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Review Article

Applications of X-ray fluorescence analysis (XRF) to dental and medical specimens

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Summary Human tissues contain many kinds of minerals and trace essential elements that act as catalytic or structural components of large biochemical molecules. In addition, various metallic and inorganic materials are used in dental and medical materials and devices. In the dental and medical fields, specimens that are wet and/or have low heat resistance are often requested for elemental analysis. Therefore, a rapid and non-destructive method of elemental analysis is required. X-ray fluorescence analysis (XRF) provides useful elemental information about specimens without causing specimen damage or requiring extra specimen preparations.

In this paper, an outline of the XRF apparatus and applications of XRF to hard and soft dental and medical specimen tissues are presented, and dental materials are reviewed.

Contents

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1. Introduction to the trace element analysis using X-ray

Human tissues contain many kinds of minerals and trace essential elements that as catalytic or structural components of large biochemical molecules. Therefore, analysis of the quantification, distribution, and chemical state of trace essential elements could provide useful information, for example, in metabolism analysis. In addition, skin, respiratory, and digestive mucosa are sometimes exposed to various foreign objects. Especially, the oral mucosa comes into contact and is exposed to dietary and various restorative materials, for example, eroded ions or debris generated from metallic restorations. Additionally, the respiratory mucosa comes into contact with inhaled and entrapped airborne debris. These foreign objects sometimes result in various lesions; therefore, the analysis of foreign objects in tissues is important in determining the diagnosis.

Qualitative and quantitative analyses of the heavy elements in biological, medical, and environmental specimens are performed using various methods, and are tabulated in Table 1. Atomic absorption spectroscopy (AAS) and inductively coupled plasma atomic emission spectroscopy (or mass spectroscopy) (ICP-AES, MS) are the most popular methods for trace element analysis. These methods have high sensitivity (ppm—ppb); however, they require a liquid specimen. Therefore, solid specimens (e.g., biological and medical tissues) should be solubilized, for example, with an acid treatment. The solubilization process decreases the concentrations of the target elements; thus, the detection of trace elements becomes more difficult. In addition, information about the distribution and chemical state of trace elements is lost during the solubilization process. Furthermore, biomedical specimens are rare and restricted in amount; therefore, elemental analysis should be performed in a non-destructive manner.

Microanalysis using an electron probe microanalysis (EPMA) and energy-dispersed spectroscopy (EDS) are also commonly used to analyze elemental information (elemental composition and distribution information). These methods provide both microscopic imaging and elemental information using emitted characteristic X-rays from the observed area. Fig. 1 shows the mechanism of characteristic X-ray generation. The bombardment of high-energy electrons and high-energy X-rays strikes a bound electron in a target atom. After the electron has been ejected, an outer shell electron falls into the vacant inner shell and then emits a characteristic X-ray with energy equal to the energy difference between the outer and inner shell energy levels. Characteristic X-ray generated with high energy X-ray irradiation is called as ''fluorescent X-ray''. Each element has unique energy level sets of electrons; therefore, emitted X-ray energies are characteristic of each element. Table 2 shows examples of characteristic X-rays energies emitted from various elements [1]. Characteristic X-rays can be used to perform an elemental analysis by electron or X-ray irradiation.

EPMA and SEM/EDS are popularly used for micro-elemental analysis because they simultaneously provide electron microscopic images and elemental distribution images. However, there are some requirements for specimens in electron microscopy observation. The specimen should have electroconductivity (or an electroconductive coating) and kept under a high vacuum during observation. Therefore, wet specimens (e.g., cells or wet tissue)

Table 1 Methods for trace element analysis.

	Name of analysis methods
Destructive analysis	AAS (atomic absorption spectroscopy) ICP-AES (inductively coupled plasma-atomic emission spectroscopy) ICP-MS (inductively coupled plasma-mass spectroscopy)
Semi-destructive	LA-ICP-MS (laser abrasion ICP-MS) SIMS (secondary ion mass spectroscopy)
Non-destructive	EDS (energy dispersive X-ray spectroscopy) WDS (wavelength dispersive X-ray spectroscopy) XRF (X-ray fluorescence spectroscopy) NAA (neutron activation analysis) PIXE (particle induced X-ray emission spectroscopy)

Table 2 Example of characteristic X-ray energies of various elements.

Atomic number	Element	Characteristic X-ray lines (keV)		
		$K\alpha_1$	$K\alpha_2$	$K\beta_1$
22	Ti	4.511	4.505	4.932
23	V	4.952	4.944	5.427
24	Cr	5.415	5.405	5.947
25	Mn	5.899	5.888	6.490
26	Fe	6.404	6.391	7.058
27	Co	6.930	6.915	7.649
28	Ni	7.478	7.461	8.265
29	Cu	8.048	8.028	8.905
30	Zn	8.639	8.616	9.572