Exploring Enamel Demineralization from SEM images using Deep Learning Algorithms

Sajid Farooq, Amanda Caramel-Juvino, Yasmin Reis Fontes, Sabrina Avelino Gardiano, and Denise Maria Zezell
Center for Lasers and Applications, Instituto de Pesquisas Energéticas e Nucleares, Av. Prof. Lineu Prestes 2242, São Paulo, 05508-000, Brazil
zezell@usp.br

Abstract: Here, we employ segmentation and convolutional neural network (CNN) to identify and quantify enamel demineralization. Our results depict that CNN model using input SEM images achieve accuracy up to 79% for enamel demineralization diagnosis.

1. Introduction

Dental caries is a multifactorial chronic disease, causing an imbalance in the dynamic process of demineralization and remineralization (DE-RE) of dental hard tissues, which occurs in the oral cavity. The DE-RE processes are mediated by saturation principles and refer to loss and gain of ions in the dental structure [1].

For didactic purposes, the pH value is a borderline for component sub-saturation in terms of saliva. Enamel hydroxyapatite has a critical pH value (5.5) that is more alkaline, resulting demineralization that causes losing calcium and phosphorus at ionic form to saliva. If the environment has a pH value lower than 5.5, then new calcium and phosphate ions are reincorporated into hydroxyapatite, promoting remineralization [2]. The presence of fluoride increases the acid resistance of the surface, changing the critical pH to 4.5 [3].

High power lasers have been used to make teeth more resistant to acid [4]. The generated heat causes chemical and structural changes to occur in hydroxyapatite through melting and re-solidification, increasing the amount of minerals and reducing the concentration of carbonate and water through evaporation, which results in greater acid resistance [5].

Recently, using the opportunity of advanced computing hardware, convolutional neural networks (NNs) employ multilayer artificial NN to possess superhuman accuracy [6]. Artificial intelligence algorithms is now powerful and precise tool for Computer Vision, therefore, the CNN models rapidly apply in practical realizations of object detection, recognition as well as classifications [7].

To evaluate the extent of acid resistance, we purpose here to explore the enamel demineralization, using fluoride and laser under 3 different conditions i.e. pH = 5.0, pH = 4.5 and pH = 4.0. The model to evaluate dental demineralization is U-type CNN, employing input scanning electron microscopy (SEM) images. Our model evidences that segmentation with CNN simulations, achieves high performance for enamel demineralization identification.

2. Materials and Methods

2.1 Materials Preparation

The samples used in our experiment were 30 permanent human molars, after the approval by the Research Ethics Committee (CAAE: 02854118.3.0000.0075), which were extracted by orthodontic indication. The excluded teeth having visual defects like enamel fractures; decay and defects on enamel surface were explored in the experiment.

To clean the teeth, we used de-ionized water and thymol, according to standard protocol of disinfection (White and Featherstone, 1987). Later on, the teeth were transformed into 60 enamel blocks (4 mm x 4 mm x 2 mm), making use of a diamond disc (Microdont, SP, Brazil) launched on a low-speed motor (KaVo, SP, Brazil). The samples were treated with a thermally activated acrylic resin (Vipi Cril Plus, Brazil) and then, polished with abrasive discs in different granulations (Carbimed Paper Discs, Buehler, USA).

2.2 Simulation Model

In order to identify the dental caries presence, we preprocessed our experimental data employing 'Gaussian Filter' and watershed to obtain ground truth mask by using Fiji Image-J software. Furthermore, the convolution neural network was applied to evaluate the enamel demineralization rapidly as well as accurately. The strong efficiency of deep learning, given enough training datasets, it could simulate and stratify patterns and features.

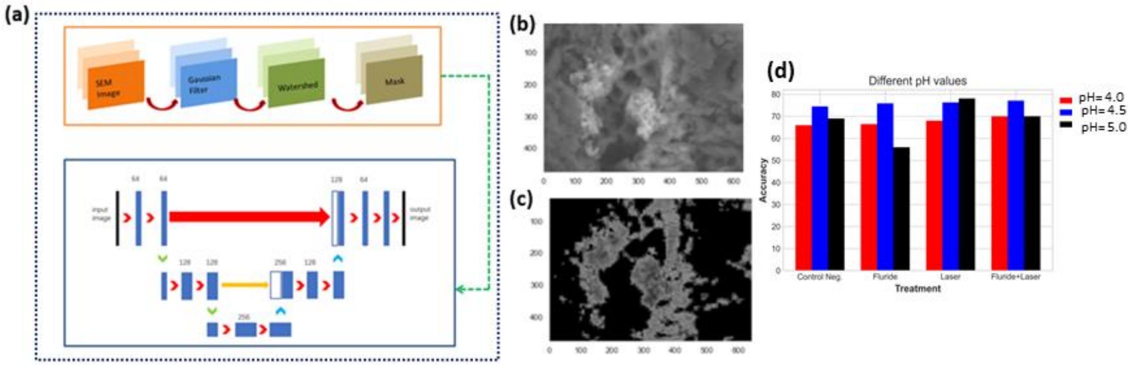

Figure 1. The model for evaluating enamel demineralization (a) using input SEM image (b) and segmented (c) with accuracy analysis (d).

3. Results and Discussion

In order to prevent of enamel demineralization, an urgent study is required due to rapid expansion of that disease. For supervised training employing CNN modeling, input data based on SEM images and their respective masks are obtained, in which each demineralization of the corresponding image is evaluated. To avoid time consumption of manually examining with low accuracy, the enamel demineralization using SEM images were used as a input, further we decided to use CNN, as shown in Fig. 1a. One can see that the input data to evaluate for neural network simulation is obtained of SEM image (Fig. 1b) and its corresponding mask image (b). Considering that the segmentation obtained by the CNN better matches the perceived demineralization than the segmentation itself. Furthermore, it is crystal clear how similar the results for the final enamel demineralization achieve from both segmentation methods. Another extraordinary 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 label ground truth segmentation masks. Figure 1c shows that presence of demineralization employing U-net computational framework (CNN) with respect to different pH values. The model achieves the presence of demineralization of up to 79% for under different treatments. Further, the accuracy at pH = 5.0 is encouraging in comparison to other treatment. Employing laser with fluoride can not only decrease the demineralization but also avoid the disease. However, there is an urgent need for improving the accuracy for classification to identify the enamel demineralization depth and optimizing the U-type CNN algorithms. However, we achieve high quantity and good quality which predict that both laser + Fluoride can prevent enamel demineralization in comparison to other methods (Fig.3).

4. Conclusion

In conclusion, we evaluated enamel demineralization using SEM images and CNN model, requiring minimal user interaction. One only has to give the SEM images and their respective masks as outlines to identify the enamel demineralization.

Our results present that higher presence of demineralization is present under Laser + Fluoride treatment at pH = 5.0. Overall, initial results encourage that more effective and good performing neural network architectures can be available in the future for better identification of enamel demineralization with high accuracy and precision.

5. Acknowledgement

We thank for the financial support of FAPESP/ PDIP 17/50332-0, CNPq INCT-465763/2014-6, Sisfoton MCTI/CNPq 440228/2021-2, CAPES/PROCAD (001) 88881.068505/2014-01.

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