Printed in the Republic of Korea
ANALYTICAL SCIENCE & TECHNOLOGY
Vol. 36 No. 2, 99-104, 2023
https://doi.org/10.5806/AST.2023.36.2.99

Investigation of trace elements in incisor and molar teeth from two different geographical areas in Sudan using micro-particle induced x-ray emission (μ-PIXE)

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(Received January 18, 2023; Revised February 5, 2023; Accepted February 6, 2023)

Abstract: Trace elements (TEs) have significant effects on both dental health and human health. Toxic effects are caused by deficiency or excess of TEs. This study was performed to determine levels of toxic and trace elements in incisor and molar teeth sampled from male and female participants residing in the north and south regions of Sudan. The tooth enamel of 18 extracted human teeth was analyzed using particle-induced x-ray emission (μ-PIXE) to determine its elemental profile and distribution. GeoPIXEII software package was used for the analysis of μ-PIXE data. The main elements determined were Na, Mg, P, S, Cl, K, Ca, Mn, Fe, Zn, Co, and Sr which were homogeneously distributed in the areas of the tooth enamel mapped with micro-PIXE.

Key words: trace elements, μ-PIXE, homogeneous elemental profile distribution, tooth enamel, molar teeth, NMP techniques

1. Introduction

Ion beam techniques have been widely employed in dentistry and their sensitivity for trace elements in various thick tissue specimens was attentively investigated. Teeth are not homogeneous in elemental composition as demonstrated in earlier studies and consequently thick targets of dental caries were used for analysis.[1] The nuclear microprobe, which can measure simultaneously the concentration of fluorine (via PIGE) and calcium (via PIXE), is the ideal instrument for such studies.[2,3] Because the method can be applied to samples of various shapes, sizes, and states of matter, it has been employed for trace

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element analysis in a variety of scientific areas that span from anthropology to medicine.[4,5] Determination of the Ca : P ratio in samples such as bone and teeth[6] is of interest in biomedicine, and small variations in the Ca : P ratio are frequently studied in order to understand conditions such as osteoporosis,[6-12] and the ontogenesis of calcified tissue.[13,14] However, the concentration of trace elements in teeth, as well as interrelationships, seems to play a key role in the teeth health. For example, it is well known that fluorine has a remarkable effect on caries prevention as it makes the teeth less acids and more resistant to caries.[15]

Teeth are a potential interesting bio-indicator and can provide information concerning environmental and dietary habits. The tooth is a constituent of a very hard structure mainly composed of hydroxyapatite, a calcium fluoride phosphate, containing traces of impurities essentially incorporated by ionic exchange with calcium.[16] Since teeth accumulate a variety of trace elements, it is very interesting to study the elemental distribution in human teeth to evaluate biological processes. The spatial distribution of trace elements in tissues is further involved in many biological functions of living organisms.[17] The basic purpose of Proton induced X-ray emission(PIXE)technique is to detect with high sensitivity elemental constituents of the target (including elements in trace amounts) and determine quantitatively the elemental composition of the investigated sample.[18,19] Analysis for activation using protons of 1-3 MeV has been given a substantial step forward with the improvements of the micro-analysis mode and development of sophisticated software for on/off line deconvolution of x-ray spectra.[6] In recent years' applications of PIXE opened important areas of research with a significant sensitivity to compete with techniques such as XRF, EDXRF, EMP and/or SEM. The μ-PIXE technique is used to investigate the morphology as well as the elemental composition of human tissues on a microscopic scale. In addition, complementary ion beam techniques are used to provide information on the major and minor components of sample.[7,8,20-22] The reason behind this great interest in the concentration of elements and certain metals.

2. Experimental

2.1. Irradiation and Measurements

The objective of this experiment was to assess the concentration profiles of light elements and metals in the tooth enamel surface by nuclear microprobe analysis using the technique : PIXE. The study area was Khartoum the capital city of Sudan.[23] A set of 18 intact molar and incisor teeth were extracted under local anesthesia from persons living at the Khartoum region, Sudan, and obtained from two different hospitals, one in the north of Khartoum (N) and the other at the south of Khartoum (G). Some teeth had superficial early signs of decay on the enamel surface. The age range of the participants were between 6-91 years and included four children fourteen adults, stratified by female (11) and male (7). Micro-PIXE analysis of samples Samples were analyzed intact without any prior chemical treatment. Only the area exposed to the proton beam probe was cleaned with de-ionised water to remove possible organic material bound to the enamel as these particulates may influence true elemental content. Measurements were performed using the nuclear microprobe at the Materials Research Department of iThemba LABS, Somerset West, South Africa. The facility uses a 6 MV single-ended Van de Graaff accelerator and Oxford magnetic quadrupole triplet for beam focusing. A proton beam of 1.50 MeV energy and ~100 pA current was focused to a 5×5 μm^2 spot and raster scanned over selected areas of samples, using rectangular or square scan patterns, with a variable number of pixels (up to 128×128). PIXE spectra were registered with a PGT detector (30 mm^2 active area, working distance 24 mm), positioned at a take-off angle of 135º with a 25 μm-thick Be absorber to shield the detector from backscattered protons. The X-ray energy range was set between 1 and 40 keV. Data were acquired in the event-by-event mode. Evaluation of X-ray spectra was performed with the software package Geo-PIXE II].[6,7]

3. Results and Discussion

A total of 18 children and adults were included in the present study from two different regions Grafe West (G) and Khartoum North (N) in Khartoum, Sudan. Due to our primary interest in the concentration levels as inferred from the overall X-ray production of the particular irradiated area. Microanalysis as only the surface layers of the teeth were analyzed, only spot analysis was performed. outside of enamel micro-areas that are polluted by contaminants, the real variability of elemental composition may alter significantly. However, in order to complement the information previously available and to employ a similar analysis area as in prior experiments.[24] Both of the regions in this work are from urban areas with healthy and middle-class standards of living. Given that these are two entirely distinct regions, the similarity in mean matrix composition between the two is notable.[16,25,26] There were no obvious changes between the two groups G and N for the concentration, according to the information. Comparatively, quantitative micro-PIXE data for test materials revealed a considerable depletion and/or increase in various trace elements, including Fe, Cu, Zn, and Sr after exposure to 1.5 MeV Protons.

4. The Statistical Analysis of Data

Descriptive statistics were used to summarize correlation and correspondence analysis were performed using SPSS software to analyse. Correspondence analysis was done to screen relationships between geographical regions based on elemental profile and correlation analysis to screen for the strength and direction of associations between elements (where these for males and females and which geographical region. *Table* 1 summarizes the elemental concentrations of Ca, Mn, Fe, Co, Cu, Zn, and Sr of the teeth sample concentration levels: mean and standard deviation (STD) and relative error in (ppm) by gender, *Table* 2 shows descriptive statistics of the teeth sample concentration levels: mean and standard deviation by type and *Table* 3 displayed the coefficient correlation which showing the relations between the elements calculated by SPSS software package. *Figs.* 1 and 2 displayed a clear depiction of the distribution of the elements by gender and type respectively in both regions.[12,14,27-30] The most important finding of this study is the significantly decreased content of Co, Cu

Table 1. Descriptive statistics of the teeth sample elemental concentration levels (in ppm) : mean and standard deviation (STD) and relative error in (ppm) by Gender

Elements	Male		Female	
	Mean	Standard Deviation	Mean	Standard Deviation
Na	7.141,00	11.396,72	2.232,09	833,10
Mg	1.883,14	1.539,66	1.132,36	1.071,73
P	67.379,00	40.688,27	56.509,55	42.757,91
S	2.411,71	3.182,13	1.181,73	1.074,82
Cl	1.023,43	877,44	2.498,00	4.297,73
K	967,00	386,25	1.629,27	2.353,84
Ca	170.789,71	109.448,43	144.933,45	102.997,32
Sc	341,86	429,34	249,36	376,25
V	47,00	65,18	32,00	38,90
Cr	131,57	173,76	293,55	394,71
Mn	344,00	287,01	251,45	306,03
Fe	159,86	91,01	122,27	75,99
Co	76,57	114,91	25,09	55,82
Cu	5,29	13,98	,00	,00
Zn	191,57	136,54	131,36	193,57
Sr	5.003,29	4.709,63	4.477,09	4.077,10

Table 2. Descriptive statistics of the teeth sample concentration levels: mean and standard deviation by Type

Elements	Type			
	Child		Adult	
	Mean	Standard Deviation	Mean	Standard Deviation
Na	2.848,43	2.298,99	4.963,73	9.156,87
Mg	1.179,29	1.309,36	1.580,27	1.309,44
P	62.731,43	39.697,72	59.467,09	43.840,58
S	2.849,29	3.016,56	903,27	893,43
Cl	3.309,71	5.331,69	1.043,09	780,17
K	1.126,57	408,62	1.527,73	2.376,69
Ca	152.914,71	103.746,62	156.308,45	107.790,85
Sc	241,29	412,80	313,36	389,05
V	20,86	38,43	48,64	54,24
Cr	247,57	185,11	219,73	405,27
Mn	144,43	213,30	378,45	309,86
Fe	175,14	102,38	112,55	58,16
Co	48,29	63,35	43,09	98,76
Cu	5,29	13,98	,00	,00
Zn	264,57	208,15	84,91	101,99
Sr	4.785,71	4.741,53	4.615,55	4.067,90

Table 3. Coefficient correlation table showing the relations between the elements calculated by SPSS software package

	Na	Mg	P	S	Cl	K	Ca	Sc	V	Cr	Mn	Fe	Co	Cu	Zn	Sr
Na	1	.167	.282	-.032	-.086	-.052	.322	.412	.579	-.148	.273	.086	.696	-.149	-.056	.295
Mg		1	.250	-.020	-.250	.222	.282	.443	.680	-.152	.041	-.346	.278	-.290	-.210	.231
P			1	-.268	.194	-.268	.986	.650	.544	.564	.616	.208	.328	-.364	.022	.822
S				1	-.018	.076	-.330	-.328	-.362	-.188	-.209	.032	-.100	.007	.454	-.409
Cl					1	.001	.171	-.126	-.212	.146	.071	-.164	.254	-.307	.583	.238
K						1	-.169	-.122	.147	-.159	-.255	-.377	-.126	-.138	-.124	-.197
Ca							1	.702	.600	.506	.602	.198	.333	-.354	-.077	.868
Sc								1	.735	.020	.171	.235	.307	-.198	-.397	.744
V									1	.178	.370	-.013	.502	-.206	-.291	.445
Cr										1	.543	.218	-.184	-.171	.113	.125
Mn											1	-.025	.376	-.222	.132	.378
Fe												1	-.114	.649	.012	.155
Co													1	-.070	.411	.360
Cu														1	.201	-.273
Zn															1	-.184
Sr																1

and V in various teeth. It is well known for example Sr content of the food and hence the human intake varies considerably. However it looks that from the two *Tables* 1 and 2 that trace elements detection such as P, S, K,Ca, Sc, Fe, Cu and Sr are have similar levels closed to each other in quantity and that are different for the trace elements Na, Mg, Cl, V, Cr, Mn, Co and Zn. *Table* 3 define the correspondence analysis results which reveals the relative relationships between and within two groups of variables, based on data given in a contingency table, where N for the Khartoum North and G displaying Grafe West region.

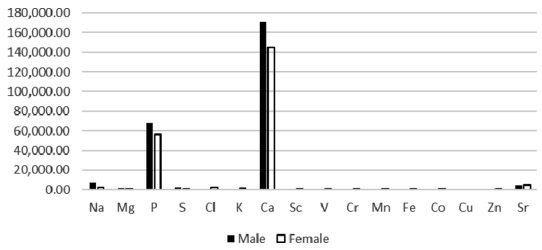

Fig. 1. Mean trace element concentration (in ppm) in enamel of human teeth. Lines on top of each bar indicate sample mean standard deviation.

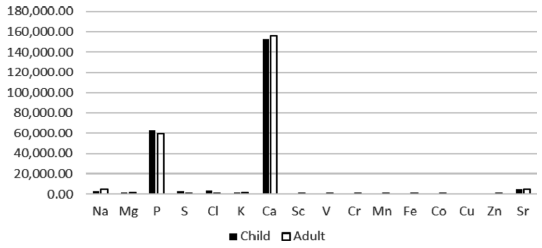

Fig. 2. Mean trace element concentration (in ppm) in enamel of human teeth.

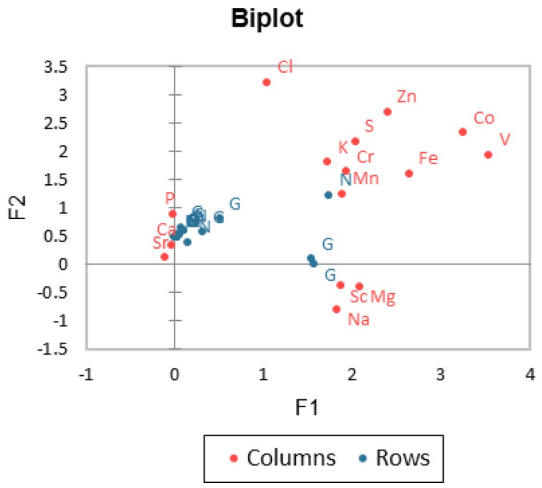

Fig. 3. Correspondence analysis result displaying the distribution of the regions and the trace elements for both regions.

5. Conclusions

All of the naturally elements are present in at least a trace level of contamination in all components of the environment. The study indicates that some elements, like calcium and phosphorus, had significantly different elemental concentrations, while the concentrations of the majority of the other elements varied only slightly. This is due to both regions are geographically close to one another, and their residents as well share similar lifestyles and dietary habits. However, both of these communities live along the banks of the River Nile, which greatly contributes to the similarity of their way of life. In the investigation of element uptake and (re)distribution at the tissue level, μ-PIXE provides a potent method and assistance. Fast sample preparation and its multielement methodology lead to its initial applicability. The study's findings provide a basis for biochemically focused research that could confirm. In neither region were toxic elements like S, V, Ni, Zn, or Pb found in greater concentrations. PIXE has proven to be an effective method for determining the concentration in biological and human hard tissues like teeth.

Acknowledgements

The authors would like to thank the Department of Materials Research at iThemba LABS for their support, Third Word Academy of Science (TWAS) Dr. Sara Mohamed, Grafe West Hospital, Dr. Z. Mohammed, Mr. M. Yassin, Northern Border University for the SPSS analysis.

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