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 ones 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.

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].

\[
\ln \left( \frac{l_{ji}}{A_{ji}g_j} \right) = -\frac{E_j}{kT_{exc}} + \ln \left( \frac{h_c N_o}{4\pi U(T)} \right) \tag{1}
\]

where \( l_{ji} \) is the intensity of the spectral line of the transition from level \( j \) to \( i \), \( \lambda_{ji} \) 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 \( \ln \left( \frac{l_{ji}}{A_{ji}g_j} \right) \) versus the energy of the upper level \( E_j \) yields a straight line called Boltzmann plot. Its slope equals \( -K T_{exc}^{-1} \) [14, 15].

\[
\frac{n_e}{2(2\pi m_e kT)^{3/2}} \frac{l_{i m n A_{j k}}}{h^3} \frac{l_{i j k m}^{II}}{l_{i j k m}^{II}} e^{-(E_{ion}+E_j-E_m)/kT} \tag{2}
\]

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 $\lambda_D$, called the Debye length ($\lambda_D$) and defined as [16]:

$$\lambda_D = \left( \frac{e_0 k_B T_e}{n_e} \right)^{1/2} \quad (3)$$

where $\varepsilon_0$ 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 $n_e \approx n_i$ (assuming singly charged ions). The plasma frequency of electron ($\omega_p$) 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.

**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.
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.

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.
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].
Figs. 6 and 7 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) compared 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 ($\lambda_D$), 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.**

<table>
<thead>
<tr>
<th>parameters</th>
<th>Age</th>
<th>Sex</th>
<th>No smoker</th>
</tr>
</thead>
<tbody>
<tr>
<td>Te (eV)</td>
<td>20-40</td>
<td>Male</td>
<td>1.580</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Female</td>
<td>2.530</td>
</tr>
<tr>
<td></td>
<td>40-60</td>
<td>Male</td>
<td>1.530</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Female</td>
<td>2.520</td>
</tr>
<tr>
<td></td>
<td>Above 60</td>
<td>Male</td>
<td>1.510</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Female</td>
<td>2.480</td>
</tr>
<tr>
<td>ne *10^{17}(cm^{-3})</td>
<td>20-40</td>
<td>Male</td>
<td>6.230</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Female</td>
<td>6.180</td>
</tr>
<tr>
<td></td>
<td>40-60</td>
<td>Male</td>
<td>5.170</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Female</td>
<td>4.880</td>
</tr>
<tr>
<td></td>
<td>Above 60</td>
<td>Male</td>
<td>5.110</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Female</td>
<td>4.550</td>
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<tr>
<td>λ_D (nm)</td>
<td>20-40</td>
<td>Male</td>
<td>373</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Female</td>
<td>473</td>
</tr>
<tr>
<td></td>
<td>40-60</td>
<td>Male</td>
<td>403</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Female</td>
<td>532</td>
</tr>
<tr>
<td></td>
<td>Above 60</td>
<td>Male</td>
<td>402</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Female</td>
<td>546</td>
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<tr>
<td>f_p(Hz)*10^{11}</td>
<td>20-40</td>
<td>Male</td>
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<tr>
<td></td>
<td></td>
<td>Female</td>
<td>2.237</td>
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<td></td>
<td>40-60</td>
<td>Male</td>
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<tr>
<td></td>
<td></td>
<td>Female</td>
<td>1.988</td>
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<td></td>
<td>Above 60</td>
<td>Male</td>
<td>2.034</td>
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<td></td>
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<td>Female</td>
<td>1.920</td>
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<tr>
<td>N_D</td>
<td>20-40</td>
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<td></td>
<td></td>
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<td></td>
<td>40-60</td>
<td>Male</td>
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<td>Female</td>
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<td>139.328</td>
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<td></td>
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<td>310.782</td>
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</table>

**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.

**Reference**


