER SUBJECT FOR TRANSITIONS OF INNER ENAMEL LESIONS (METHOD 1).

TRANSITION TO		12 MONTHS MEAN	12 MONTHS SE	24 MONTHS MEAN	24 MONTHS SE
S	(A)	0.00	0.00	0.00	0.00
	(B)	0.00	0.00		
	(C)	0.00	0.00		
OE	(A)	7.84	6.08	11.76	8.05
	(B)	8.69	6.01		
	(C)	6.70	3.23		
IE	(A)	44.11	11.24	17.64	9.53
	(B)	23.89	8.75		
	(C)	27.10	7.51		
OD	(A)	21.56	8.40	20.59	8.76
	(B)	42.75	10.09		
	(C)	38.89	8.02		
ID	(A)	1.96	1.96	0.00	0.00
	(B)	0.00	0.00		
	(C)	1.23	1.23		
SD	(A)	0.00	0.00	2.94	2.94
	(B)	8.69	6.01		
	(C)	5.55	4.07		
F	(A)	12.74	7.22	45.09	11.32
	(B)	12.31	6.31		
	(C)	9.32	3.26		
E	(A)	5.88	5.88	1.96	1.96
	(B)	0.00	0.00		
	(C)	3.70	3.70		
O	(A)	5.88	5.88	0.00	0.00
	(B)	4.34	4.35		
	(C)	7.40	5.14		

KEY:

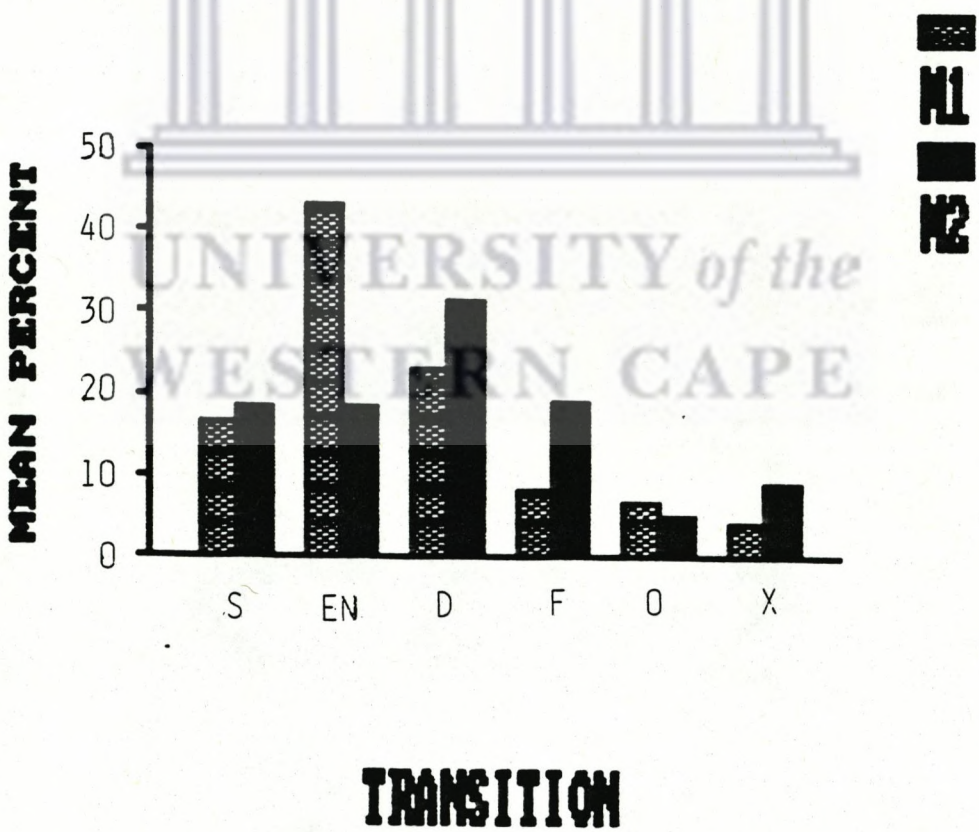
SEE TABLE 5.6
(A) T1-T2, N=17
(B) T2-T3, N=23
(C) T1-T2 AND T2-T3 COMBINED, N=27

TABLE 5.9 THE MEAN PER SUBJECT OF TRANSITIONS OF ENAMEL LESIONS USING METHODS 1 AND 2.

	12 MONTHS				24 MONTHS			
	M1 N=38		M2 N=29		M1 N=30		M2 N=20	
	MEAN	SE	MEAN	SE	MEAN	SE	MEAN	SE
S	16.43	4.80	18.39	6.04	19.44	6.54	24.16	9.17
E	43.10	5.66	18.39	5.91	23.89	6.86	15.00	8.19
OD	22.40	4.95	31.03	7.48	23.89	6.17	12.50	7.14
ID	0.53	0.53	0.00	0.00	0.00	0.00	0.00	0.00
F	7.51	2.20	18.97	6.22	25.22	6.34	38.33	10.27
O	6.30	3.39	4.60	3.60	5.33	3.82	10.00	6.88
X	3.68	2.81	8.86	5.13	2.22	1.54	0.00	0.00
RE	59.53	6.08	36.78	7.63	43.33	8.13	39.16	12.29
PD	30.44	5.36	50.00	8.05	49.11	7.90	50.83	12.50

KEY: SEE TABLE 5.4

FIGURE 5.2 PERCENT OF ENAMEL LESIONS PER SUBJECT THAT PROGRESSED/DID NOT PROGRESS OVER 12 MONTHS



KEY : See Fig. 5.1

TABLE 5.10 MEAN PERCENT PER PATIENT FOR TRANSITIONS OF INNER AND OUTER ENAMEL (COMBINED) LESIONS (METHOD 1).

TRANSITION TO		12 MONTHS MEAN	12 MONTHS SE	24 MONTHS MEAN	24 MONTHS SE
S	(A)	20.11	6.94	19.44	6.54
	(B)	7.29	3.17		
	(C)	16.43	4.80		
EN	(A)	49.67	7.5	23.89	6.86
	(B)	43.23	7.71		
	(C)	43.10	5.66		
OD	(A)	15.67	4.73	23.89	6.17
	(B)	26.82	7.1		
	(C)	22.44	4.95		
ID	(A)	1.11	1.11	0.00	0.00
	(B)	0.00	0.00		
	(C)	0.53	0.52		
SD	(A)	0.00	0.00	6.94	3.83
	(B)	4.17	3.26		
	(C)	1.69	1.36		
F	(A)	6.77	3.07	18.28	5.05
	(B)	7.03	3.53		
	(C)	5.82	1.74		
E	(A)	3.33	3.33	2.22	1.54
	(B)	3.13	3.12		
	(C)	3.68	2.80		
O	(A)	3.33	3.33	5.33	3.82
	(B)	8.33	4.49		
	(C)	6.30	3.39		

KEY: S SOUND, OE OUTER ENAMEL, IE INNER ENAMEL, OD OUTER DENTINE, ID INNER DENTINE F FILLED, SD SECONDARY DECAY, E EXCLUDED, O OVERLAPPED.

(A) T1-T2, N=30
(B) T2-T3, N=32
(C) T1-T2 AND T2-T3 COMBINED, N=38.

TABLE 5.11 MEAN PERCENT PER PATIENT FOR TRANSITIONS OF ENAMEL LESIONS (METHOD 2).

		12 MONTHS MEAN	SE	24 MONTHS MEAN	SE
S	(A)	22.50	9.23	24.17	9.17
	(B)	13.63	6.27		
	(C)	18.39	6.04		
EN	(A)	24.17	8.41	15.00	8.19
	(B)	18.18	7.74		
	(C)	18.39	5.91		
OD	(A)	23.33	9.39	12.5	7.14
	(B)	34.09	10.07		
	(C)	31.03	7.48		
ID	(A)	0.00	0.00	0.00	0.00
	(B)	0.00	0.00		
	(C)	0.00	0.00		
F	(A)	25.00	9.24	38.3	10.27
	(B)	18.18	8.41		
	(C)	18.97	6.21		
M	(A)	0.00	0.00	0.00	0.00
	(B)	4.54	4.54		
	(C)	3.45	3.45		
O	(A)	0.00	0.00	10.00	6.88
	(B)	9.09	6.67		
	(C)	4.60	3.59		
X	(A)	5.00	5.00	0.00	0.00
	(B)	2.27	2.27		
	(C)	5.17	3.80		

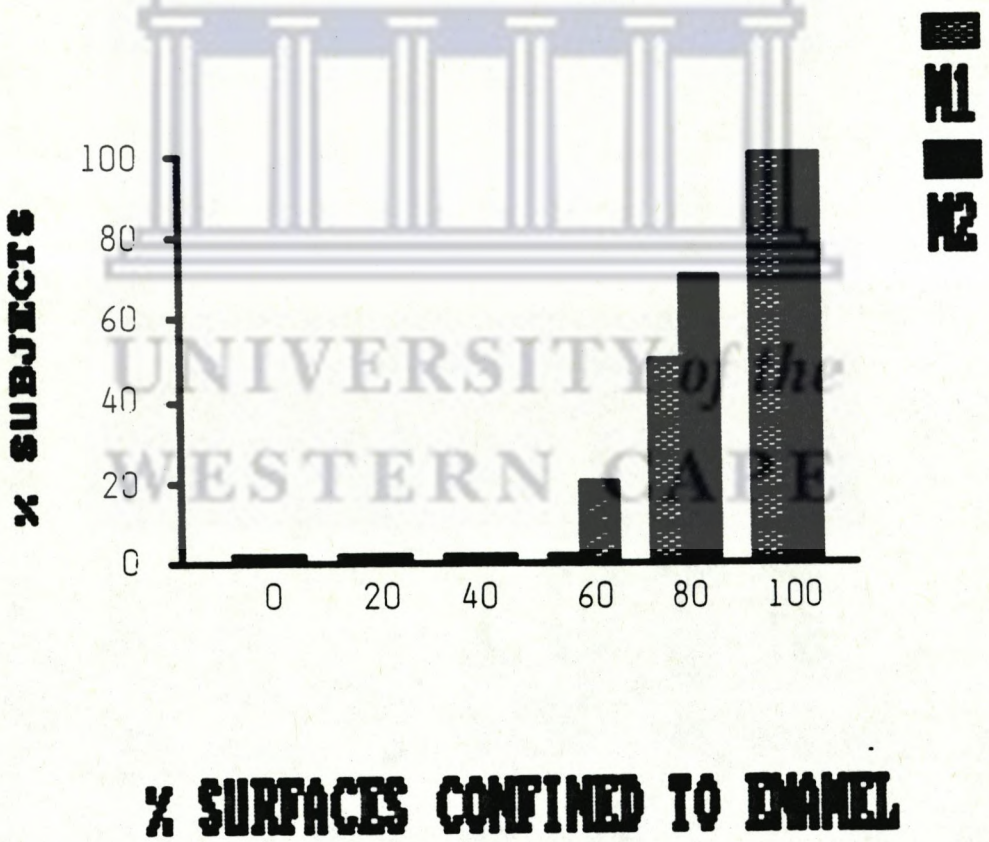
KEY S-SOUND, EN-ENAMEL, ID INNER DENTINE, F FILLED, M-MISSING, O-OVERLAPPED, X-EXCLUDED
(A) T1-T2, N=20
(B)-T2-T3, N=22
(C) T1-T3 N=20

TABLE 5.12 CUMULATIVE FREQUENCY DISTRIBUTION OF SUBJECTS ACCORDING TO PERCENTAGE OF SOUND SURFACES THAT REMAINED CONFINED TO ENAMEL.

A*	12 MONTHS				24 MONTHS			
	M1		M2		M1		M2	
	N	%	N	%	N	%	N	%
0	1	2	1	2	0	0	0	0
1-20	0	2	1	2	0	0	0	0
21-40	0	2	10	20	6	12	4	8
41-60	0	2	10	20	13	26	20	40
61-80	25	50	35	70	26	52	39	76
81-100	50	100	50	100	50	100	50	100

A* PERCENTAGE SURFACES THAT REMAINED CONFINED TO ENAMEL.

FIGURE 5.3 CUMULATIVE FREQUENCY DISTRIBUTION OF SUBJECTS ACCORDING TO THE PERCENTAGE OF SOUND SURFACES THAT REMAINED CONFINED TO ENAMEL (12 MONTHS).



Key : X Axis: 0 : 0%
20 : 1-20%
40 : 21-40%
60 : 41-60%
80 : 61-80%
100: 81-100%

TABLE 5.13 CUMULATIVE FREQUENCY DISTRIBUTION OF SUBJECTS ACCORDING TO THE PERCENTAGE OF SOUND SURFACES THAT PROGRESSED TO DENTINE OR WERE FILLED.

	12 MONTHS				24 MONTHS			
A*	M1		M2		M1		M2	
	N	%	N	%	N	%	N	%
0	32	64	26	52	29	58	27	54
1-20	49	98	48	96	43	86	40	80
21-40	50	100	50	100	50	100	50	100

A* PERCENT SURFACES THAT PROGRESSED TO DENTINE/FILLED.

FIGURE 5.4 CUMULATIVE FREQUENCY DISTRIBUTION OF SUBJECTS ACCORDING TO THE PERCENTAGE OF SOUND SURFACES THAT PROGRESSED TO DENTINE OR WERE FILLED (12 MONTHS).

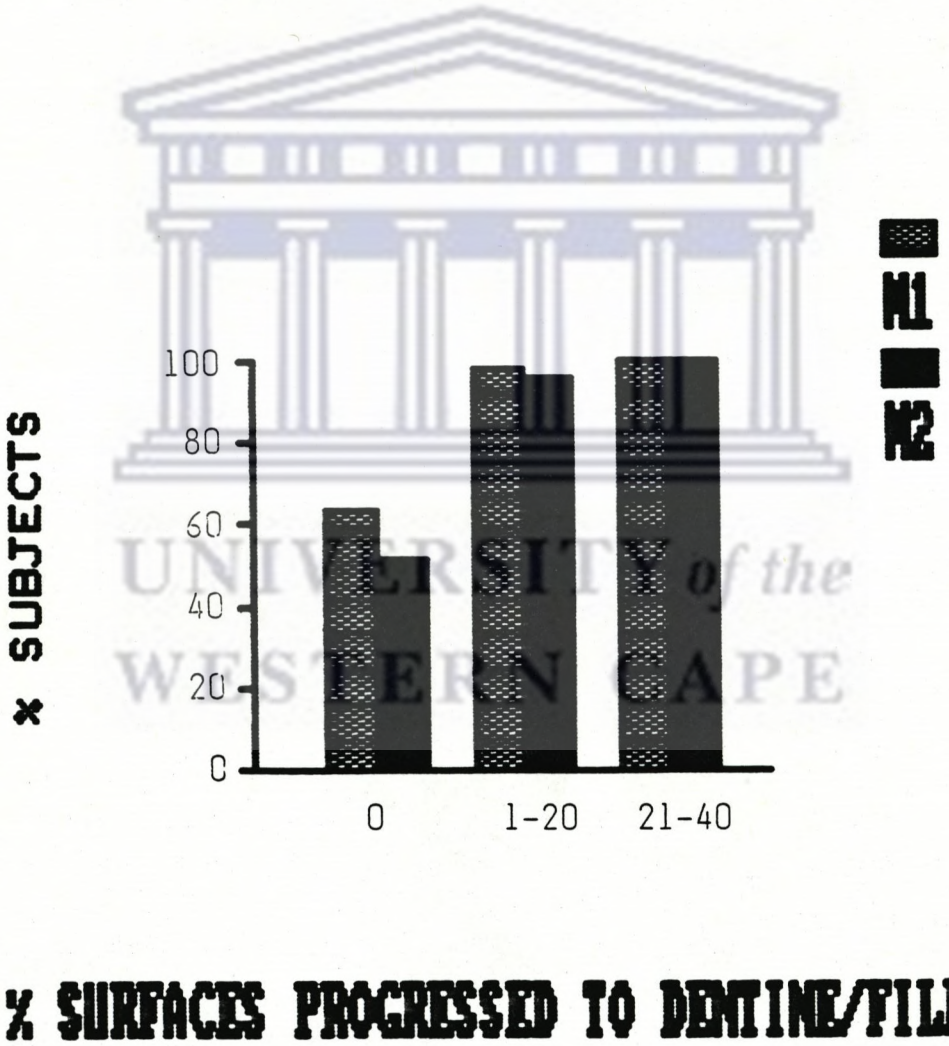
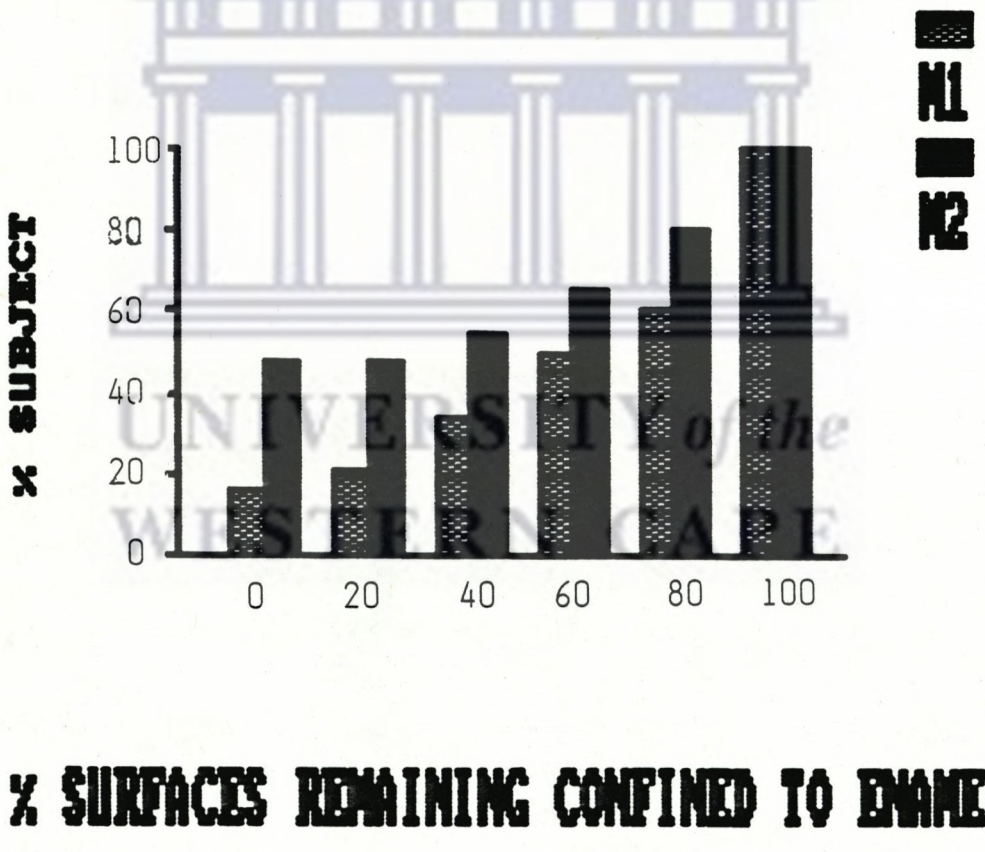


TABLE 5.14 CUMULATIVE FREQUENCY DISTRIBUTION OF SUBJECTS ACCORDING TO THE PERCENTAGE OF ENAMEL LESIONS REMAINED CONFINED TO ENAMEL.

A*	12 MONTHS				24 MONTHS			
	M1		M2		M1		M2	
	N	%	N	%	N	%	N	%
0	6	16	14	48	13	43	11	55
1-20	8	21	14	48	13	43	11	55
21-40	13	34	16	55	17	56	12	60
41-60	19	50	19	65	19	63	13	65
61-80	23	61	23	80	20	66	13	65
81-100	38	100	29	100	30	100	20	100

A* PERCENTAGE OF LESIONS REMAINING IN ENAMEL.

FIGURE 5.5 CUMULATIVE FREQUENCY DISTRIBUTION OF SUBJECTS ACCORDING TO THE PERCENTAGE OF ENAMEL LESIONS REMAINED CONFINED TO ENAMEL.



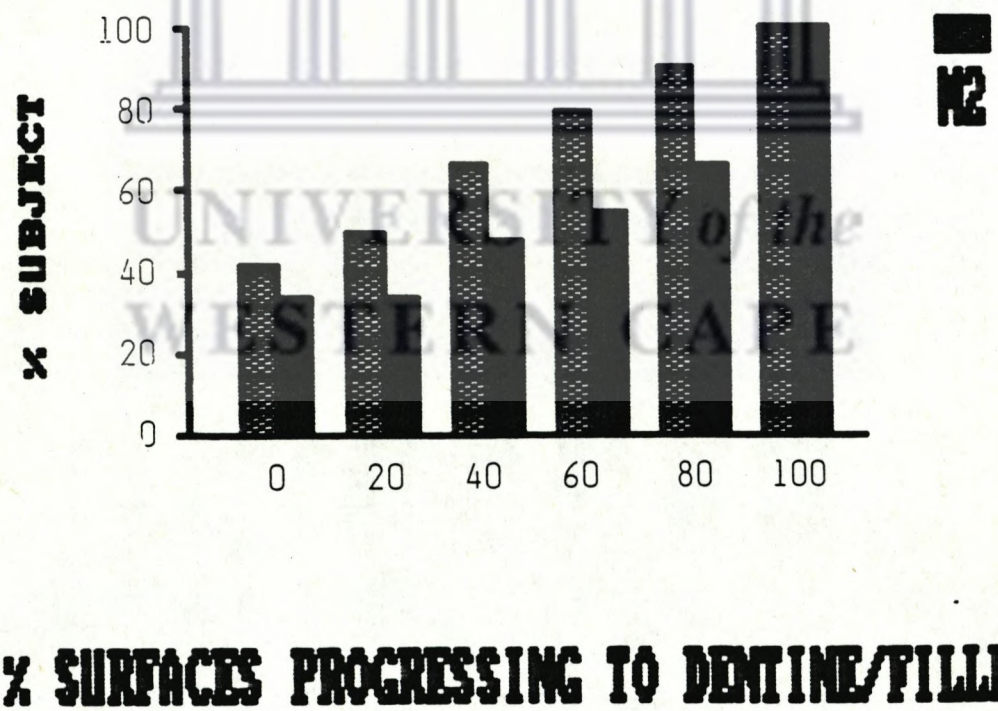
Key X:axis See Fig. 5.3

TABLE 5.15 FREQUENCY DISTRIBUTION OF SUBJECTS ACCORDING TO THE PERCENTAGE OF ENAMEL LESIONS THAT PROGRESSED TO DENTINE OR WERE FILLED.

A*	12 MONTHS				24 MONTHS			
	M1		M2		M1		M2	
	N	%	N	%	N	%	N	%
0	16	42	10	34	11	37	18	40
1-20	19	50	10	34	11	37	18	40
21-40	25	66	14	48	14	47	18	40
41-60	30	79	16	55	16	54	19	45
61-80	34	90	19	66	20	67	20	50
81-100	38	100	29	100	30	100	30	100

A* PERCENT ENAMEL LESIONS THAT PROGRESSED.

FIGURE 5.6 FREQUENCY DISTRIBUTION OF SUBJECTS ACCORDING TO THE PERCENTAGE OF ENAMEL LESIONS THAT PROGRESSED TO DENTINE OR WERE FILLED.



APPENDIX A

EXAMINERS RELIABILITY IN THE DETECTION AND CODING THE EXTENT OF CARIES ON RADIOGRAPHS DURING THE STUDY.

A.1 Introduction

The importance of the use of consistent, reproducible methods in surveys and in clinical trials is clearly recognised (WHO 1977, FDI 1982), and has been discussed in detail in Chapters 1 and 3. Backer Dirks et al.(1951) commented on the fact that in many of the clinical studies the authors never prove the reproducibility of the methods used. Without a measure of the reproducibility of the methods used it would be difficult to determine whether the statistical differences are due to the factor which was varied in the experiment or due to a statistical difference in the diagnosis. Murray and Shaw (1975) pointed out that if examiner variability cannot be maintained within reasonable limits, then the choice of an examiner could be just as important as the choice of the test substance. It was with these considerations in mind that a check on the overall reliability to detect and record the level of caries penetration was carried out throughout the study.

A.2 Methods

The reliability of the examiner throughout the investigation was monitored by randomly selecting 10% of the radiographs that had been interpreted during one day and placing them among the radiographs to

be examined on the next working day. For the Reproducibility Study a total of 60 radiographs were re-examined (30 each for Methods 1 and 2). For the Progression Study 30 radiographs were re-examined (15 each for Methods 1 and 2).

While the reproducibility for the main study was expressed using Kendall's Tau-B as an estimation of Weighted Kappa, for this part of the study the reproducibility is expressed using the more traditional methods in order to allow comparisons with the findings of other studies.

The reliability for detecting caries was expressed according to the reproducibility ratio (FDI, 1974).

Reproducibility ratio= A/B

A- no. of surfaces with disagreement as to caries

B- no. of surfaces consistently diagnosed as caries

Agreement as to the extent of penetration of lesions was evaluated using the agreement ratio (Pliskin et al. 1984).

Agreement ratio= C/D

C- no. surfaces with complete agreement of caries extent

D- Total no. of surfaces recorded for that category.

The use of the above formulas have been discussed in detail in Chapter 1. The results were summarised in matrix form, with the rows representing the rows representing the scores of the first examination, and the columns the score of the second examination. Score changes from carious to overlapped were excluded from the analysis. The main study was carried out in two parts: a study comparing reproducibility (Reproducibility Study Chapter 3) and an investigation to determine the effect on progression rates of the use of different scoring systems (Progression Study Chapter 4). In each part of the study two scoring systems were used, one proposed by Pitts (1983)(Method 1) and the other based on a system used by Murray and Majid (1978)(Method 2). The examiners overall reliability will thus be presented in terms of the reliability for the reproducibility study (Method 1 and 2 separately) and the progression study (Method 1 and 2 separately). A more detailed account of the methods is presented in Chapter 2.

A.3 Results

The results for the two methods (separately) are summarised in the tables below. The results for the reliability in detecting the presence of caries expressed in terms of the Reproducibility Ratio is presented in Table A1. The results for the reliability in recording depth, expressed in terms of the Agreement Ratio is presented in Table A2.

A.4 Discussion

Shaw and Murray (1975) reviewed the reproducibility ratios reported in various investigations and cited the range to be from .06 to .6. The Reproducibility Ratios with respect to detection of caries in the present investigation ranged form .11 to .17, and falls within the range reported in other investigations. Data related to the errors associated with recording the extent of penetration of caries is very limited. Pliskin et al.(1984) reported intra examiner agreement on depth of lesion to range from 64% to 84%, while inter-examiner agreement on depth to range form 59% to 76%. Ekanayake (1986) reported intra-examiner agreement ratios ranging from 57% (for outer enamel lesions) to 100% (for inner dentinal lesions). Mileman et al. (1983) used a different approach to determine the reproducibility on assessing depth. They determined the agreement of nine dental teachers on the presence and the depth of lesions using a validated form. The mean intra-examiner agreement associated with recording caries in each third of enamel was less than 40% and less for dentinal lesions less than 70%. Pitts and Renson reported on the reproducibility of computer aided image analysis derived estimates of depth and area of radiolucencies in proximal enamel. They reported that the average reliability coefficients ranged from .82 to .96. The findings of the latter two studies are not comparable to the findings of the present investigation because of differences in the methodologies used.

The Agreement Ratios obtained in the present investigation ranged from 59% (for outer enamel lesions) to 100%. The values obtained thus appear to be within the range reported by other investigations.

A.5 Summary and conclusions

Intra-examiner reproducibility was monitored throughout the study by re-examining 10% of the radiographs on the following working day. The reproducibility was expressed using methods used in other investigations in order to facilitate comparisons of the findings. The reliability for detecting caries was expressed according to the reproducibility ratio (FDI, 1974). Agreement as to the extent of penetration of lesions was evaluated using the agreement ratio (Pliskin et al. 1984). The Reproducibility Ratios with respect to the detecting the presence of caries ranged from .11 to .17, and the Agreement Ratios with regard to agreement on depth lesion ranged from 59% to 100%. These values are within the range of values reported by other investigations.

Table A1. REPRODUCIBILITY RATIOS (for detecting caries).

	N	A	B	RR
Rep. Study				
Method 1	30	10	66	.15
Method 2	30	8	56	.14
Prog. Study				
Method 1	15	6	35	.17
Method 2	15	4	28	.11

Key:
N- Number of radiographs re-examined.
A- no. of surfaces with disagreement as to caries.
B- no. of surfaces consistently diagnosed as caries.
RR- reproducibility ratio (A/B).

Table A2. AGREEMENT RATIO (FOR RECORDING DEPTH).

	C	D	AR(%)	C	D	AR(%)
METHOD 1						
OUTER ENAMEL	10	16	63	17	29	59
INNER ENAMEL	6	10	60	11	18	61
OUTER DENTINE	9	12	75	24	33	72
INNER DENTINE	4	4	100	5	7	86
METHOD 2						
ENAMEL	7	11	64	13	20	65
OUTER DENTINE	11	14	78	24	32	75
INNER DENTINE	2	2	100	5	5	100

C- no. surfaces with complete agreement of caries extent
D- Total no. of surfaces recorded for that category.
AR(%) Agreement Ratio (expressed in percent)

APPENDIX B
ANALYSIS OF CARIES PROGRESSION DATA USING THE THE SURFACE AS THE SAMPLING UNIT

TABLE B.1 METHOD 1: DISTRIBUTION OF SURFACE SCORE CATEGORIES AT BASELINE (T1), 12 MONTHS (T2) AND 24 MONTHS (T3) (POOLED DATA).

	T1		T2		T3	
	N	PERCENT	N	PERCENT	N	PERCENT
SOUND	596	75	536	67	457	57
OE	42	5	33	4	22	3
IE	24	3	28	4	27	3
OD	44	6	46	6	50	6
ID	6	1	7	1	10	1
F	6	1	11	1	20	3
SD	6	1	41	5	60	8
E	20	3	34	4	41	5
O	56	7	64	8	113	14

KEY: OE- OUTER ENAMEL; IE- INNER ENAMEL; OD- OUTER DENTINE; ID- INNER DENTINE; F- FILLED; SD- SECONDARY DECAY; E- EXCLUDED; O- OVERLAPPED.

TABLE B.2 METHOD 2: DISTRIBUTION OF SURFACE SCORE CATEGORIES AT BASELINE (T1), 12 MONTHS (T2) AND 24 MONTHS (T3) (POOLED DATA).

	T1		T2		T3	
	N	PERCENT	N	PERCENT	N	PERCENT
SOUND	572	72	534	67	417	52
IE	26	3	26	3	21	3
OD	44	6	48	6	41	5
ID	6	1	7	1	8	1
F	12	2	52	7	80	10
M	6	1	6	1	20	3
O	107	13	102	13	177	22
X	27	3	25	3	36	5

KEY: OE- OUTER ENAMEL; IE- INNER ENAMEL; OD- OUTER DENTINE; ID- INNER DENTINE; F- FILLED; X- MISSING,UNERUPTED,EXTRACTED; O- OVERLAPPED; X-PRESUMED PRESENT BUT NOT ON RADIOGRAPH.

TABLE B.3 COMPARISON OF THE DISTRIBUTIONS (%)OF SCORE CATEGORIES USING METHOD 1 AND METHOD 2.

	T1		T2		T3	
	M1	M2	M1	M2	M1	M2
S	75	72	67	67	57	52
E	8	3	8	3	6	3
OD	6	6	6	6	6	5
ID	1	1	1	1	1	1
F	2	2	6	7	11	10
O	7	13	8	13	14	22
E	7	4	4	4	5	8

TABLE B.5 METHOD 1 DISTRIBUTION OF TRANSITIONS IN SCORE CATEGORIES FROM 12 MONTHS (T2) TO 24 MONTHS(T3)

		T3								
		0	1	2	3	4	6	7	8	80	TOTAL
	0	399	7	11	12	0	1	1	23	82	536
	1	7	9	5	2	0	0	1	2	7	33
	2	0	2	6	13	0	2	4	0	1	28
	3	0	0	0	16	4	5	15	3	3	46
T2	4	0	0	0	1	4	0	0	2	0	7
	6	0	0	0	0	0	6	3	1	1	11
	7	0	0	0	0	0	6	35	0	0	41
	8	20	0	2	2	2	0	0	6	2	34
	80	31	4	3	4	0	0	1	4	17	64
TOTAL		457	22	27	50	10	20	60	41	113	800

TABLE B.4 METHOD 1: DISTRIBUTION OF TRANSITION IN SCORE CATEGORIES FROM BASELINE (T1), TO 12 MONTHS (T2).

		T2								
		0	1	2	3	4	6	7	8	80	TOTAL
	0	477	16	9	11	0	0	10	22	51	596
	1	12	11	9	6	0	0	3	1	0	42
	2	0	2	9	6	1	0	4	1	1	24
	3	0	0	0	21	4	4	12	2	1	44
T1	4	0	0	0	0	2	1	3	0	0	6
	6	0	0	0	0	0	3	3	0	0	6
	7	0	0	0	0	0	2	4	0	0	6
	8	12	2	0	0	0	0	0	6	0	20
	80	35	2	1	2	0	1	2	2	11	56
TOTAL		536	33	28	46	7	11	41	34	64	800

TABLE B.6 METHOD 1. DISTRIBUTION OF TRANSITIONS IN SCORE CATEGORIES OVER 12 MONTHS. (TRANSIONS BETWEEN T1 AND T2; AND T2 AND T3 COMBINED)

		12 MONTHS									
		0	1	2	3	4	6	7	8	80	TOTAL
	0	876	23	20	23	0	1	11	45	133	1132
	1	19	20	14	8	0	0	4	3	7	75
	2	0	4	15	19	1	2	8	1	2	52
	3	0	0	0	37	8	9	27	5	4	90
TIME 0	4	0	0	0	1	6	1	3	2	0	13
	6	0	0	0	0	0	9	6	1	1	17
	7	0	0	0	0	0	8	39	0	0	47
	8	32	2	2	2	2	0	0	12	2	54
	80	66	6	4	6	0	1	3	6	28	120
TOTAL		993	55	55	96	17	31	101	75	177	1600

TABLE B.7 METHOD 1. DISTRIBUTION OF TRANSITIONS IN SCORE CATEGORIES FROM BASLINE (T1) TO 24 MONTHS(T3)

		T3									
		0	1	2	3	4	6	7	8	80	TOTAL
	0	409	10	17	29	1	3	12	27	88	596
	1	11	6	3	8	0	3	6	1	4	42
	2	0	2	3	6	0	1	11	1	0	24
	3	0	0	0	6	7	8	17	3	3	44
T1	4	0	0	0	0	1	1	3	1	0	6
	6	0	0	0	0	1	2	3	0	0	6
	7	0	0	0	0	0	0	6	0	0	6
	8	8	3	0	0	0	0	0	6	3	20
	80	29	1	4	1	0	2	2	2	15	56
TOTAL		457	22	27	50	10	20	60	41	113	800

TABLE B.8 METHOD 2. DISTRIBUTION OF TRANSITIONS IN SURFACE SCORE FROM BASELINE (T1) TO 12 MONTHS (T2)

		T2								
		0	1	2	3	5	6	7	8	TOTAL
	0	440	15	23	0	8	0	68	18	572
	1	5	7	6	0	7	0	0	1	26
	2	3	0	18	3	17	0	1	2	44
	3	0	0	0	3	3	0	0	0	6
T1	5	0	0	0	0	10	0	0	2	12
	6	0	0	0	0	0	6	0	0	6
	7	69	2	0	0	3	0	32	1	107
	8	17	2	1	1	4	0	1	1	17
TOTAL		534	26	48	7	52	6	102	25	800

TABLE B.9 METHOD 2. DISRTRIBUTION OF TRANSITION IN SURFACE SCORES BETWEEN 12 MONTHS (T2) AND 24 MONTHS(T3)

		T3								
		0	1	2	3	5	6	7	8	TOTAL
	0	357	8	11	2	8	5	115	28	534
	1	4	5	9	0	4	1	2	1	26
	2	2	2	13	3	20	3	4	1	48
	3	0	0	2	2	1	2	0	0	7
T2	5	0	0	0	0	44	2	3	3	52
	6	0	0	0	0	0	6	0	0	6
	7	38	5	3	1	3	1	48	3	102
	8	16	1	3	0	0	0	5	0	25
TOTAL		417	21	41	8	80	20	177	36	800

TABLE B.10 METHOD 2. DISTRIBUTION OF TRANSITIONS IN SURFACE SCORES OVER 12 MONTHS (T1 AND T3; T2 AND T3 COMBINED)

		12 MONTHS								
		0	1	2	3	5	6	7	8	TOTAL
	0	797	23	34	2	16	5	183	46	1106
	1	9	12	15	0	11	1	2	2	52
	2	5	2	31	6	37	3	5	3	92
	3	0	0	2	5	4	2	0	0	13
TIME 0	5	0	0	0	0	54	2	3	5	64
	6	0	0	0	0	0	12	0	0	12
	7	107	7	3	1	6	1	80	4	209
	8	33	3	4	1	4	0	6	1	52
TOTAL		951	47	89	15	132	26	279	61	1600

TABLE B.11 METHOD 2. DISTRIBUTION OF TRANSITION IN SURFACE SCORES FROM BASELINE (T1) AND 24 MONTHS (T3)

		T3								
		0	1	2	3	5	6	7	8	TOTAL
	0	351	17	26	2	24	6	120	26	572
	1	6	3	4	0	11	0	2	0	26
	2	1	0	8	4	21	5	5	0	44
	3	0	0	0	2	3	1	0	0	6
T1	5	0	0	0	0	10	0	0	2	12
	6	0	0	0	0	0	6	0	0	6
	7	57	1	2	0	5	2	34	6	107
	8	2	0	1	0	6	0	16	2	17
TOTAL		417	21	41	8	80	20	177	36	800

FIG B.12 PROGRESSION OF SOUND SURFACES (METHOD 1)

		12 MONTHS NO	(%)	24 MONTHS NO	%
S	(A)	477	80	409	67
	(B)	399	74		
	(C)	876	77		
OE	(A)	16	3	10	2
	(B)	7	1		
	(C)	23	2		
IE	(A)	2	2	17	3
	(B)	11	2		
	(C)	20	2		
OD	(A)	11	2	29	5
	(B)	12	2		
	(C)	32	3		
ID	(A)	0	0	1	0
	(B)	0	0		
	(C)	0	0		
SD	(A)	0	1	3	0
	(B)	1	1		
	(C)	1	1		
F	(A)	10	2	12	2
	(B)	1	0		
	(C)	11	1		
E	(A)	22	4	27	5
	(B)	23	4		
	(C)	45	4		
O	(A)	51	9	88	15
	(B)	82	15		
	(C)	133	11		

KEY:
(A) T1(BASELINE) TO T2(12 MONTHS), N=596
(B) T2 TO T3, N=536
(C) T1 TO T2 AND T2 TO T3 (12 MOHTS) COMBINED, N=1132
S-SOUND, OE-OUTER ENAMEL, IE-INNER ENAMEL,OD-OUTER DENTINE,
ID-INNER DENTINE, SD-SECONDARY DECAY, F-FILLED,
E-EXCLUDED, O-OVERLAPPED.

FIG B.13 PROGRESSION OF SOUND SURFACES (METHOD 2)

		12 MONTHS NO	(%)	24 MONTHS NO	%
S	(A)	440	(77)	351	(61)
	(B)	357	(67)		
	(C)	797	(72)		
EN	(A)	15	(3)	17	(3)
	(B)	8	(1)		
	(C)	23	(2)		
OD	(A)	23	(4)	26	(5)
	(B)	11	(2)		
	(C)	33	(3)		
ID	(A)	0	(0)	2	(0)
	(B)	2	(0)		
	(C)	2	(0)		
F	(A)	8	(1)	24	(4)
	(B)	8	(1)		
	(C)	16	(1)		
M	(A)	0	(0)	6	(1)
	(B)	5	(1)		
	(C)	5	(1)		
O	(A)	68	(12)	120	(21)
	(B)	115	(22)		
	(C)	183	(17)		
X	(A)	18	(3)	26	(5)
	(B)	28	(5)		
	(C)	46	(4)		

KEY:

(A) T1(BASELINE) TO T2(12 MONTHS),N=596.
(B) T2 TO T3, N=536
(C) T1 TO T2 AND T2 TO T3 (24 MONTHS) COMBINED, N=1032.
S-SOUND, EN-ENAMEL, OD-OUTER DENTINE, ID-INNER DENTINE,
F-FILLED, M-MISSING, O-OVERLAPPED, X-EXCLUDED.

TABLE B.14 COMPARISON OF PROGRESSION OF SOUND SURFACES USING METHOD 1 AND METHOD 2

	12 MONTHS		24 MONTHS	
	M1	M2	M1	M2
S	75	72	67	61
E	4	2	5	3
OD	3	3	5	5
ID	0	0	0	0
F	2	1	2	4
O	11	17	15	21
X	4	5	5	6

KEY: S-SOUND, E-ENAMEL, OD-OUTER DENTINE,
ID-INNER DENTINE, F-FILLED, O-OVERLAPPED,
X-EXCLUDED.
M1-METHOD 1, M2-METHOD 2.
T1- BASELINE, T2-12 MONTHS, T3-14 MONTHS.
(a) 12 REFERS TO THE DATA FOR T1-T2 AND T2-T3 COMBINED.

FIG B.15 PROGRESSION OF OUTER ENAMEL LESIONS.(METHOD 1)

	12 MONTHS N (%)		24 MONTHS N (%)
S	12 (29)	(A)	11(26)
	7 (21)	(B)	
	9 (25)	(C)	
OE	11 (26)		6 (14)
	9 (27)		
	20 (27)		
IE	9 (21)		3 (7)
	5 (15)		
	14 (19)		
OD	6 (14)		8 (19)
	2 (6)		
	8 (11)		
ID	0 (0)		0 (0)
	0 (0)		
	0 (0)		
SD	0 (0)		3 (7)
	0 (0)		
	0 (0)		
F	3 (7)		6 (14)
	1 (3)		
	4 (5)		
E	1 (0)		1 (0)
	2 (6)		
	3 (4)		
O	0 (0)		4 (10)
	7 (21)		
	7 (9)		

A T1-T2, N=42.
B T2-T3, N=33.
C T1-T2 AND T2-T3 COMBINED, N=75.
S-SOUND, OE-OUTER ENAMEL, IE-INNER ENAMEL,
OD-OUTER DENTINE, ID-INNER DENTINE,SD-SECONDAY CARIES,
F-FILLED, E-EXCLUDED, O-OVERLAPPED.

FIG B.16 PROGRESSION OF INNER ENAMEL LESIONS (METHOD 1)

	12 MONTHS N	(%)	24 MONTHS N	(%)
S	0	(0)(A)	0	(0)
	0	(0)(B)		
	0	(0)(C)		
OE	2	(8)	2	(8)
	2	(7)		
	4	(8)		
IE	9	(36)	3	(13)
	6	(21)		
	15	(29)		
OD	6	(25)	6	(25)
	13	(46)		
	19	(37)		
ID	1	(4)	0	(0)
	0	(0)		
	1	(2)		
SD	0	(0)	1	(4)
	2	(7)		
	2	(4)		
F	4	(17)	11	(46)
	4	(14)		
	8	(15)		
E	1	(4)	1	(4)
	1	(2)		
O	1	(4)	0	(0)
	1	(4)		
	2	(4)		

IE T1=24
IE T2=28

A T1-T2, N=24.
B T2-T3, N=28
C T1-T2 AND T2-T3 COMBINED, N=52
S-SOUND, OE-OUTER ENAMEL, IE-INNER ENAMEL,OD-OUTER DENTINE,
ID-INNER DENTINE, SD-SECONDARY DECAY, F-FILLED,
E-EXCLUDED, O-OVERLAPPED.

FIG B.17 PROGRESSION OF ENAMEL LESIONS (OUTER AND INNER COMBINED).(METHOD 1)

	12 MONTHS N (%)	24 MONTHS N (%)
S	12 (18)(A)	11 (17)
	7 (11)(B)	
	19 (15)(C)	
EN	31 (47)	14 (21)
	22 (36)	
	53 (42)	
OD	12 (18)	14 (21)
	15 (25)	
	27 (21)	
ID	1 (2)	0 (0)
	0 (0)	
	1 (1)	
SD	0 (0)	4 (6)
	2 (3)	
	2 (2)	
F	7 (11)	17(25)
	5 (8)	
	12 (9)	
E	2 (3)	2 (3)
	2 (3)	
	4 (3)	
O	1 (2)	4 (6)
	8 (13)	
	9 (7)	

E T1=66
E T2=61

A T1-T2, N=66.
B T2-T3, N=61.
C T-T2 AND T2-T3 COMBINED, N=122.
S-SOUND, OE-OUTER ENAMEL, IE-INNER ENAMEL,OD-OUTER DENTINE, ID-INNER DENTINE, SD-SECONDARY DECAY, F-FILLED, E-EXCLUDED, O-OVERLAPPED.

FIG B.18 PROGRESSION OF ENAMEL LESIONS .(METHOD 2)

	12 MONTHS N (%)	24 MONTHS N (%)
S	5 (19)(A)	6 (23)
	4 (15)(B)	
	9 (17)(C)	
EN	7 (26)	3 (12)
	5 (19)	
	12 (23)	
OD	6 (23)	4 (15)
	9 (35)	
	15 (28)	
ID	0 (0)	0 (0)
	0 (0)	
	0 (0)	
F	7 (26)	11(42)
	4 (15)	
	11 (21)	
M	0 (0)	0 (0)
	1 (4)	
	1 (2)	
O	0 (0)	2 (8)
	2 (8)	
	2 (4)	
X	1 (4)	0 (0)
	1 (4)	
	2 (4)	

EN(T1) =26
EN(T2) =26

KEY:
A T1-T2, N=66
B T2-T3, N=61
C T1-T2 AND T2-T3 COMBINED,N=122.
S-SOUND, EN-ENAMEL, OD-OUTER DENTINE, ID-INNER DENTINE,
F-FILLED, M-MISSING, O-OVERLAPPED, X-EXCLUDED.

TABLE B.19 COMPARISON OF PROGRESSION OF ENAMEL LESIONS USING METHOD 1 AND METHOD 2.

	12 MONTHS(a)		24 MONTHS	
	M1	M2	M1	M2
S	15	17	17	23
E	42	23	21	12
OD	21	28	21	15
ID	1	0	0	0
F	11	21	32	42
O	7	4	6	8
X	3	6	3	0

KEY: S-SOUND, E-ENAMEL, OD-OUTER DENTINE,
ID-INNER DENTINE, F-FILLED, O-OVERLAPPED,
X-EXCLUDED.
M1-METHOD 1, M2-METHOD 2.
T1- BASELINE, T2-12 MONTHS, T3-14 MONTHS.
(a) 12 REFERS TO THE DATA FOR T1-T2 AND T2-T3 COMBINED.

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