International Journal of ChemTech Research
CODEN (USA): IJCRGG, ISSN: 0974-4290, ISSN(Online):2455-9555
Vol.10 No.6, pp 882-889, 2017

Characterization of healthy and carious human permanent teeth using laser induced breakdown spectroscopy

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Abstract : Tooth samples were analyzed for their elemental constituents using the atomic transition lines of selected samples by LIBS method. The elements detected in a tooth sample were: calcium, phosphorous, magnesium, iron, lead and sodium. It was concluded that the caries-affected part contained less calcium, phosphorous and sodium in comparison with the healthy part. While higher concentration of magnesium and lead were found in the caries affected part. Many differences of Ca, P, Mg, Na and Pb contents were found between female's teeth and male's teeth. Also Pb and Mg content increase with age in teeth samples was noticed.
Keywords : LIBS; permanent teeth; healthy and caries; Laser irradiation.

Introduction

Light emitting plasmas have been studied in earnest since the 1920s, and laser induced plasmas since 1960 [1]. Laser Induced Breakdown Spectroscopy (LIBS) is basically an emission spectroscopy technique where atoms and ions are primarily formed in their excited states as a result of interaction between a tightly focused laser beam and the material sample. The interaction between matter and high density photons generates plasma plume, which evolves with time and may eventually acquire thermodynamic equilibrium [2].LIBS has become of interest to many researchers owing to its unique properties such as minimal time duration of preparing the sample, low cost capability of being used in all three states of materials, and its nondestructive nature [3]. This method is used to detect corpse's bones and humans' fossils. It is also used to detect backgrounds characteristic like age, sex, and statues of bodies [4]. This method is used in dentistry to detect the caries parts of a tooth, and also in teeth modification. Spectral analysis plasma glow made by pulse laser can be used safely and accurately to monitor the occurrence of cancer [5-7]. Due to the increase use of lasers in clinical dental practice, LIBS can be achieved to create one-dimensional or two-dimensional concentrations maps as a function of location or depth which permits the study of elements distribution. Also, it can be used for early diagnosis of diseased or caries in tooth [8-10].

The human tooth consists of four main tissues, enamel, the hardest material found in human body, protects the other fragile tooth parts from damage, Dentin has a bone like consistency, pulp of root canal is the central part of the tooth and contains vessels and nerves and the cementum layer which covers the tooth root [11].

Electron temperatures can be calculated using intensities of same species according to Boltzmann equation [12].

$$\ln\left(\frac{I_{ji}\lambda_{ji}}{A_{ji}g_j}\right) = -\frac{E_j}{kT_{exc}} + \ln\left(\frac{hc\,N_o}{4\pi\,U(T)}\right) \quad \text{……………………………………..(1)}$$

Where $I_{ji}$is the intensity of the spectral line of the transition from level jto i, λ_{ji} is the wavelength, A_{ji} is the transition probability, g_j is the statistical weight, E_j is the energy value of higher level, and $T_{exc}$is the excitation temperature. Thus, a plot of $\ln\left(\frac{I_{ji}\lambda_{ji}}{A_{ji}g_j}\right)$versus the energy of the upper level E_j yields a straight line called Boltzmann plot,its slope is equals to$-\,(KT_{exc})^{-1}$.

According to the Saha-Boltzmann equation electron density can be deduced from the intensity ratio of two lines matching to different ionization stages [12, 13].

$$n_e = \frac{2(2\pi m_e kT)^{3/2}}{h^3}\frac{I_{mn}^{I}A_{jk}g_j^{II}}{I_{jk}^{II}A_{mn}g_m^{I}}e^{-(E_{ion}+E_j^{II}-E_m^{I})/kT} \quad \ldots\ldots\ldots\ldots\ldots..(2)$$

Where E_m and E_j are the upper level energies of neutral and single ionized transitions, E_{ion} is the ionization energy and n_e is the electron density.

2. Experimental Part

Samples of permanent human teeth were supplied by the dental clinics inAlfurat Hospital(Baghdad,Iraq). They were washed in sodium hypochlorite diluted with distilled water for 10 min to remove contamination from the outer surface, dried at room temperature, and thenthey were preserved in formalin solution.

The optical emission spectra for plasma ablated near teeth samples surfaces were recorded using LIBS experimental system shown in Fig. 1.It consists of pulse Nd: YAG laser of 10 ns duration, 10 Hz pulse repetition frequency, using wavelengths of 1064nm and 532 nm, with different energies (300-800 mJ). The laser beam was focused on the surface of the sample which is located at the focal length of a converging lens (f=10 cm). Optical fiber adjusted at 45° with beams directed at 5 cm distance from the sample where plasma was generated. Spectroscopic information was obtained from the laser induced targets plasma spectra in air, under atmospheric pressure. Each spectrum was obtained over a 150-1000 nm wavelength range.

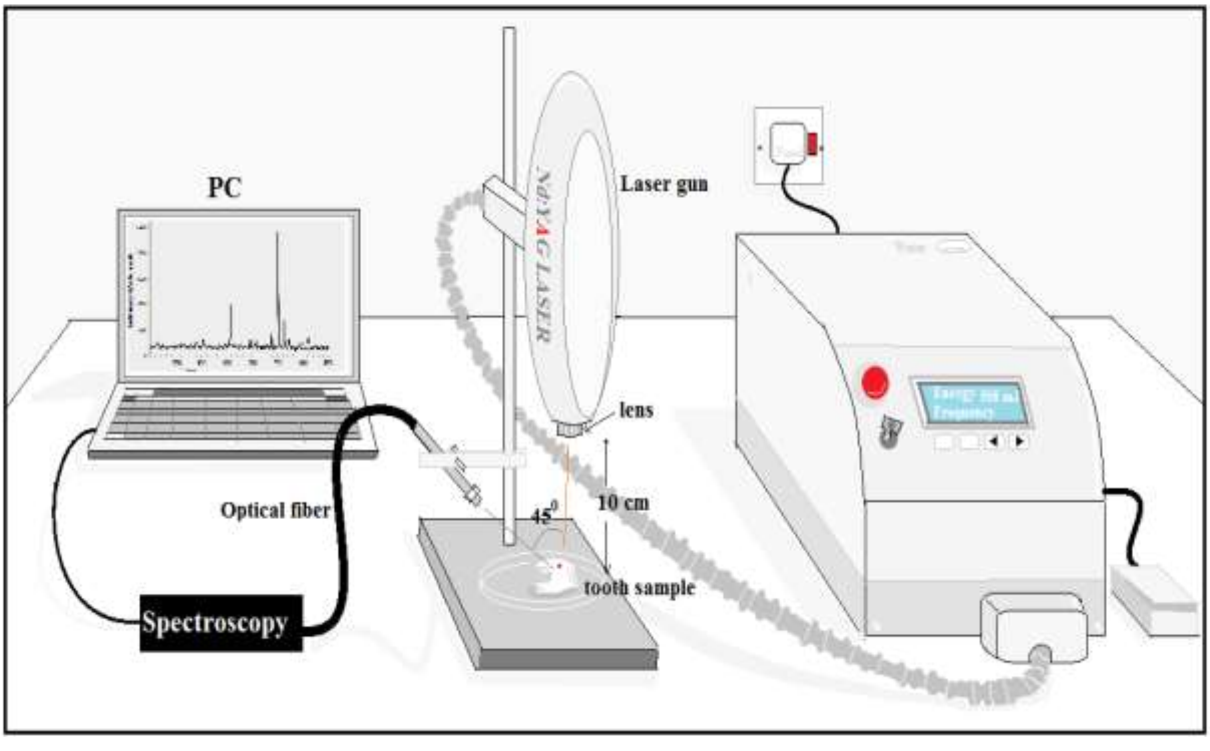

Fig. (1) The conventional LIBS system configuration

3. Results and Discussion

3.1 Healthy Teeth

The results obtained from the enamel of males and females healthy permanent teeth showed statistically significant differences for Ca, P,Na, Mg and Fe. Concentrations of Ca, P and Na were higher in females, whereas Mg concentration was higher in males. The atomic lines intensities of these elements increased at high energies compared with that of low energies. Figure (2,a and b) shows LIBS spectra of males and females healthy teeth, respectively of age less than30 years in spectral range 150-1000 nm at different energies of 300-800 mJ.

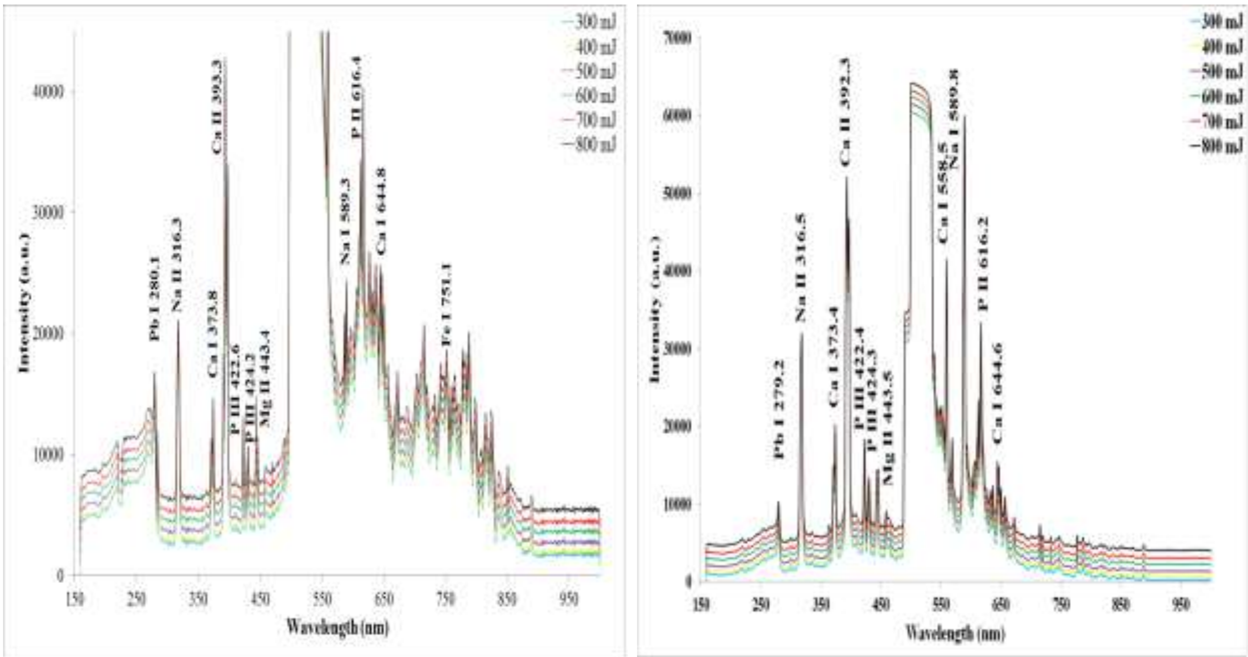

Fig. (2) LIBS spectra of healthy enamel teeth (a. Males and b. Females) at different energies

3.2 Human Teeth (Healthy and Carious)

Many elements, including Ca, F, Na, Mg, Fe and Pb were detected in the enamel of teeth samples. Changes of the elements relative composition of teeth are different with age and sex for healthy or non-healthy teeth.

Figures.(3-5) show the spectra of healthy and carious enamel tissue of male and female for age groups of(20-40),(40-60) and (above 60) years, respectively. It can be observed that the relative intensity of the elements Ca, P, Na and Fe for healthy enamel are higher than in carious enamel parts. A high contentof Pb and Mg was detected in the caries enamel. These results are in agreement with that of O. Samek[5].

Fig. (3) LIBS spectra of caries and healthy enamel teeth for group (20-40 year) (a. Males b. Females) at 800mJ

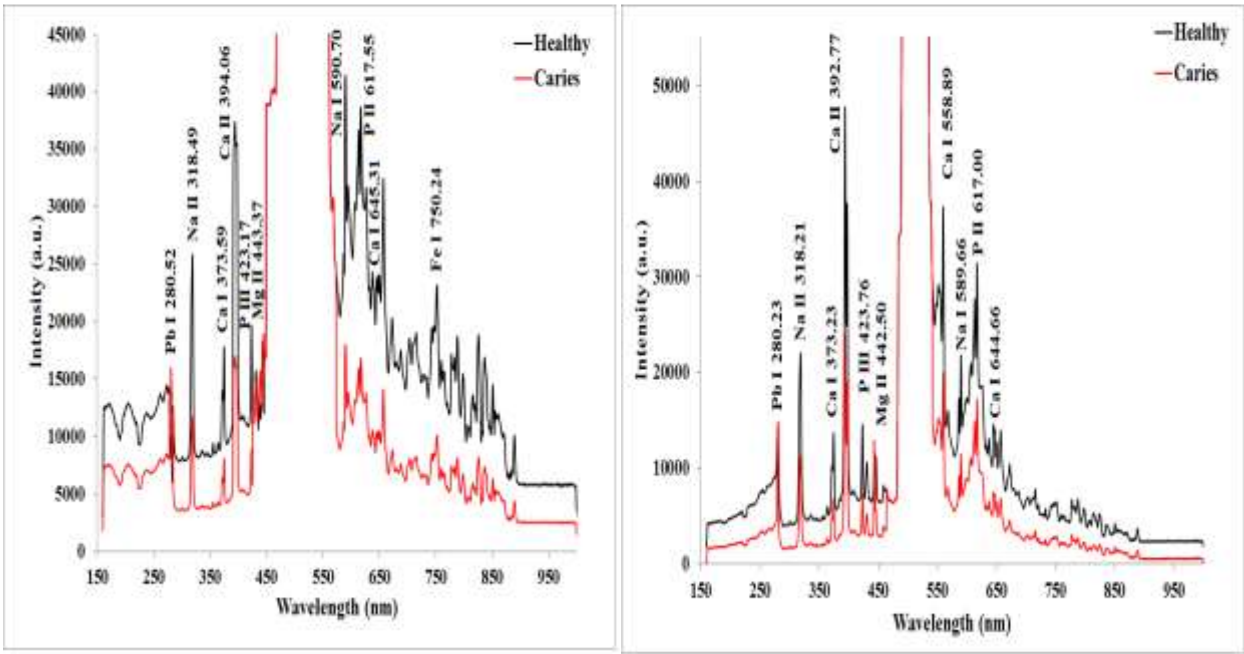

Fig. (3) LIBS spectra of caries and healthy enamel teeth for group (20-40 year) (a. Males b. Females) at 800mJ

a **b**

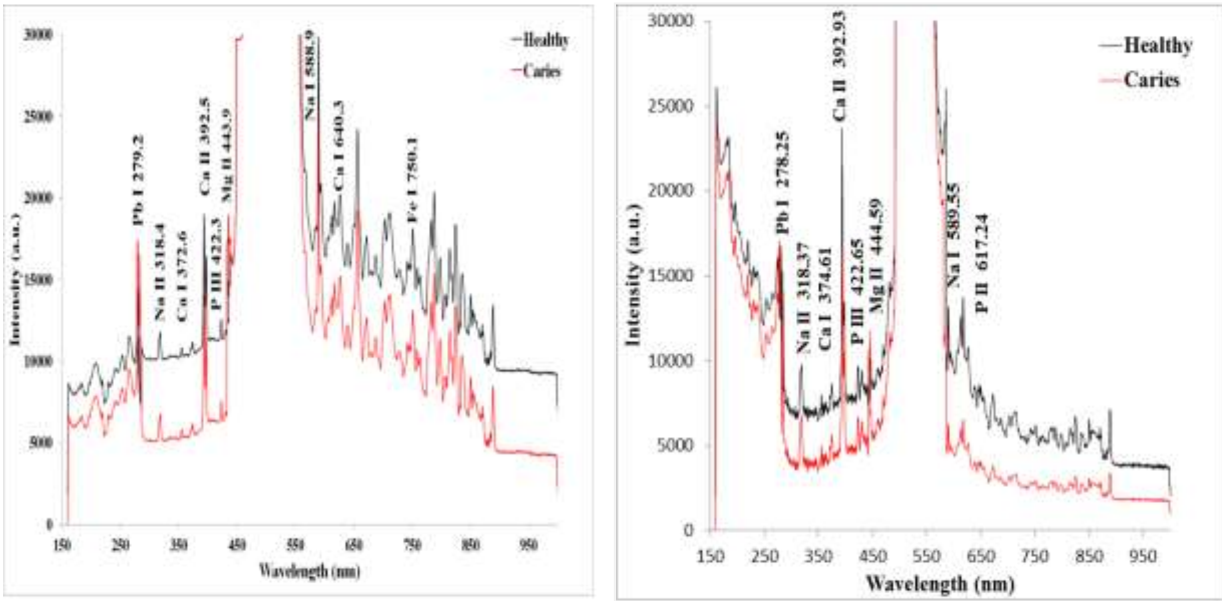

Fig.(4) LIBS spectra of caries and healthy enamel teeth for group (40-60year) (a. Males b. Females) at 800mJ

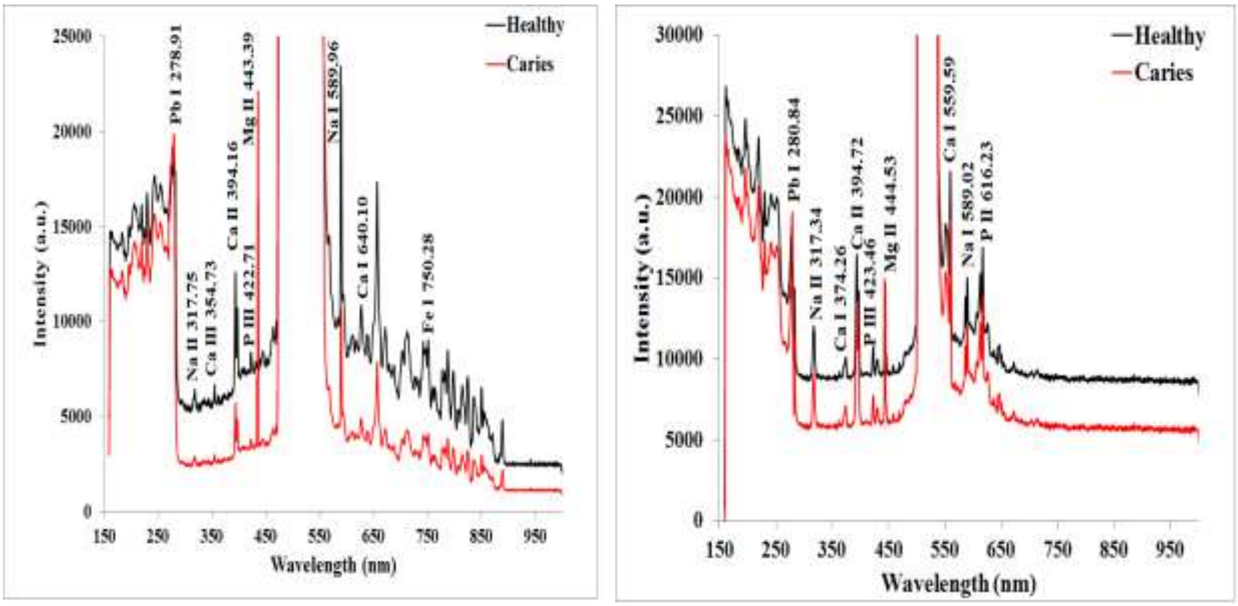

Fig. (5) LIBS spectra of caries and healthy enamel teeth for group (> 60 year) (a. Males b. Females) at 800mJ

3.3 Relative statistics of Ca and Pb in human teeth

This section studies Ca and Pb concentration in the enamel of teeth on the basis of database (age and sex). Figure.6 (a, and b) clearly depicts the Ca concentration of different ages and gender. It can be observed that maximum calcium concentration belongs to the age group 20-40, irrelevant of gender. Further, it is also observed that calcium concentration is almost twice in healthy teeth as compared to carious. In addition, it can be noticed from figure.6 (c and d), that lead can concentration in carious with age. But, carious parts of teeth have higher concentration of lead than its healthy parts. These results are agreement with that ofI. Baranowska[14].

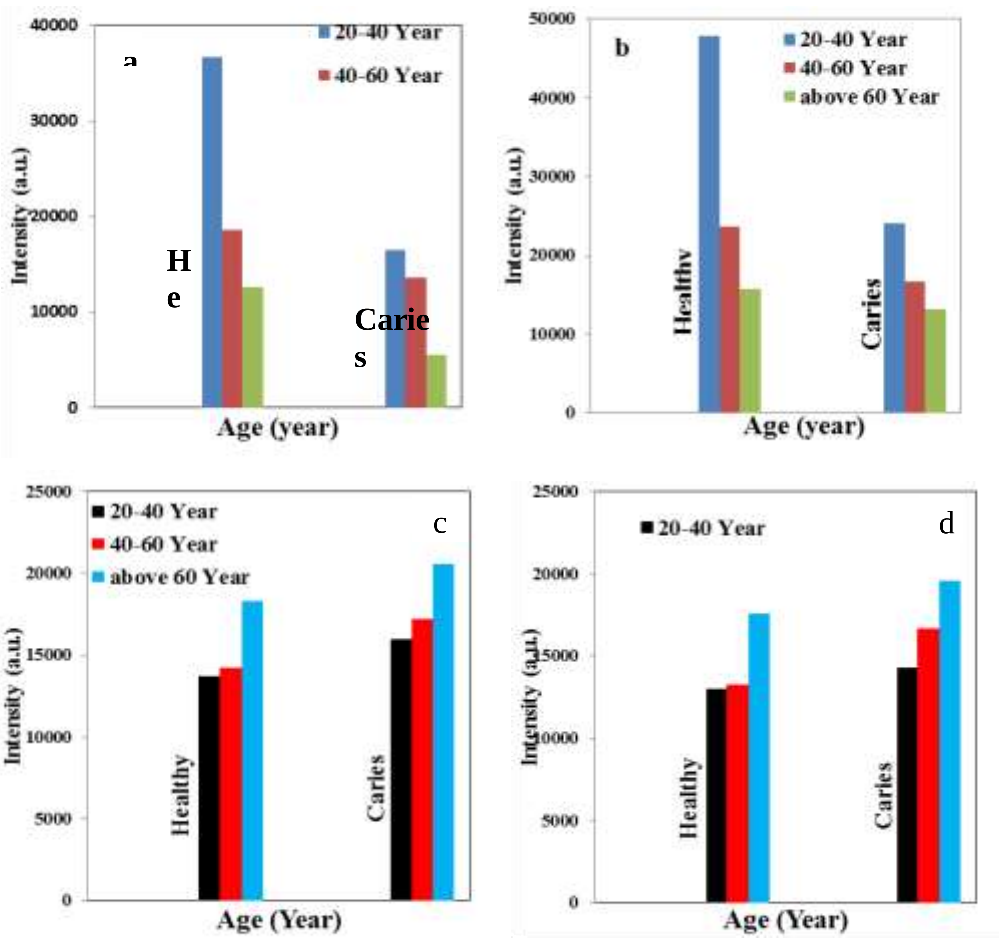

Fig. (6) Concentration of elements Ca and Pb at different ages (a. Ca in males, b. Ca in female's c. Pb in male's, and d. Pb in females)

3.4 Some qualitative analysis of plasma parameters

The plasma parameters can be used to calculate electrons temperature and electron density according to Boltzmann equation and Saha-Boltzmann equation, respectively [12, 13].The Debye length is the measure of the penetration depth of the external electrostatic fields, i.e. of the boundary charge sheath thickness. The applied electrical potential will therefore develop mostly near surface, over a distance λ_D ,called the Debye length and defined by [15].

$$\lambda_D = \left(\frac{\varepsilon_0 k_B T_e}{n_e e^2}\right)^{1/2} \quad \ldots\ldots (3)$$

Where $\varepsilon_\circ$ is permittivity of free space,$k_B$the Boltzmann constant and e^2electron charge. It can be showed that the Debye length is a function of electron temperature (T_e), and plasma density $n_e \cong n_i$(assuming singly charged ions). The plasma frequency of electron (ω_p) can be calculated by[15].

$$\omega_p = \left(\frac{n_e\, e^2}{\varepsilon_0 m_e}\right)^{1/2} \quad \ldots\ldots (4)$$

Table.1 shows the plasma parameters calculation from healthy human teeth samples.

Table1. Some qualitative analysis of plasma parameters

Te (eV)	1.243
n_e *10^{14}(cm^{-3})	3.176
λ_D(cm)	0.0000478
f_p(Hz)*10^{11}	1.604

4. Conclusions

The results of the present work have shown the potential use of the LIBS technique for discriminating between healthy and carious enamel teeth tissue of males and females. The concentration matrix elements (Ca and P) and non-matrix elements (Na, Fe) increase in healthy part while Mg and Pb increase in carious part. The concentration of several atomic elements in teeth sample changes with gender and age. Exploiting the changes in concentration ratios between the matrix elements (Ca and P) and non-matrix elements (Na, Fe, Mg and Pb), represented by the relative changes in the line intensities as seen in the LIBS spectra, of different ages and sex. The several atomic elements such as Ca, P and Na decrease with age. While a positive correlation for Pb and Mg content in teeth samples with age was noticed. The Ca concentration increases in females compare with males. Further developments could introduce LIBS allowing the dentist to monitor and control the problems of teeth during laser drilling of tooth.

Acknowledgment

Special thanks to Dr. Zainab AL-Shaibany for my assistance.

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