Identification of enamel demineralization using high performance convolutional neural network

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***Abstract*—Here, we traces use segmentation and convolutional neural network (CNN) to trace, diagnose and quantify enamel demineralization for research. The preprocessing, histograms based methods are used to enhance the contrast and equalize the brightness through the scanning electron microscope images. Our result evidence that the deep learning based CNN model is highly efficient to process the dental image to achieve high accuracy of enamel demineralization and presents promising outcomes with optimal precision.**

***Index Terms*—Neural Network, Demineralization, CNN, Deep Learning, SEM, Enamel**

I. Introduction

Dental caries is a multi factorial disease, in which the first signs appear in the form of demineralization [1]. Accuracy of diagnosis of dental Caries is still a huge challenge for dentist and consequently for research. Methods such as 2-image radiography and Quantitative Light-induced Fluorescence (QLF), although widely used in clinical dentistry, have some disadvantages [2], [3]. Among the limitations of the methods, it only allows the diagnosis when there is loss of tooth structure [1]. For research, they are not effective for light demineralization detection as is possible with Scanning Electron Microscopy (SEM). SEM is widely used for morphological analysis of tooth structure, however, it necessitates methods that can quantify the morphological data of demineralization. With the affordability of advanced computing hardware, deep learning neural networks (NNs) that applies multilayer artificial NN to achieve superhuman accuracy [4]. Deep learning is now employed as efficient and accurate tool for Computer Vision, thereby the deep learning models rapidly deploy in every field of practical application for object detection, recognition as well as classification [5].The strong efficiency of deep CNNs is that, given enough training datasets, it could simulate and stratify patterns and features in images with higher precision and accuracy [6].

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We propose segmentation of enamel demineralization using U shape neural network for identifying caries with high precision and accuracy. The input data obtained from Scanning electron microscopy (SEM) for several samples at different treatment i.e. Neg. Control, Fluoride, Laser and Laser+Fluoride. Our model suggest segmentation using U-type convolutional neural network could achieve high performance using SEM images as well as with their ground truth masks.

II. Methods and Materials

We used ten permanent human molars extracted by orthodontic indication after approval by the Research Ethics Committee (CAAE: 02854118.3.0000.0075). Teeth using visual defects on the enamel surface, such as decay and enamel fractures, were eliminated. The teeth were cleaned manually, disinfected with de-ionized water and thymol, according to standard protocol (White and Featherstone, 1987), which transformed into 20 enamel blocks (4 x 4 x 2 mm) applying a diamond disc (Microdont, SP, Brazil) mounted on a low-speed motor (KaVo, SP, Brazil). The samples were conditioned in thermally activated acrylic resin (Vipi Cril Plus, Brazil) and later on, polished with abrasive discs in decreasing different granulation (Carbimed Paper Discs, Buehler, USA).

All the samples were stored in relative humidity at 4ºC throughout the experimental procedures.The samples were randomly assigned to four treatment groups (n=5/group): Negative Control; Fluoride (Professional acidulated phosphate fluoride gel application); Laser (Irradiated with Nd:YAG laser 84 J/cm); and Fluoride + Laser.

After the treatments, the samples underwent pH cycling in order to simulate the carious process that takes place in the oral environment. All samples were analyzed in a Scanning Electron Microscope (TM 3000 Tabletop Microscope - Hitachi, Japan) and an image was acquired of the central region of each sample, at 4,000x magnification.

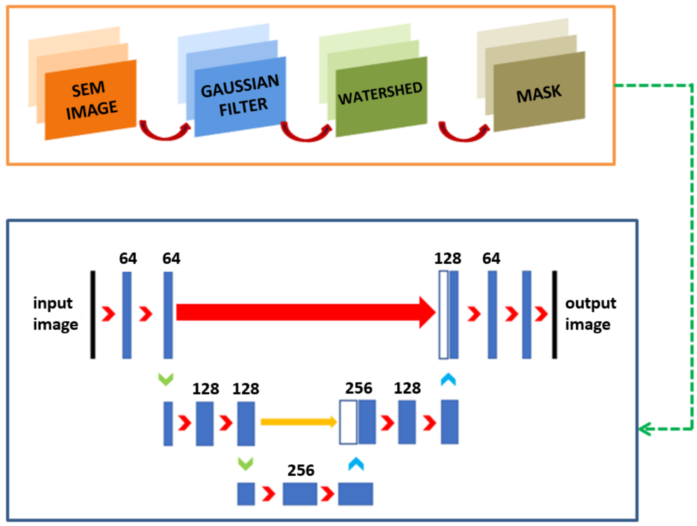

Fig. 1. The workflow of pre-processing of SEM images as input data and Neural Network (Unet) for computational simulations.

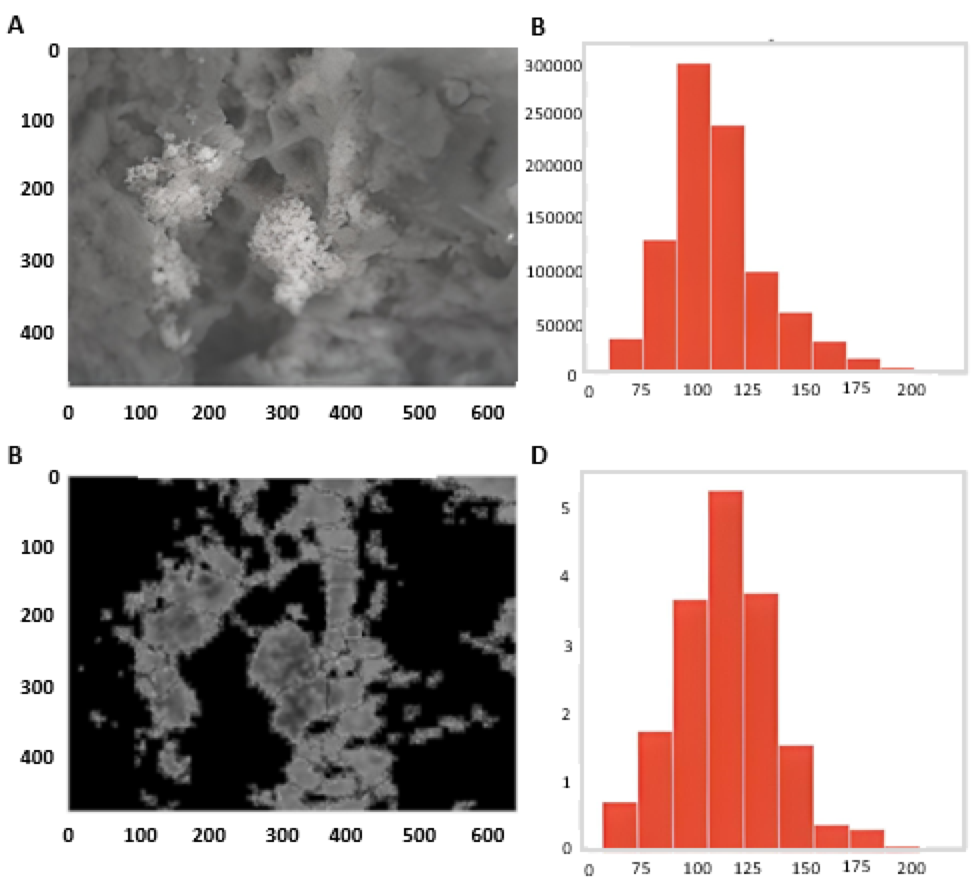

Fig. 2. SEM images and their respective histograms obtained with the methods mentioned in the text.

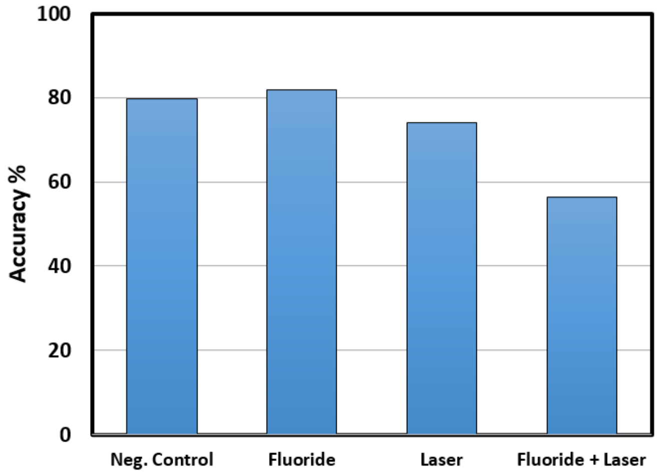

Fig. 3. Accuracy in different treatments.

The complete procedure of computational as well as preprocessing is shown in Figure 1. The SEM input image data is preprocessed and then applied to identify demineralization using U type NN algorithm.

Preprocessing involing 'Gussian Filter', watershed to obtain ground truth mask was achieved by using Fiji ImageJ software. 60 images were obtained, 50% were used for training and 50% for testing. Convolution neural network were used after preprocessing to measure the enamel demineralization rapidly and accurately applying SEM input images.

III. Results and Discussions

The prevention of enamel demineralization is a subject of urgent study due to rapid expansion and prevention of disease. For the supervised training of such a segmentation network, a set of paired images is obtained such as a SEM image and its respective ground truth segmentation mask, in which each demineralization in the image is outlined. To avoid the tedious task of manually examining the enamel demineralization employing SEM images, we decided to use segmentation employing CNN for the automated generation of the training data [7], [8]. As shown in Figure 2, the data is analysed of SEM image (a) and its corresponding distribution image (b). Using this input data information, segmented image (c) and its distribution (d) is achieved employing ground truth mask. Considering that the segmentation obtained by the CNN better matches the perceived demineralization than the segmentation itself [4]. Therefore, it is interesting how similar the results are for the final teeth Caries achieved from both segmentation methods. Another noteworthy fact is that the CNN is trained on simulated data that provided final demineralization which were even in agreement to the values acquired from the ground truth segmentation masks. Contrary to that, our results show that the network that was trained directly on the ground truth masks presented good accuracy of demineralization. Figure 3 depicts the presence of demineralization employing Unet computation framework (CNN).

The accuracy was 79.81%, 81.8%, 74.1% and 56.4% with respect to Neg. Control, Fluoride, Laser and Laser + Fluoride, respectively (Fig.3). Fig.3 also shows that dental Caries can be predicted more accurately using Unet Neural Network. There is also demand for improving the computational model for classification of enamel demineralization depth as well as optimizing the algorithms. Further, our results show that Neural Network using SEM images can distinguish with higher accuracy and precision.

IV. Conclusion

In conclusion, we proposed a workflow that provided fully automated enamel demineralization segmentation from scanning electron microscopy images as input dataset, requiring minimal user interaction. One only has to give the SEM images and some exemplary enamel demineralization shapes outlines. Our results show that higher presence of demineralization is present under the Fluoride treatment (80.8%) and lower with 56.4% (Laser+Fluoride treatment). Further, initial results evidence that more efficient and better performing neural network architectures become available in the future for diagnoses enamel demineralization.

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V. Conflict of Interest

The authors declare no conflict of interest

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