Characterization of smoker and non smoker human teeth using laser induced breakdown spectroscopy

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Abstract

In this work, the elemental constituents of smoker and nonsmoker teeth samples of human were analyzed by Laser induced breakdown spectroscopy method (LIBS). Many elements have been detected in the healthy teeth samples, the important once are Ca, P, Mg, Fe, Pb and Na. Many differences were found between (female and male) teeth in Ca, P, Mg, Na and Pb contents. The concentrations of most toxic elements were found significantly in the smoker group. The maximum concentrations of toxic elements such as Pb, Cd and Co were found in older male age above 60 year. Also, it was found that the minimum concentrations of trace elements such as Ca, P and Na exist in this age group. From these results it is clear that the LIBS technique is a powerful tool for fast identification of teeth problems.

Key words

Smoker teeth, non-smoker teeth, LIBS.

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توصيف الاسنان البشرية للمدخنين وعدم المدخنين باستخدام طيف الانهيار المحتث بالليزر

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الخلاصة

تم في هذا البحث تحليل مكونات عناصر نماذج من اسنان المدخنين وغير المدخنين بأستخدام طيف الانهيار المحتث بالليزر (LIBS). ثم تشخيص العديد من العناصر في الاسنان السليمة اهمها الكالسيوم والفسفور والمغنيسيوم والحديد والرصاص والصوديوم. تم ايجاد العديد من الفروقات في محتوى عناصرالكالسيوم والفسفور والمغنسيوم والصوديوم والرصاص لاسنان الذكور عن الاناث. وجد ان التركيز لاغلب العناصر السامة يختلف بشكل واضح في الاشخاص المدخنين. اكثر نسبة لتركيز العناصر السامة مثل الرصاص والكادميوم والكوبلت كانت في مجموعة الذكور ضمن العمر اكبر من 60 سنة. كذلك كانت اقل نسبة للعناصر الاساسية الكالسيوم والفسفور والصوديوم في نفس المدى العمري. يظهر بوضوح من هذه النتائج ان LIBS هي طريقة فعالة للتشخيص السريع لمشاكل الاسنان.

Introduction

Light emitting plasmas have been studied earnestly since the 1920s, and laser induced plasmas since 1960 [1]. Laser induced breakdown spectroscopy (LIBS) technique based on analyzing of atomic emission spectroscopy for excited atoms and ions of the elements in plasma formed on the surface of the samples by means of focused pulsed laser. There are several new developments of the LIBS method that are reported elsewhere [2]. The main benefit of the LIBS technique is that it can be used for direct chemical analysis without difficult chemical preparation provided for the samples. It has a very high sensitivity, reach parts per million [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].

Human teeth

The human tooth consists of four main tissues, enamel is the hardest material found in the human body which protects the other weakly tooth parts from damage, Dentine has a bone like consistency, pulp is found in the tooth center and contains vessels and nerves that keep the tooth alive and the cementum layer covers tooth root [6]. The crystalline enamel of a tooth is a biological composite containing 4% water, 95% mineral (carbonated hydroxyapatite), and 1% organic matter [7]. These components are not evenly distributed through the tissue. Hydroxyapatite is a mineral with an ideal composition of $Ca_{10}(PO_4)_6(OH)_2$. The carbonated hydroxyapatite in tooth enamel is crystalline in nature. A large number of trace elements in the range below the parts per billion concentrations are encountered in calcified tissues. The excess or deficiency of trace elements often provides information about diseased states [8].

Smoking effects

Nicotine is the most important constituent among more than 4000 potentially toxic substances in tobacco products. It is the main chemical component responsible for tobacco addiction, appears to mediate the hemodynamic effects of smoking, and has been implicated in the pathogenesis of numerous diseases [9]. Studies have also demonstrated the detrimental effects of smoking on oral health. A clinical study [10] observed that smokers had a higher prevalence of moderate and severe periodontitis and higher prevalence and extent of attachment loss and gingival recession than non-smokers, suggesting poorer periodontal health in smokers. In addition, smokers had a higher number of missing teeth than non-smokers. Concerning the bone-implant interface, the deleterious effects of tobacco smoke reflects a series of direct and indirect systemic and local effects on bone metabolism [11]. It has been strongly suggested that local exposure of the peri-implant tissues to tobacco products is the main factor leading to an overall increase in implant failure rate in smokers [12]. A recent meta-analysis on the subject [13] observed that smoking was associated with a higher risk of dental implant failure.

Some qualitative analysis of plasma parameters

The plasma parameters electron temperature and electron density can be calculated according to Boltzmann equation and Saha-Boltzmann equation respectively [14, 15].

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

where I_{ji} is the intensity of the spectral line of the transition from level j to 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 equals $(-KT_{exc}{}^{-1})$ [14, 15].

$$n_e = \frac{2(2\pi m_e kT)^{3/2}}{h^3}\frac{I^{I}_{mn}A_{jk}g^{II}_j}{I^{II}_{jk}A_{mn}g^{I}_m}\, e^{-(E_{ion}+E^{II}_j-E^{I}_m)/kT} \quad (2)$$

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.

Also 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 the surfaces, over a distance λ_D, called the Debye length (λ_D) and defined as [16]:

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

where ε_o is permittivity of free space, k_B the Boltzmann constant and e is the electronic charge. It can be showed that the Debye length is a function of the electron temperature (T_e), and the plasma density $n_e \cong n_i$ (assuming singly charged ions). The plasma frequency of electron (ω_p) can be calculated by [16]:

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

The number of particles in Debye sphere (N_D) can be calculated using the equation [16]:

$$N_D = 1.72 \times 10^9 \frac{T_e^{3/2}}{n_e^{1/2}} \quad (5)$$

where T_e in eV and n_e in cm^{-3}.

Experimental part

a. Samples preparation

The teeth samples were supplied by dental center in Alfurat Hospital (Baghdad, Iraq). They were washed in sodium hypochlorite diluted with distilled water for 10 min to remove all the contamination from the outer surface and dried at room temperature. Then they were preserved in formalin solution. Fig. 1 shows some of teeth samples using in the present work.

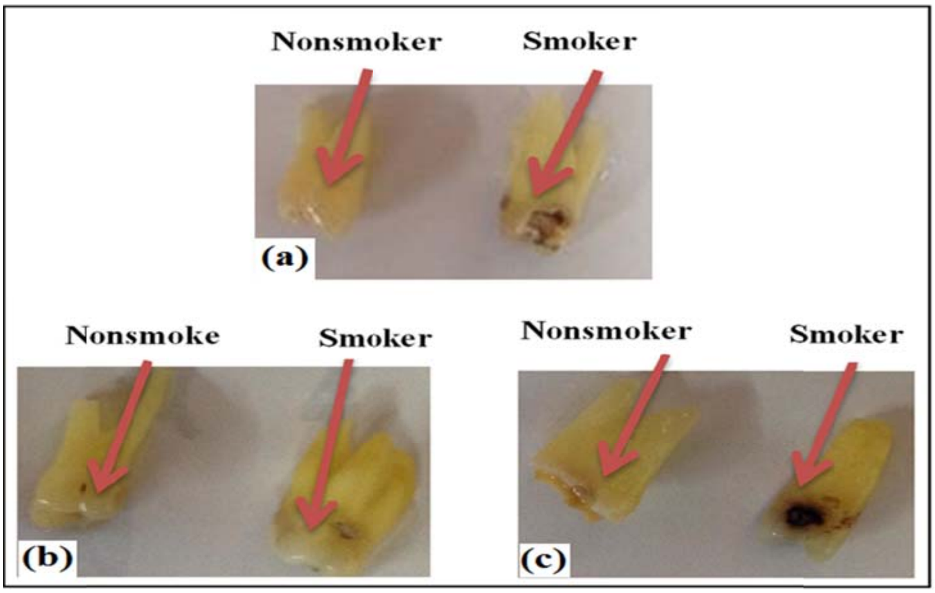

Fig.1: Some of teeth samples using in this work (a) permanent teeth age group (20-40 year) (b) permanent teeth age group (40-60 year) (c) permanent teeth age group (>60 year).

b. LIBS system

The optical emission spectra for plasma ablated from teeth samples surfaces were recorded using LIBS experimental system which is shown in Fig. 2. The system consists of pulse Nd: YAG laser with 10 ns duration and 10 Hz pulse repetition frequency, with wavelength 1064nm. Different energies (300- 800 mJ) were used laser beam is focused on the surface of the sample located at the focal length of the 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, at atmospheric pressure. Each spectrum was recorded over a 150-1000 nm wavelength range.

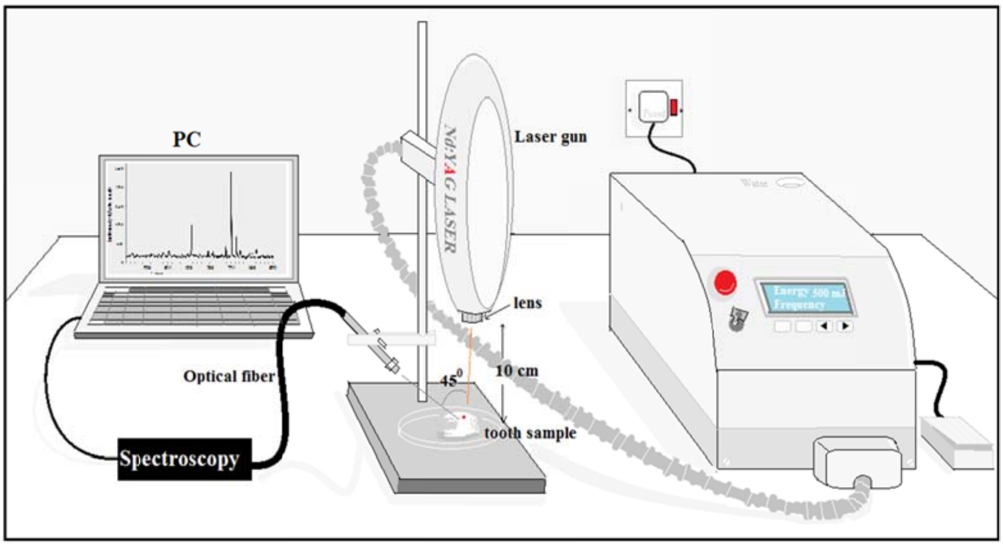

Fig.2: Schematic of the experimental setup for the laser induced breakdown spectroscopy.

Results and discussion

a. Non-smoker teeth

Fig. 3 shows LIBS spectrum of the healthy teeth for male and female ages less than 30 year in spectral range 150-1000 nm at different laser pulse energies varied from 300-800 mJ. It can be observed that the intensities of the atomic lines increased with increasing laser energy, it may be due to the increase in the number of atoms excited at high laser energies. Also the intensity of the atomic lines increased for female compared with male.

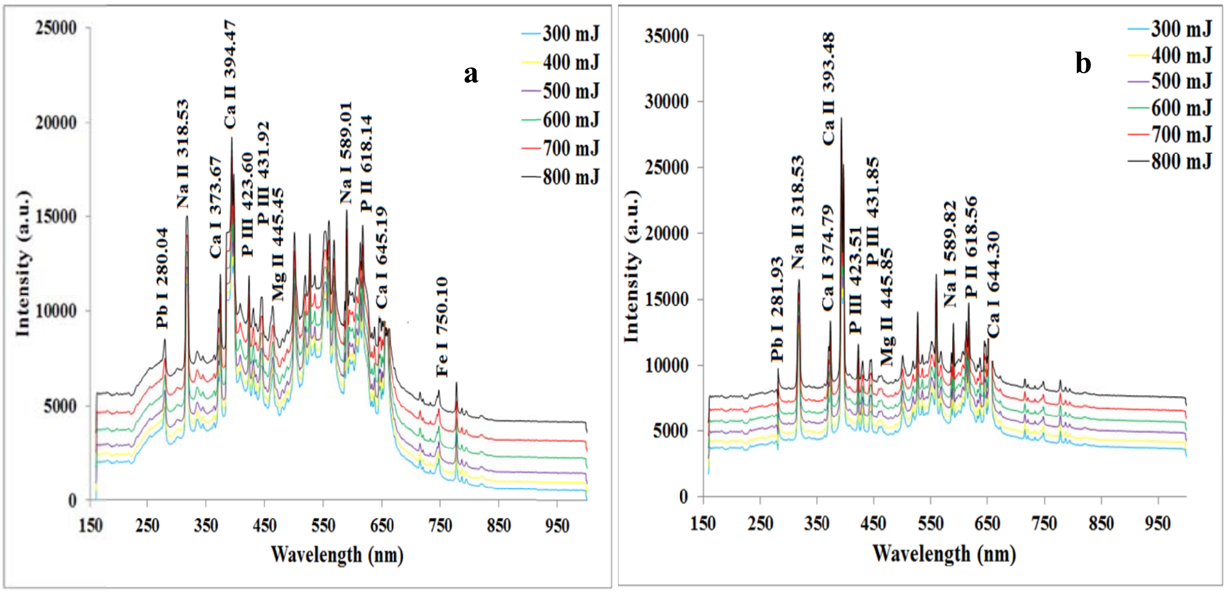

Fig. 3: LIBS spectra of healthy enamel teeth for (a) male and (b) female at different laser energies.

b. Smoker teeth

The LIBS spectra of different smoker teeth samples were recorded and are depicted in Figs. 4 and 5, age group (20-40 year), for males and females respectively. Different elements peaks were identified in the smoker teeth samples, such as Pb, Cd and Co, with trace elements (Ca, P, Na and Fe) within the range (150–1000) nm wavelength. The atomic transition lines of Pb, Cd and Co elements were more carried in males compare with females.

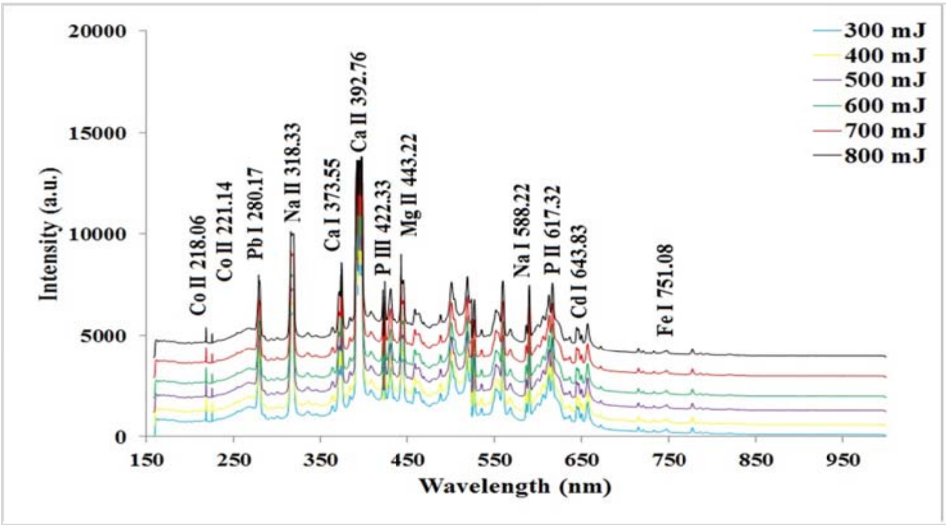

Fig.4: LIBS spectra of smoker enamel teeth for male group (20-40 year) at different laser energies.

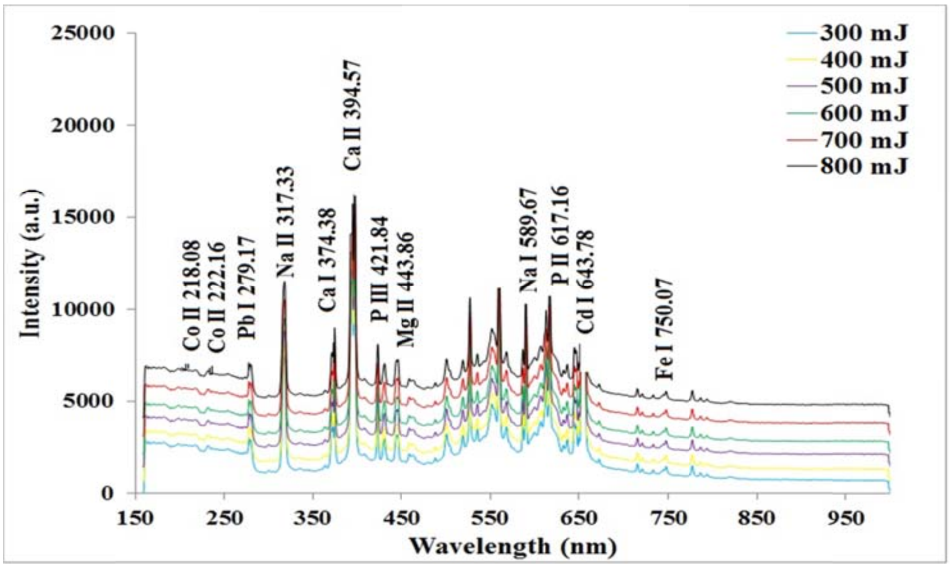

Fig.5: LIBS spectra of smoker enamel teeth for female group (20-40 year) at different laser energies.

The fingerprint wavelength of each element present in the smoker teeth samples was also identified as shown in Figs. 6 and 7 for males and females, respectively, with age group (40-60 year). The spectral marker lines of these elements were used for the calibration and quantifications of these elements. It was found that the concentration of toxic elements Cd, Co and Pb present in the teeth samples increase with age, while the trace elements Ca, P, Na and Fe decrease with age. The concentrations of most toxic elements were significantly high in the smoker group. This results due to adsorption of these toxic elements by periodontal teeth tissue for the smokers, which presence in passive smoking [17].

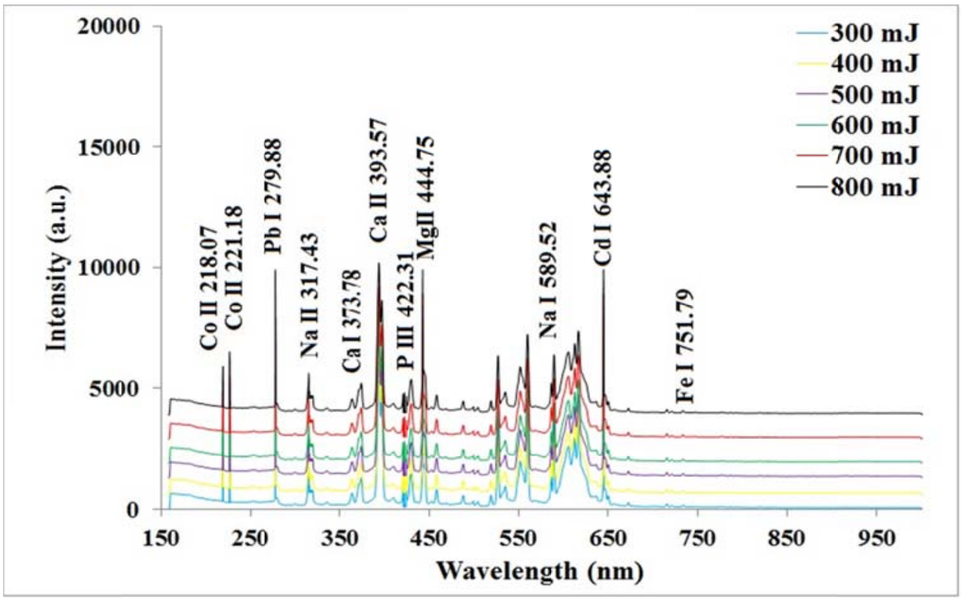

Fig.6: LIBS spectra of smoker enamel teeth for male group (40-60 year) at different laser energies.

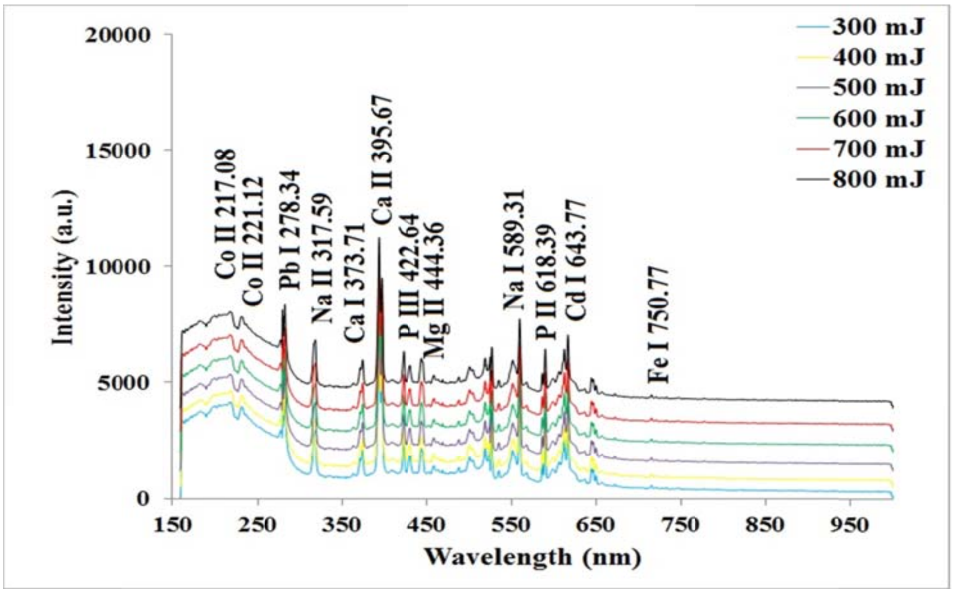

Fig.7: LIBS spectra of smoker enamel teeth for female group (40-60 year) at different laser energies.

Figs. 8 and 9 are charts plot of mean LIBS signal intensity recorded for elements in smoker teeth age group (above 60 year) for males and females, respectively. The maximum concentrations of toxic elements such as Pb, Cd and Co were found in older age above 60 year, smoking male, and the minimum concentrations of trace elements Ca, P and Na in this age group. It significant risk factor for the increase of clinical attachment loss, and these may be useful indicators of periodontitis high-risk groups [18].

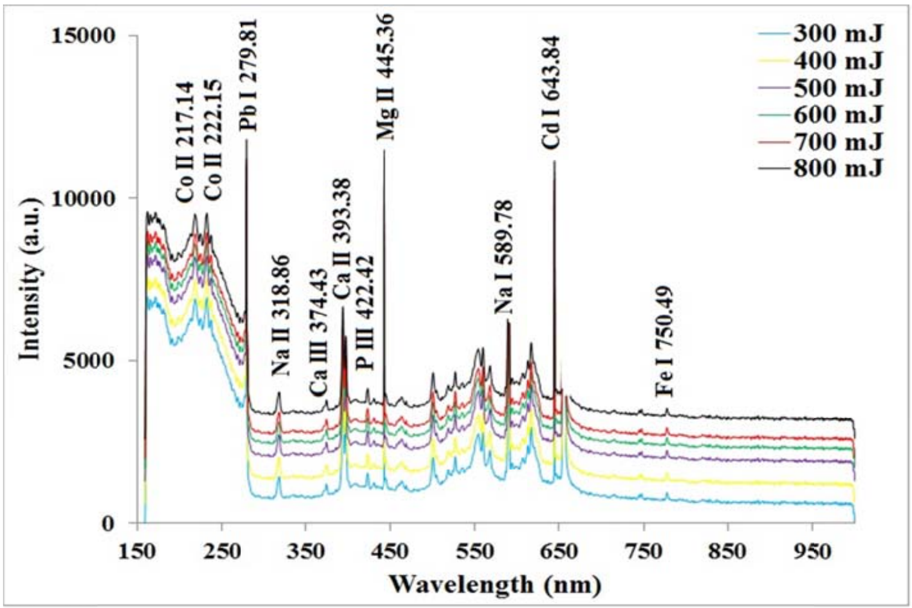

Fig.8: LIBS spectra of smoker enamel teeth for male group (>60 year) at different laser energies.

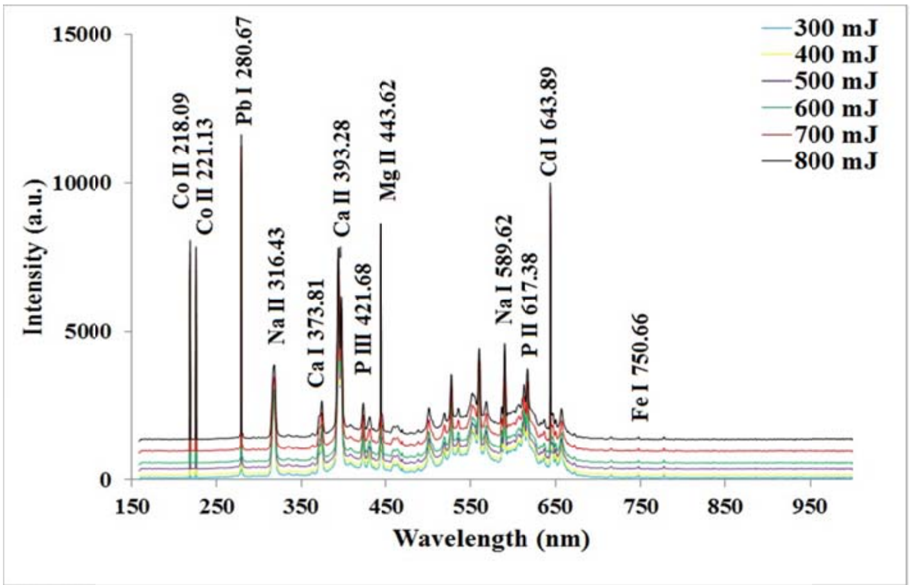

Fig.9: LIBS spectra of smoker enamel teeth for female group (>60 year) at different laser energies.

Also, the X- Ray fluorescence (XRF) used to investigate the elements concentration in smoker and nonsmoker teeth. Fig. 10 shows the relative statistics concentration of toxic elements cobalt and cadmium smoker teeth at different age groups. The maximum concentration of toxic elements Co and Cd were found in age group (above 60 year). The present of toxic elements in male smoker due to some habit like smoking or drinking alcohols are more as compared to normal [17].

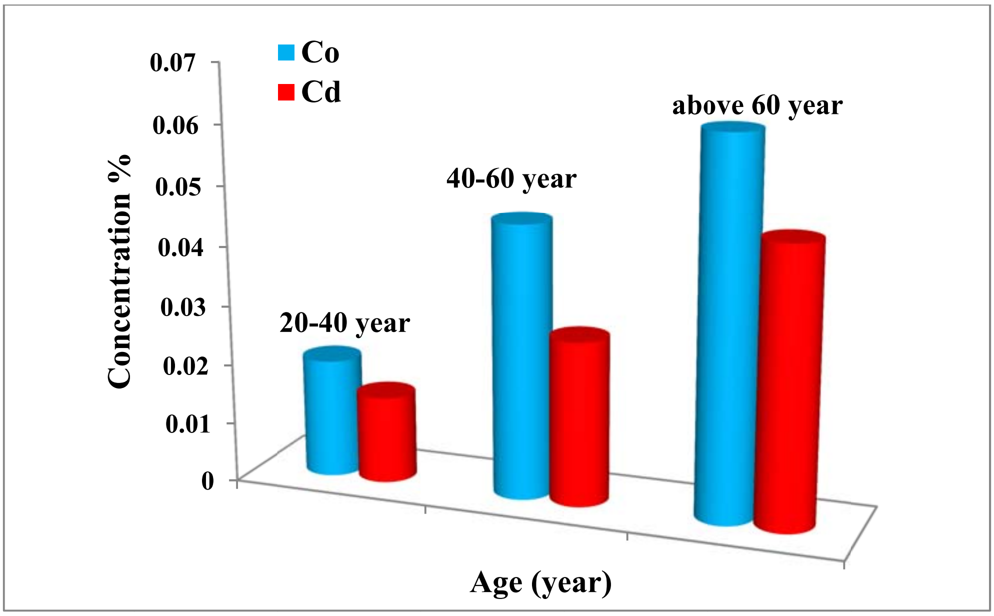

Fig. 10: Concentration of elements in smoker teeth at different age groups.

Fig. 11 shows the relative statistics of calcium concentration in smoker and nonsmoker human teeth according to age groups.

The maximum calcium concentration belongs to nonsmoker age group (20-40 year) compare with other groups. Furthermore, it is also observed that the calcium concentration is almost higher in nonsmoker as compared to smoker.

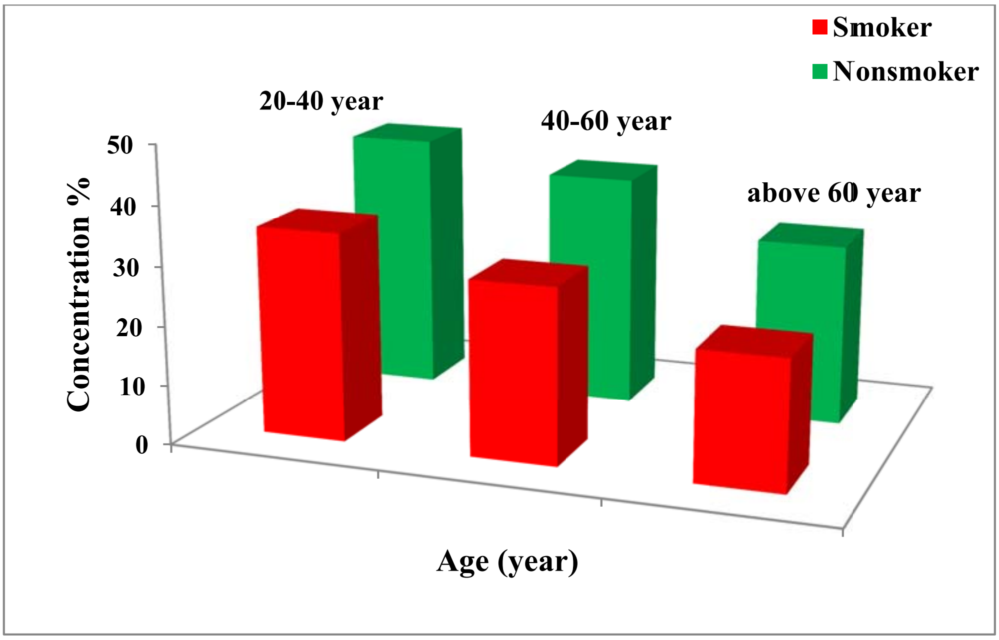

Fig. 11: Concentration of Ca in smoker and nonsmoker at different age groups.

Finally the plasma temperature is evaluated using Boltzmann Eq.(1) and the electron density can be calculated using Saha-Boltzmann Eq. (2). Also the Debye length (λ_D), plasma frequency f_p and number of particles in Debye sphere (N_D) were calculated using Eqs. (3 - 5) respectively.

Table 1 shows the plasma parameters calculation for nonsmoker human teeth samples, male and female, at different energy in mJ. The parameters of smoker human teeth don't calculate due to not appearance enough number of peek needed for calculation.

Table 1: Some qualitative analysis of plasma parameters for Ca element.

parameters	Age	Sex	No smoker
Te (eV)	20-40	Male	1.580
		Female	2.530
	40-60	Male	1.530
		Female	2.520
	Above 60	Male	1.510
		Female	2.480
n_e *10^{17}(cm^{-3})	20-40	Male	6.230
		Female	6.180
	40-60	Male	5.170
		Female	4.880
	Above 60	Male	5.110
		Female	4.550
λ_D (nm)	20-40	Male	373
		Female	473
	40-60	Male	403
		Female	532
	Above 60	Male	402
		Female	546
f_p (Hz)*10^{11}	20-40	Male	2.246
		Female	2.237
	40-60	Male	2.046
		Female	1.988
	Above 60	Male	2.034
		Female	1.920
N_D	20-40	Male	135.060
		Female	274.771
	40-60	Male	141.278
		Female	307.379
	Above 60	Male	139.328
		Female	310.782

Conclusions

LIBS technique can be used for direct chemical analysis for tooth samples without performing a sample preparation. The method has a high sensitivity and its detection for the problems of a tooth sample in a very short time. Distinguishing between nonsmoker and smoker teeth was possible by exploiting the change in the intensity ratios of the spectral lines of the matrix constituent elements Ca and P, and the non-matrix elements in the LIBS spectra of tooth sample. The concentrations of most toxic elements were significantly in the smoker group. The maximum concentrations of toxic elements such as Pb, Cd and Co were found in older male age (above 60 year). Also, the minimum concentrations of trace elements Ca, P and Na in this aged groups.

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