Image Processing Techniques for Assessment of Amelogenesis Imperfecta and Dental Fluorosis - A Review

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***Abstract*—Hypoplasia is a defect of the teeth caused by defective enamel matrix formation. It is classified into several categories based on its root cause and the region of defect. In this study, we discuss the hypoplasia occurring in the enamel part of the teeth. Enamel hypoplasia occurring due to environmental factors is called Dental Fluorosis and which occurs due to hereditary problems is called Amelogenesis Imperfecta. Both AI and DF can be cured effectively if they are detected in the early stages of formation. The appearance of stains is similar in both cases which results in a diagnostic dilemma for the dentists. Currently, due to the technological advancements, different radiographs such as panoramic and periapical radiographs are used for diagnosis. Radiographs can provide accurate results, but the frequent exposure to radiation can result in some deterministic and stochastic health effects like cell killing, damage of tissues. Also, this process can be time-consuming for screening a large number of patients for epidemiological surveys.**

***Keywords*— Hypoplasia, Amelogenesis Imperfecta, Dental Fluorosis, Image Processing.**

I. INTRODUCTION

Amelogenesis Imperfecta (AI) is a developmental disorderof genomic origin, associated with the abnormal enamel formation. AI is caused due to an assemblage of hereditary diseases that results in the defective formation or calcification of enamel. In AI, the enamel defects occur without any sign of generalized or systemic defects. It involves both primary and permanent dentitions. Although AI is considered as a single disease entity**,** it represents a group of heterogeneous conditions, with diverse structural defects of enamel resulting in a range of clinical phenotypes. It is characterized by clinical and genetic heterogeneityin the absence of systemic abnormalities or diseases. The AI is also known by varying names such as hereditary enamel dysplasia, hereditary brown enamel, and hereditary brown opalescent teeth. The enamel may be hypoplastic, hypo mineralized or both. The affected teeth may have symptoms such as discoloration, sensitivity and disintegration. Diagnosis is based on the family history, pedigree plotting and meticulous clinical observation. This condition results in the problems such as socialization and discomfort, but can be managed by vigorous treatment in the early stages, both preventive and restorative. Primary dentition can occur inchildren, which is protected using metal crowns on the posterior region. The long-term care is provided by either crown adhesive or plastic restorations.

Dental fluorosis (DF) is a disturbance in the tooth formation caused by the excessive ingestion of fluoride during the formative period of the dentition. Depending on the quantity of the fluorine intake, different degrees of changes in the enamel are observed. The fluoresced enamel retains a relatively high proportion of immature matrix protein (high proline contents). An incomplete removal of amelogenin proteins under influence of fluoride during tooth development leads to fluorosis. Fluoride has been assigned as the single most factor for causing enamel mottling. Thus, the differential diagnosis of enamel fluorosis from non-fluorotic enamel defects is critical for accurate assessment of the prevalence of dental fluorosis.

The most critical period for the development of fluorosis in permanent dentition is during the latter stages of pre-eruptive tooth development. the critical exposure period for the development of permanent dentition is between 11 months and seven years of age. The clinical appearance of milder forms of the enamel fluorosis is characterized by narrow white lines following the perikymata, cuspal snow-capping, and a snow flaking appearance that lack a clear border with unaffected enamel. In the initial stages, the affected tooth becomes coloured from yellow to brown to black. As the severity increases, there occurs discoloration of the teeth or the formation of pits in the teeth.

In the present-day scenario, image processing in medical fields is being recognized at a faster rate. Imaging techniques play an important role in accelerating the early diagnosis process. Segmentation is an essential step in image processing to obtain the region of interest. The accuracy of segmentation process determines the success or failure of the final analysis process. The texture analysis is used when the objects are to be segmented based on texture rather than on intensities.

II. LITERATURE REVIEW

Over the decades, there has been many modern technologies emerging in the field of medicine. In this era of technology, It has become a necessity to adopt newer techniques to cater to the needs of the growing population. One such emerging technology is the digital image processing which has its wide range of applications in medicine. Some of the articles by eminent scholars are studied and discussed below.

In [1], Amelogenesis Imperfecta (AI) has been studied with the help of case reports. AI represents a group of inherited defects and is genomic in origin. It affects the structure and clinical appearance of the enamel of all or nearly all the teeth in aequal manner. AI is a developmental condition of the dental enamel that is characterized by hypoplasia or hypomineralization. This paper also categorises the case reports into one of the three classifications of AI: hypoplastic AI, hypomaturation AI and hypocalcified AI. These classifications were based on a) molecular defect (when known) (b) Biochemical result (when known) (c) Mode of inheritance (d) Phenotype.

It suggests the importance of radiology in the assessment of enamel density and to develop a more appropriate treatment plan in patients with enamel defect. It states that the differential diagnosis considered most probable is dental fluorosis. The variability of this condition, from mild white “flecking” of the enamel to profoundly dense white coloration with random, disfiguring areas of staining and hypoplasia, entails careful interrogation to distinguish from AI.

In [2], the assessment of dental fluorosis is carried out by clinical, hematological, biochemical and radiological methods. The study was conducted in Maharashtra, India. 60 families were screened for dental and skeletal fluorosis. All these study subjects were evaluated for clinical, hematological, biochemical and radiological investigations. The concentration of fluoride in drinking water was measured using ion selective electrode method using orion-ptt meter. a total of 43.2% of the study subjects were affected by grade I (mild) dental fluorosis, 27.4% of the study subjects with grade II (moderate) dental fluorosis and 29.4% with grade III (severe) dental fluorosis. From the results of the study it was concluded that there is a direct association between the high fluoride concentration and the dental and skeletal changes.

In [3], the dental fluorosis was quantified using fluorescent imaging technique. A particular set of population in Chiang Mai, Thailand were investigated and were assigned to groups of different water fluoride content intervals based upon the data generated from the cooking water samples. The fluorescent images of the affected portions were captured using the high-resolution imaging equipment. MATLAB image processing software was used to analyze the bitmap images obtained from the fluorescence image capture. A series of process applications included the image blur, the subtraction mask and the analysis of the resultant image. The convex hull analysis software was employed to quantify the level of hypomineralization of the tooth surface image. The image reconstruction process was carried out in several stages. Firstly, the analysis software detected dark areas by reconstructing a “clean” image of the tooth surface and then subtracted the captured image. The reconstruction converted the image into a set of coordinates in the dimensions x, y and brightness. The convex hull of these points in these three dimensions was then calculated using the Quickhull algorithm.

The convex hull was then converted back to an image using a simple software rendering algorithm. The result was an image of the tooth where dark areas were filled with an interpolation between surrounding areas. The map of fluorescence loss could then be thresholded to remove background noise, with all pixels below the threshold set to zero and all those above the threshold included in the map. In this study, to include milder forms of fluorosis the threshold was set at a level of 5 (out of 255) pixels. These images underwent a complete analysis procedure. Statistical analysis was done using ANOVA and Mann Whitney U Test. Correlation coefficients of the photographic scores and the output from the software analyses were determined. These results were compared with the QLF metrics ($Area_{blur} \Delta F_{blur}$ ΔQ_{blur} and $Area_{ch}$ ΔF_{ch} ΔQ_{ch}). Thus, the convex hull analysis software demonstrated a better association with the photographic scores than the existing technique for all outcome metrics. This study proves that the fluorescence imaging technique can be used effectively for the quantification of dental fluorosis.

The presence of plaque, stain, caries and other developmental defects of enamel such as demarcated enamel opacities are confounding factors in fluorosis assessment using fluorescence imaging and the subsequent analysis.

It is arguable which analysis technique in fluorescent imaging is more appropriate to discriminate between populations with differing fluoride exposures. Further work is needed to develop the capturing system and software if it is to become a viable means of objectively quantifying fluorosis in large scale epidemiological surveys.

Paper [4] implements the image processing technique for assessing the dental caries from photographic color tooth images according to the International Caries Detection and Assessment System (ICDAS II). These caries are located on the occlusal surfaces of posterior teeth. The proposed methodology consists of two stages: (a) obtaining regions of interest and (b) the classification of the detected regions. In the first stage, pre-processing, segmentation and post-processing mechanisms were employed. For each pixel of the detected regions, a 15X15 neighborhood is used and a set of intensity-based and texture-based features were extracted. A correlation based technique was applied to select a subset of

36 features which were given as input into the classification stage, where five classifiers (J48, Random Tree, Random Forests, Support Vector Machines and NaïveBayes) were compared to conclude to the best one, in our case, to Random Forests. The methodology was evaluated on a set of 103 digital color images where 425 regions of interest from occlusal surfaces of extracted permanent teeth were manually segmented and classified, based on visual assessments by two experts. The classification stage consists of four steps: (a) feature extraction, (b) feature selection, (c) classification where pixels of the detected regions are assigned to one of the seven classes defined according to the ICDAS II system using the Random Forests classifier, and (d) classification of the region. The set of features consist of texture-based features, such as co-occurrence matrices and Local Binary Patterns (LBPs) and of intensity-based features such as the mean intensity of the neighbourhood and the entropy.

The methodology correctly detected 337 out of 340 regions in the detection stage with accuracy of detection 80%. For the classification stage an overall accuracy 83% is achieved. It does not subject the patients to radiation exposure. It can become a very useful tool assisting the dentist to take a more consistent unbiased and accurate decision for the treatment of occlusal caries. It has the advantage of improving as more pictures with known classification is used to train it and even more importantly the algorithm can always be adjusted to incorporate any new knowledge on caries diagnosis through the utilization of appropriate features and inclusion or exclusion rules. Although the achieved performance is satisfactory, more research is needed to validate the present results with the histological gold standard of the lesions.

Paper [5] proposes a work carried out using dental radiographs which aids the dentist in treatment planning by facilitating the process of categorizing the dental cyst using image processing techniques based on texture information. Dental cysts are usually caused due to root infection involving the tooth affected greatly by carious decay. The most common forms of dental cysts include Ameloblastoma, Keratocyst and Dentigerous cyst. The treatment is planned based on the type of cyst. Initially, the dental radiographs are enhanced using contrast enhancement. Image negation and contrast stretching technique are used to extract the region of interest. Special stretch which is a kind of contrast stretch projects the hiddendetails in the desired region. Texture Analysis refers to the methods developed to quantify the image texture that can be used for image segmentation and classification. Classification is performed using texture parameter estimation based on GLCM approach. The estimated texture features include Contrast, Correlation, Energy, Homogeneity and Mean. These parameters are used for classifying the dental cyst using K-means classifier in feature space. The Euclidean distance in feature space is used to classify the cyst. The cyst is assigned to the class that minimizes the distance between its texture parameters and the centroid of the respective class. Useful information cannot be made from contrast, correlation and homogeneity as they are almost in the same range for the three types of cysts. The useful parameters here are energy and mean. The energy parameter is very less for Ameloblastoma, whereas it differs a little in case of Keratocyst and Dentigerous cyst. The mean value is less for Dentigerous cyst when compared to the other two types and lies in the range of 50-100, slightly higher for Ameloblastoma which lies in the range of 120- 160. Keratocyst has the highest mean value which lies in the range of 190-230. The classification results obtained based on centroid and K-means classifier in feature space is found to be encouraging. This study will assist the dental surgeon in accurate identification of dental cyst and treatment planning.

Paper [6] presents an algorithm to detect enamel caries and interproximal caries from digital periapical radiographic images. This study makes use of MATLAB and it performs caries detection in three stages. First stage is the preprocessing phase where rotation of an image is performed, if necessary. Histogram study of the image is carried out to understand the intensity of carries. The second phase is image segmentation where individual tooth area is separated. Third phase is the identification phase where caries is detected. Two software tools viz. Digora and Oslo are used to detect approximal caries. It is concluded that both the tools have their own merits and demerits and would not suffice in detecting approximal caries independently and accurately. An algorithm to provide end-to-end solution integrating preprocessing, segmentation, and identification of caries with specific reference to periapical radiographs was developed. This algorithm consisted of three modules. In the first module preprocessing is performed by rotating the image to remove skew, if any. In the second module, segmentation of a radiograph is carried out to separate each tooth. The third is identification module where histogram study is performed to detect caries. This is done based on respective intensity ranges of caries. This algorithm provided a less complex automatic segmentation method which produced satisfactory results for 25 test images.

Paper [7] presents two distinct image processing algorithms for detection of dental anomalies. A novel approach for detection of dental caries using hybridized negative transformation and statistical texture analysis for the dental images containing cysts along with dental caries. The texture analysis is used when the objects are to be segmented based on texture content rather than intensities. The texture of panoramic image is characterized by Gray Level Cooccurrence Matrix (GLCM). The texture features obtained from the GLCM are energy, entropy, homogeneity, contrast and correlation. These texture features are used to find texture boundaries to obtain segmentation about the region of cysts. This transformation algorithm gives true positive results for seven out of ten images. Results obtained by both the methods were satisfactory correlating with the diagnosis made by the maxillofacial radiologists.

In [8], an efficient segmentation algorithm for panoramic dental images is proposed to diagnose the problems with the wisdom teeth. The proposed segmentation method aims to extract wisdom teeth to be used later in classification and extract useful information such as teeth shape and degree of deviation. This information can be used to classify wisdom teeth as impacted, partially erupted, or completely erupted. Segmentation of the wisdom teeth is done in three stages, pre-processing, ROI extracting or defining and finally post-processing.The pre-processing methods include contrast enhancement, thresholding using Otsu's method, morphological dilation, connected component labeling, removing unwanted objects and image multiplication. The region of interest (ROI) was extracted automatically based on the common characteristics between the panoramic images and nature of jaws and wisdom teeth location. The steps in post-processing include histogram equalization, Global Otsu's threshold, morphologically open image operation, connected component labeling, removing unwanted region and image multiplication. The obtained results from the proposed method have shown that it could successfully extract the wisdom teeth, the segmented images can be used later in classification system.

Paper [9] suggests a method for segmentation and feature extraction of dental x-ray images. The method has been implemented by using clustering (k-mean) method for segmentation after image enhancement and illustrate contour for teeth to complete the segmentation step. Several features are extracted from dental x-ray images by gray-level co-occurrence matrix(GLCM). The experimental results show that it is a promising technique for segmentation, but needs improvements.

Paper [10] proposes a semi-supervised fuzzy clustering algorithm for dental segmentation from radiographic images. The spatial features of a dental X-ray image are formulated in a feature database. A semi-supervised fuzzy clustering algorithm with spatial constraints (SSFC_SC) is modeled for the dental segmentation problem and this model is solved using the Lagrange multiplier method. Then the additional information required for the clustering process is determined by mixing optimal results of Fuzzy C-Means with spatial constraints. Finally, a novel clustering algorithm (SSFC-SC) is designed. The findings of the study reveal that SSFC-SC has better performance than the relevant algorithms such as FCM, Otsu and eSFCM.

Table.1: COMPARISON TABLE

S. NO	TITLE	TECHNIQUES	FOCUS	ISSUES
1	Amelogenesis Imperfecta: A Series of Case Report	Family history, pedigree plotting, radiographic investigations such as IOPA and OPG	Classification of AI, based on molecular defect, Biochemical result, Mode of inheritance and Phenotype.	Radiology technique is required in the assessment of enamel density
2	A Clinical Hematological Biochemical and Radiological Assessment of Dental Fluorosis in Endemic Fluoridated Area of Maharashtra India	The assessment of dental fluorosis is carried out by clinical, hematological, biochemical and radiological methods	There is a direct association between the high fluoride concentration and the dental and skeletal changes.	There is no alternative method to counteract the problem of absolute change in the cell wall of RBCs with endemic fluoridated area
3	Dental fluorosis in populations from Chiang Mai,Thailand with different fluoride exposures - Paper2: The ability of fluorescence imaging to detectdifferences in flourosis prevalence and severityfor different fluoride intakes from water	Dental flourosis was quantified using fluorescent imaging technique	The result was an image of the tooth where dark areas were filled with an interpolation between surrounding areas	The inability todifferentiation Fluorosis from caries and other non-fluorotic defects existed
4	A computer-aided automated methodology for the detection and classification of occlusal caries from photographic color images	Segmentation using K-means algorithm and feature extraction using GLCM	This methodology provides an objective and fully automated caries diagnostic system for occlusal carious lesions	The achieved performance is satisfactory, more research is needed to validate the present results with gold standard of the lesions
5	Texture Based Classification of Dental Cysts	Classification is performed using texture parameter estimation based on GLCM approach. The GLCM parameters are used for classifying the dental cyst using K-means classifier in feature space	The classification results based on centroid and K-means classifier assists the dental surgeon in accurate identification of dental cyst and treatment planning	Concentrates only on three types cysts and not extended for other cysts

6	Algorithm to Identify Enamel Caries andInterproximal Caries Using Dental DigitalRadiographs	Image segmentation of the periapical radiographs	This provides a less complex automatic segmentation method which produced satisfactory results for 25 test images	Only satisfactory results are obtained. Specific only to enamel and interproximal caries.
7	Characterization of Dental Pathologies using Digital Panoramic X-RayImages based on Texture Analysis	Hybridised negative transformation to detect the dental caries and texture parameter estimation using GLCM	These algorithms gave true positive results for seven out of ten images	Advance stages of pattern recognition is not employed
8	An Efficient Segmentation Algorithm for Panoramic Dental Images	The region of interest is obtained using proposed segmentation algorithm and the performance is measured using Mean Absolute Error(MAE)	The result showed the successful extraction of wisdom teeth	Considers only the wisdom teeth and not the other regions.
9	Dental X-Ray Image Segmentation andMultiple Feature Extraction	K-means method for segmentation and feature extraction of dental x-ray images	The experimental result showed that it is a promising technique	Needs improvements in the segmentation technique for more accurate results
10	Dental segmentation from X-ray images using semi-supervised fuzzyclustering with spatial constraints	Semi-Supervised Fuzzy Clustering algorithm with SpatialConstraints (SSFC-SC), Lagrange multiplier method for solving SSFC-SC	The results reveal that the proposed work has better accuracy than any other relevant methods	High processing time

III. CONCLUSION

This paper presents the image processing techniques applied for the diagnosis of different dental problems especially AI and DF. This paper proposes an idea of applying image processing techniques for the diagnosis of AI and DF. It is achieved by capturing the image of the affected teeth and then applying it through various stages such as preprocessing, segmentation and feature extraction. By the application of efficient algorithms such as k-means clustering and gray-level co-occurrence matrices, the final output displays whether it is AI or DF. Thus, this rapid screening of hypoplasia, useful for epidemiological surveys, is achieved through image processing.

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