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Daily urinary excretion of uranium in members of the public of Southwest Nigeria

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ABSTRACT

The main aim of this study was to determine and evaluate urinary excretion values of uranium in members of the public of Southwest Nigeria living in areas of low environmental uranium. As several uranium mines are running in Nigeria and the operations could be a risk of contamination for the workers as well as for the members of the public, biomonitoring of urine could provide information about the exposure to uranium for the subjects. Therefore, baseline values of uranium in urine are needed from subjects living in areas without mining activities. Volunteers of both genders (age range 3 to 78 years) were asked to collect 24 h-urine samples. The concentration measurements of uranium in urine were performed by Inductively Coupled Plasma Mass Spectrometry (ICP-MS). In addition, urinary creatinine values were determined for normalization of the renal uranium relative to the creatinine concentrations.

The urinary uranium concentrations and their creatinine normalized values ranged from <10.4 to 150 ng L^{-1} (median 13.8 ng L^{-1}) and from 2.52 to 252.7 ng g^{-1} creatinine (median 33.4 ng g^{-1} creatinine), respectively, for adult subjects above 15 years of both genders. An increased uranium excretion value of 61.6 ng L^{-1} (median), and of 76.0 ng g^{-1} creatinine, respectively, were found in young subjects below 15 years. The median of daily excreted uranium was estimated to be 14.2 ng d^{-1} for adults and of 45.1 ng d^{-1} for children, respectively. The uranium excretion from males and females living in Nigeria in a non-mining area was comparable to reference values reported from other countries with low level of environmental uranium. The data can be considered as baseline values of urinary uranium in unexposed subjects in Nigeria.

1. Introduction

The objective of this study was to determine and evaluate urinary excretion values of uranium in members of the public from Southwest Nigeria and to use these data as background values for humans living and working in areas of environmental low level of uranium. So far, such an investigation on daily urinary excretion of uranium is missing in Nigeria; and to the best of our knowledge no data are available from other African countries for comparison.

Uranium is a primordial radioactive element ubiquitously present in the Earth's crust at an average concentration of 2.8 mg kg^{-1} (UNSCEAR, 2000). Natural uranium consists of a mixture of three radioactive isotopes: ^{234}U ($t_{1/2}=2.455\times10^5$ y, 0.0054% by atom), ^{235}U ($t_{1/2}=7.038\times10^8$ y, 0.7204% by atom), and ^{238}U ($t_{1/2}=4.468\times10^9$ y, 99.2742% by atom). All three natural isotopes are alpha-emitters. Due to its presence in soil, rocks, surface and underground water, air, plants, and animals, uranium can be found in trace amounts in many foods and in drinking water, which represents the primary intake sources for non-occupationally exposed persons.

The daily intake of uranium is estimated to be 1–2 μg in food and 1.5 μg in drinking water (ATSDR, 1999). On the other side, occupational human exposure occurs primarily by inhaling dust and other small particles at workplaces that involve uranium mining, milling, or processing. Urine monitoring is the preferred method to determine workers' exposure to soluble compounds of uranium, since the quantity lost per day via urine is related to the total level of uranium present in the body. However, the interpretation of the measured uranium values in urine of workers requires knowledge of the baseline uranium excretion rate. Levels of natural background uranium in urine of unexposed subjects are reported for different regions and population groups and may reflect variable intakes of uranium through food and beverages (Dang et al., 1992; Ting et al., 1999; Bagatti et al., 2003; Heitland and Köster, 2006; Tolmachev et al., 2006; Muikku et al., 2007; Oeh et al., 2007a). For the major part of the world population, the average concentration of uranium in urine is about 10 ng L^{-1} in non-exposed subjects ranging from a few ng of uranium per liter to hundreds of ng L^{-1} (WHO, 2001). Higher values were found in Finland (Kurttio et al., 2002; Karpas

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et al., 2005b) and Jordan (Al-Jundi et al., 2004), which were attributed to a high natural uranium background in the environment.

Information on urinary uranium baseline levels in Nigeria, or more generally in African populations, is therefore of considerable interest, since uranium deposits have been discovered in several Nigerian states. Besides, in Nigeria, tin mining and processing extensively carried out in open pit style led to the accumulation of tailings with significant amounts of natural radionuclides like ^{238}U (Arogunjo et al., 2009; Leopold et al., 2009). Not only the mining activity itself, but also the circumstance of a considerable uranium ore deposit near large inhabited areas may contribute to an increased level of uranium in the environment and could lead to an enhanced uranium exposure of the workers and of the members of the public.

This study was set up to address the need for data on the distribution of uranium excretion in Nigerian subjects who were living in an area without mining activities and unlikely to have been exposed to uranium above the "normal" background levels. Inductively coupled plasma mass spectrometry (ICP-MS) was applied for the measurement of uranium in urine of the Nigerian study group. The use of this measure technique instead of traditional ones such as neutron activation analysis (Byrne and Benedik, 1991) and alpha spectrometry (Huertgen, 2001) has meanwhile become very widespread for uranium determination at trace levels in biological fluids due to its high sensitivity, high sample throughput and good precision (Allain et al., 1991; Haldimann et al., 2001; Oeh et al., 2007b).

2. Materials and methods

2.1. Subjects and urine sampling

A total of 213 Nigerian volunteers living in and around the city of Akure (capital of the Ondo State of the south-western region of Nigeria, West-Africa) participated in the study. Their daily urine excretion volumes and urinary uranium as well as creatinine concentrations were investigated. The randomly selected subjects (79 women and 134 men, age range 3 to 78 years) were not exposed to high levels of uranium and its compounds. The urine samples were collected during July/August 2008. All participants were provided with polyethylene bottles of 3 L capacity (Sarstedt, Nümbrecht, Germany) and were given instructions on how to collect the urine samples without contamination. Urine was collected over a period of 24 h. After the first void, the urine sample in the container was acidified with 0.5 mL HCL (20%) to prevent decomposition. The containers were returned to the laboratory after 24 h and the total volume/amount and weight of the 24 h-urine was recorded. As the estimation of the daily urine amounts turned out to be imprecise, the daily urine volumes (in mL) were calculated by dividing the weighed urine masses (in g) by the urine specific density factor; for healthy persons, the urine density was estimated at 1.020 ± 0.015 g mL^{-1} (ICRP, 1975). A 30 mL sub-sample of the daily urine collection was drawn and transferred to a sterile polystyrene test tube. These urine samples were transported without any delay from Nigeria to our laboratory at the Helmholtz Zentrum München and stored frozen at −20 °C until analysis. To determine urinary creatinine, the urine samples were sent to a medical laboratory and measured using an alkaline picrate procedure (Rock et al., 1986).

2.2. Uranium measurements

The uranium analysis of the urine samples was performed at the Central Analytical Service of the Helmholtz Zentrum München using a high-resolution inductively coupled plasma sector field mass spectrometry (ICP-SF-MS) model ELEMENT 1 (Finnigan MAT, now Thermo Electron, Bremen, Germany). The instrument parameters and the method applied have been described elsewhere (Schramel, 2002). Three aliquots were taken from each urine sample and analyzed. Fifteen urine samples (each 3 aliquots) were randomly selected and channelled again into measurement sequence for analyst-blind repetition. The urine samples were diluted 1:10 in 5% HNO_3. An internal standard solution (1 µg L^{-1} ^{193}Ir, final concentration) was added to each sample to correct for matrix interferences. The instrument was calibrated using a 6-point calibration between blank and 1000 ng L^{-1}. After ten measurements regularly, three blank determinations and a control determination of a certified standard were performed. Calculation of results was carried out on a computerized lab-data management system, relating the sample measurements to calibration curves, blank determinations and control standards. The detection limit, calculated as blank + 3 times the blank standard deviation (SD) was 1 ng L^{-1}, the limit of quantification (blank + 10 × SD) was LOQ = 10.4 ng L^{-1}.

2.3. Statistical data analysis

Arithmetic means, standard error of the mean (SE), medians and geometric means were calculated for urinary uranium concentration (ng L^{-1}), urinary creatinine (g d^{-1}), daily uranium excretion (ng d^{-1}) and uranium content normalized to creatinine (ng g^{-1} of creatinine). The box plots comprised values between the 25th percentile and 75th percentile distribution (lower and upper boundary of the box) while the line inside the box represents the median value. Extreme values are plotted as open squares.

3. Results and discussion

3.1. Subjects

The Nigerian volunteers of both genders were divided into children/adolescents (age range 3–15 years) and adults (age range 15–78 years). Table 1 presents the mean arithmetic body weights per age group; however, not all body weights were recorded. Noticeably, the body weights of the adult Nigerian males (61.2 ± 0.8 kg) and females (56.7 ± 1.6 kg) were lower than the body weight data assigned to the Reference Man of the International Commission on Radiation Protection (ICRP) that was based primarily on the Caucasian populations of Western Europe and North America (ICRP, 2003). The younger participants aged between 11 and 15 years did not reach the reference body weight values of the 15-years-old Caucasians boys and girls (56 kg and 53 kg). The body weights of the adult Nigerian subjects were rather similar to data of the Asian Reference Man that is based on the race of Mongoloids and the South Caucasian population (IAEA, 1998). Other anthropometric data, like height of the volunteers, were not measured in this study. However, Nigerian males and females, in general, have a body height lower than the Caucasians (168 cm and 158 cm versus 176 cm and 163 cm) (Rotimi et al., 1999) and are rather comparable to the Asians (170 cm and 160 cm). Even children in rural southwestern Nigeria exhibited substantially shorter height compared to reference means (Ayoola et al., 2009). These differences in anthropometry were kept in mind when the experimental data of this study were compared with the reference data of the ICRP. The Caucasian and Asian populations differ significantly in their physique, dietary habits and general

Table 1
Parameters of age and body weights of Nigerian subjects of both genders, in comparison to the ICRP Reference Man (ICRP, 2003) and Asian Reference Man (IAEA, 1998).

Nigerian subjects (number)	Age range (y)	Body weights of Nigerians (kg) mean ± SE	ICRP reference man	Asian reference man
			Body weights (kg)	
Male children (28)	3–15	28.9 ± 1.7		
Female children (21)	3–15	28.7 ± 2.1		
All children (9)	3–5	18.7 ± 0.8	M[a] 19, F[b] 10	
All children (28)	6–10	28.3 ± 1.3	M 32, F 32	
All children (12)	11–15	37.5 ± 2.9	M 56, F 53	
Male adults (91)	16–78	61.2 ± 0.8	73	60
Female adults (49)	16–60	56.7 ± 1.6	60	51

a: M = males; b: F = females.

life style. Obviously, there is also a distinction between the Caucasians and the Africans. However, the population of West Africa, thus of Nigeria, have to be regarded as a major variable ethnic group. There may be, in addition, a difference on where Africans are living (i.e., living as local inhabitants or as people of African heritage in e.g. USA). Due to their changed life style and nutrition, the Afro-Americans often show similar high body weights to the Americans and therefore differed from the Nigerian study group (Luke et al., 1997; Jacobs et al., 2002; Bankir et al., 2007).

3.2. Urinary creatinine

Creatinine, a natural metabolic product of creatine (muscle metabolism), is produced at a nearly constant rate in the body due to muscular activity and is excreted through glomerular filtration in the urine. Urinary creatinine is significantly correlated with age, body weight and is influenced by the muscle mass (Heymsfield et al., 1983; Baxman et al., 2008). Further, high dietary protein can increase the urinary creatinine value. Analysis of creatinine in urine is widely used for testing the completeness of 24 h-urine samples.

Creatinine values of all volunteers were measured and analyzed in urine corresponding to the guidelines of the WHO (1996) (WHO, 1996). These guidelines for valid urine samples recommended urine samples with a range of 0.3–3.0 g L^{-1} creatinine that corresponded in general to the urinary creatinine values of the adult population. Exceptionally high or low creatinine levels may indicate problems with the sample (incomplete collection, direct or indirect dilution of the sample) or the subject (abnormally functioning kidneys). In these cases, such samples may be rejected. In the present study, 50 out of the 213 urine samples fell below these guideline values ($<$0.3 g L^{-1}). There was no sample with a creatinine concentration above 3.0 g L^{-1}. However, in children or elderly people over 60 years, the production and excretion of creatinine could be diminished, presumably reflecting a lower muscle mass in these groups. Therefore, in our study, a urinary creatinine concentration of minimum 0.2 g L^{-1} was still accepted for the younger (3–15 years) and the elderly people ($>$60 years). As a consequence, 40 urine samples in total were rejected; hence, 173 samples were utilized for the calculation of the daily creatinine excretion rate for both age groups and genders. These data are shown in Fig. 1. The adult female group revealed lower creatinine values (1.05 ± 0.07 g d^{-1}) than the adult males (1.38 ± 0.10 g d^{-1}), as was expected due to a usually lower muscle mass of women. Within the group of boys and girls, there was scarcely a difference in the daily urinary creatinine excretion amount. According to ICRP 89, the reference man and woman excrete 1.7 g d^{-1} creatinine and 1.0 g d^{-1} creatinine, respectively (ICRP, 2003). The creatinine excretion of the adult Nigerian males was remarkably lower than that of the ICRP reference man, whereas the excretion values of the Nigerian women were similar to the values of the ICRP reference women. The arithmetic mean amount of urinary creatinine of the male and female young subjects up to 15 years was low (0.60 ± 0.11 g d^{-1} and 0.64 ± 0.11 g d^{-1}, respectively) and rather comparable to ICRP data of a 10 years old group (0.65 g creatinine per day). Other reports on creatinine excretion mentioned higher values in Africans than Caucasians (Jacobs et al., 2002; Barr et al., 2005) or a 5% higher urine creatinine per kg body mass, which was attributed to a higher relative muscle mass in Africans (ICRP, 2003). However, all these study groups were Afro-Americans with high body weights and probably changed life style and nutrition, and not local inhabitants of Nigeria.

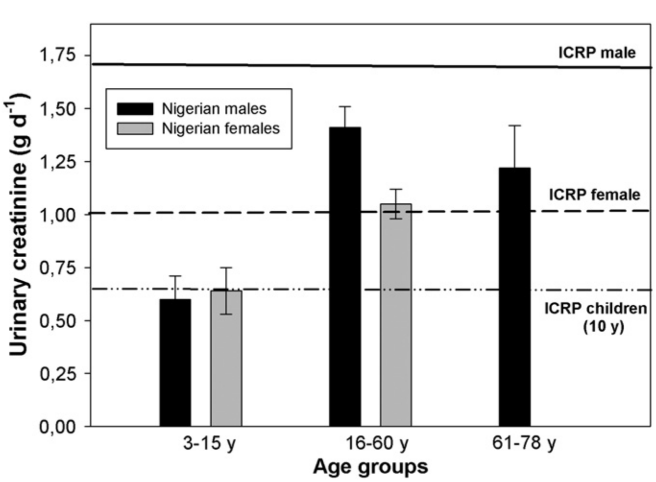

Fig. 1. Daily urinary creatinine excretion of Nigerian males and females of different age groups, compared to the ICRP reference data of male and female adults and of the 10 years old group (ICRP, 2003).

As mentioned above, the ICRP Reference Man comprised the Caucasian race with a higher body weight in comparison to our investigated Nigerian males. Their lower creatinine production and lower urinary excretion could be explained by a reduced muscle mass probably caused by a chronic malnutrition (Rotimi et al., 1999) or low intake of (red) meat. Meat is not the common diet in Nigeria, which is mostly comprised of vegetables, grains and tubers (roots) (Arogunjo, 2003; Jibiri et al., 2007). In particular, Akure is the trade center for a farming region where cocoa, yams, cassava, and corn are grown.

The creatinine clearance depends also on nephron functioning; therefore, the reduced creatinine values, specially found in the Nigerian adult men and also children, could partly be due to the high incidence of kidney problems observed in Nigeria (Alebiosu et al., 2006; Bamgboye, 2006). Chronic glomerulonephritis and hypertension together with diabetes mellitus are the principal causes of kidney diseases in the Tropical Africa and East Africa, and acute renal failure often based on malaria infections are common in Nigeria, especially with children (Olowu and Adelusola, 2004).

3.3. Urine volumes

The frequency distribution of the daily (24 h) urine excretion volumes of the Nigerian male and female participants is presented in Fig. 2. Only those data of volunteers are used whose urinary creatinine values were within the range of 0.2–3.0 g L^{-1}. In general, the measured urine volumes ranged between 326 mL and 3000 mL and reflected the individual variability for both genders. The urine volumes of the males peaked between 800–1200 mL d^{-1}, with a median of 1183.3 mL d^{-1} for the adults. The daily urine volumes of the females showed a broader distribution with a median of 1622.5 mL d^{-1} for the adult women. As presented in Table 2, the arithmetic mean values ($\pm$SE) for males were found to be 1302.1 ± 57.4 mL d^{-1} for the adults and 760.1 ± 60.1 mL d^{-1} for the age group below 15 years. The corresponding arithmetic mean urine excretion volumes of the female adults were 1596.3 ± 84.0 mL d^{-1} and 984.8 ± 143.7 mL d^{-1} for the younger subjects below 15 years, respectively. The urine volumes of the Nigerian females significantly differed from the currently assumed reference value of the ICRP 89 standard female of 1.2 L d^{-1} (ICRP, 2003). However, an American study on ethnic differences in urine volumes found also similar high daily urine volumes of 1.6 L d^{-1} for the American women; furthermore, gender differences in the group of Afro-Americans were reported with women having urine volumes approximately 20% higher than men (Bankir et al., 2007). This corresponds to our results. According to ICRP-89, the standard male (of 73 kg) excretes 1.6 L d^{-1} of urine volume. Hence, the Nigerian adult men of our study excreted less urine per day than the ICRP reference man. The study by Bankir et al. (2007) estimated also daily urine volumes to be significantly lower (ca. 20%) in Afro-Americans than Americans (Bankir et al., 2007); this may be also applicable to our results. It was reported that Africans, in comparison to Caucasians, excreted more concentrated urine possibly due to a lower capacity of ion reabsorption in their renal diluting segment (Hancock et al., 2010). It is discussed that a slower urine flow rate and a less excretion of urine could have provided an advantage

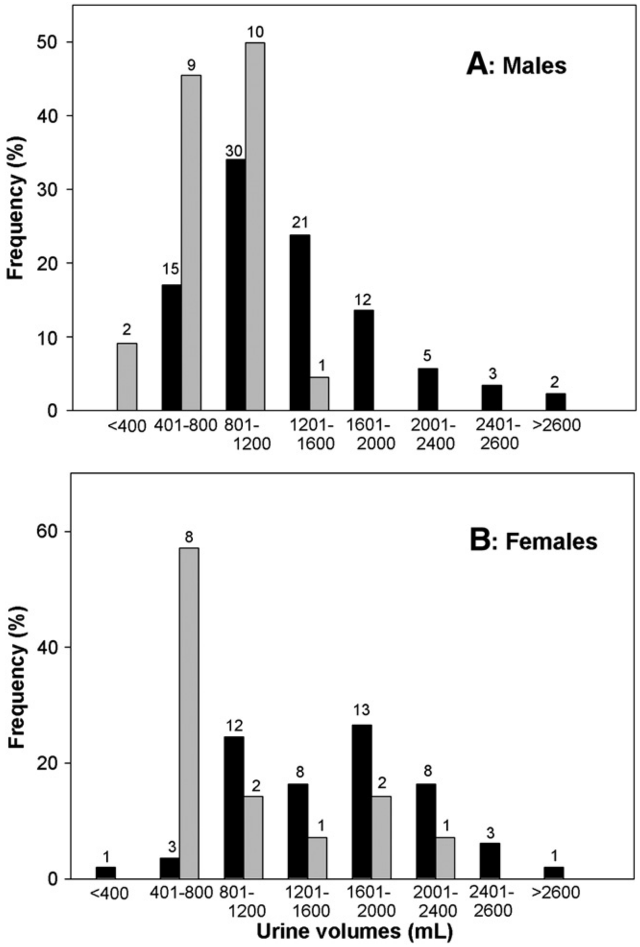

Fig. 2. Frequency distribution of daily (24 h)-urine volumes of Nigerian subjects. (A) males, (B) females; gray bars: children; black bars: adults. Figures above the columns represent the number of subjects.

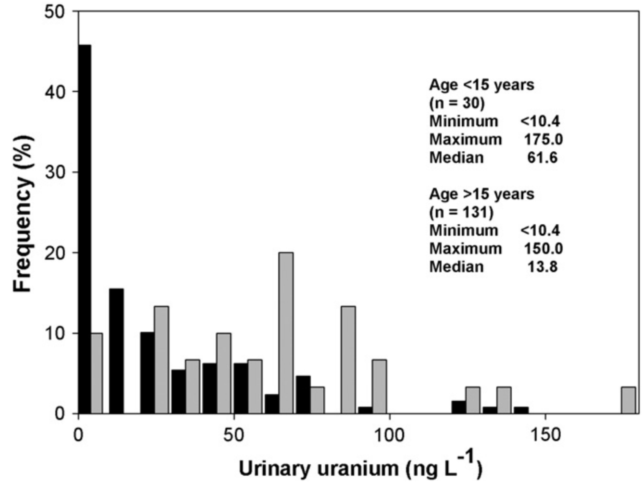

Fig. 3. Frequency distribution of uranium concentration in urine of unexposed Nigerian subjects of both age groups (gray bars: children; black bars: adults). First two rows indicate the range below the quantification limit (LOQ = 10.4 ng L^{-1}).

with respect to the ability of the Africans living in a tropical hot and humid climate to conserve water. A considerable amount of water (and electrolytes) is lost from the body in form of sweat and an enhanced sweating in Nigeria, as in other tropical countries, is well known, specially referred to men who lose more sweat than women (Ugwu, 1991). All of this could explain the reduced urine volume formation of our Nigerian male study group. Additionally, women working at home/kitchen might have the chance to drink more fluid and therefore excrete more urine than men.

In this respect, a pilot study on daily urine volumes of a small group of male subjects in two parts of Nigeria of different altitude and weather conditions found lower urine volumes (and lower urinary creatinine values) compared to the ICRP 89 data (Arogunjo et al., 2007). The daily dietary habits and level of exercise are considered to contribute significantly to the daily urinary excretion in these subjects; and environmental factors, such as air temperature, pressure, and humidity seemed to play a major role in the tropical environment of Nigeria.

3.4. Uranium excretion

Uranium ingested by food and drinking water will be gradually excreted and can be detected and quantified in samples of urine. The uranium content in urine in the general population may vary considerably depending on where people live, their diet and their drinking water.

Fig. 3 illustrates the distribution of the excreted uranium in urine of the Nigerian study group. The uranium concentrations in the 24 h-urine samples for the 30 subjects below 15 years ranged from limit of quantification (LOQ = 10.4 ng L^{-1}) to 175.0 ng L^{-1} with a median of 61.6 ng L^{-1}. Two values far above 350.0 ng L^{-1} were not included due to problems during sample preparation. For adults (>15 y), the concentrations of uranium in urine varied between "not detectable" to 150.0 ng L^{-1}, with a median of 13.8 ng L^{-1}. These data showed a log-normal distribution. About 56% of all 161 measured urine samples of adults and children showed unquantifiable uranium concentrations, mostly referred to adult males (50%). The number of usable samples was less than the actual 173 urine samples; 12 samples have been ignored for further analysis as no reliable results could be obtained after repeat measurements.

The analysis results for the group of children and adults were separated into gender and are summarized in Table 3. In order to compare

Table 2
Daily urine volumes of Nigerian volunteers (n = 173) compared to data of the ICRP Reference Man (ICRP, 2003).

Nigerian subjects (number)	Age range (y)	Urine volumes (mL d^{-1}) mean ± SE	ICRP reference man (mL d^{-1})
Male children (22)	3–15	760.1 ± 60.1	
Female children (14)	3–15	984.8 ± 143.7	
All children (8)	3–5	597.8 ± 19.1	500
All children (24)	6–10	868.4 ± 6.79	700
All children (5)	11–15	1231.9 ± 139.2	1200
Male adults (88)	16–78	1302.1 ± 57.4	1600
Female adults (49)	16–60	1596.3 ± 84.0	1200

Table 3
Uranium concentrations in urine of children (<15 y) and adults (>15 y); mean, range, geometric mean (GM), median values and percentage below LOQ are presented.

Subjects (number)	Mean[a] (ng L^{-1})	Range (ng L^{-1})	GM (ng L^{-1})	Median (ng L^{-1})	%<LOQ
Children					
Male (18)	71.4	20.4–175.0	61.3	66.2	0
Female (12)	43.7	LOQ-92.9	28.3	42.0	25
Adults					
Male (85)	22.9	LOQ-132.7	13.1	5.2	50
Female (46)	31.1	LOQ-150.0	18.3	19.3	36

[a] Concentrations of uranium below the LOQ were calculated as LOQ/2.

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the results with those of other studies, the arithmetic mean (M) and geometric mean (GM) were also calculated.

The uranium excretion data of the children's group were significantly higher than the adult excretion data. Possibly, these higher values observed with children may be associated with incorrect sampling, such as contamination of urine samples with dust/soil during sampling, e.g., due to removing of the bottle cap prior to providing the urine sample or due to unwashed/dusty hands. Furthermore, behavioral characteristic of children differ from that of adults. Children spending their time more often outdoors and playing on the ground may be exposed to uranium in dust/soil particles, thereby also consuming soil particles by hand-to-mouth activities. Hence, children could absorb, and excrete, more uranium via soil ingestion than adults. A study on uranium content in soil from different regions in Nigeria determined a uranium concentration of approximately 5.3 mg kg^{-1} (66 ± 11 Bq kg^{-1}) in the soil of Akure (Arogunjo et al., 2009), which was higher than the mean soil uranium concentration of 2.8 mg kg^{-1} reported by UNSCEAR (2000) (UNSCEAR, 2000).

Similar differences between children and adults in their uranium excretion were found by normalizing the urinary uranium concentrations to urinary creatinine concentrations to reduce effects of urine dilution (McDiarmid et al., 1999). The results are presented as box plots in Fig. 4 showing increased excretion values in children. This might be due to the fact that they excreted less creatinine and more uranium than the adult subjects. The adult women showed significantly higher values compared to the men. In total, the value of 16.5 ng g^{-1} creatinine (median) for adults was higher than the geometric mean value of 7 ng g^{-1} presented in the US NHANES (2009) study for adult subjects >20 years (NHANES, 2009). A Japanese work on the same issue found a median of 4.15 ng g^{-1} (Tolmachev et al., 2006). Higher creatinine-normalized uranium concentrations ranging from 10–50 ng g^{-1} creatinine were reported for non DU exposed Gulf War veterans, with a median value of 10 ng g^{-1} creatinine (McDiarmid et al., 1999).

Daily excreted uranium was calculated by multiplying the individual uranium concentration in urine (g L^{-1}) by the individual daily urine volume. To find an age-dependency, the adult age group was further subdivided into three age groups: 16–30 y, 31–50 y, and 51–78 y. Fig. 5 illustrates the results. The daily uranium excretion of both male and female subjects <15 y were comparable. By contrast, the data of the adult age groups showed a wider distribution and differed between women and men. There was no dependency of the daily uranium excretion with age. The lowest value of 8.5 ng d^{-1} (median) was determined for the male subjects between 16–30 years. In total, the daily excretion of uranium of all adult female subjects (median 24.1 ng d^{-1}) was twice as much as the excreted uranium concentrations of the adult male group (11.0 ng d^{-1}). A comprehensive study on daily urinary uranium excretion in German peacekeeping personnel and residents of the Kosovo region revealed similar excretion values of 14.4 ng d^{-1}; an age-dependent effect on daily uranium excretion could not be confirmed as well (Oeh et al., 2007a).

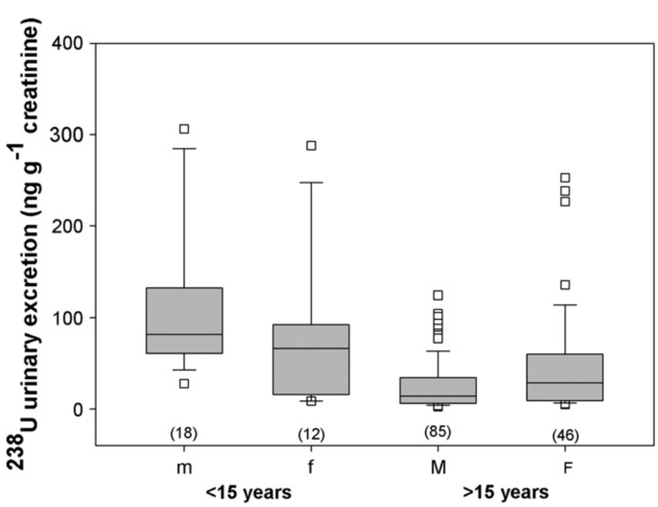

Fig. 4. Box plots of creatinine-normalized uranium concentrations in urine of unexposed Nigerian subjects separated into gender and different age groups. The number of subjects is indicated in parentheses. Male (m) and female (f) subjects <15 years: left boxes; male (M) and female (F) subjects >15 years: right boxes. Results included also the non-quantifiable uranium values below LOQ, which were considered as LOQ/2. The box plots comprised values between the 25th percentile and 75th percentile distribution (lower and upper boundary of the box) while the line inside the box represents the median value. Extreme values are plotted as open squares.

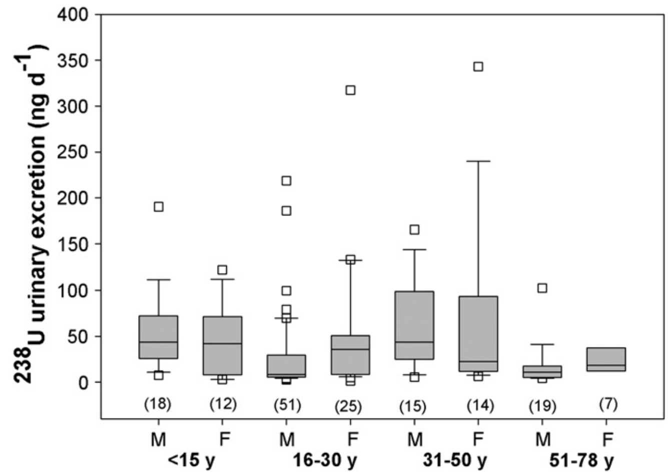

Fig. 5. Daily uranium excretion in unexposed Nigerian subjects divided into different age groups (<15 y, 16–30 y, 31–50 y, 51–78 y) and gender (M: male, F: female). The number of subjects is indicated in parentheses. The box plots comprised values between the 25th percentile and 75th percentile distribution (lower and upper boundary of the box) while the line inside the box represents the median value. Extreme values are plotted as open squares.

The gender-specific difference found in the present study may result in terms of figures from the larger quantity of unquantifiable uranium concentrations in the urine of the male subjects, and from their lower daily urine volumes. Possibly, the women ingested a little more uranium through food and beverages as they had a better opportunity to reach foodstuffs and drinking water in sufficient amounts when staying/working at home. The fact that the adult women showed a higher urine volume than men could also result from a larger daily intake of fluid.

The World Health Organisation (WHO, 2001) reported data from the early 1990s suggesting that the urinary uranium concentration in the general population is about 10 ng L^{-1} (WHO, 2001). The data of the present study were of the same order of magnitude of published ranges as summarized in Table 4. The uranium concentrations in urine of the Nigerian adult subjects were comparable to those measured in other studies, but lower than the values measured in Jordan (Al-Jundi et al., 2004) or Southern Finland, where exceptionally high concentrations of uranium have been determined in private drilled wells in the granite areas of Southern Finland (Karpas et al., 2005a). However, similar high mean excretion values of uranium were presented with the Nigerian subjects below 15 years, which was traced back to a possible enhanced consumption of soil by playing with it. In general, the uranium concentration found in urine of the Nigerian study group may result from the variable uranium intake through food and beverages. Due to the dusty climate condition, even in the rainy season in Nigeria, a slightly higher uptake and thereafter excretion of uranium in urine might occur through inhalation of additionally suspended dust in the air; and/or furthermore through consumption of cereals and starchy tubers grown on soil with higher uranium content (Arogunjo, 2003) .

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Table 4
Reference data on uranium concentrations in urine (in ng L^{-1} or ng d^{-1}) of unexposed subjects from different countries; number (N) and age of subjects, arithmetic mean values ± standard deviation (M ± SD), median, geometric mean (GM), and ranges of daily urinary ^{238}U excretion are presented.

Country (N)	Age (y)	Uranium excretion (ng L^{-1} or ng d^{-1})	Ranges
Nigeria (131)	16–78	Median 14.2 ng d^{-1}	1.6–150.0 ng d^{-1}
Nigeria (30) (present study)	3–15	Median 45.1 ng d^{-1}	3.2–170.4 ng d^{-1}
Germany (113) (Oeh et al., 2007a)	3–92	Median 14.4 ng d^{-1}	1.4–77.5 ng d^{-1}
Jordan (60) (Al-Jundi et al., 2004)	6–95	Mean 320 ng d^{-1}	18–3420 ng d^{-1}
Germany (285) (Höllriegl et al., 2002)	25–64	(M ± SD) 23 ± 18 ng d^{-1}	8.8–30.2 ng d^{-1}
Finland (951) (Muikku et al., 2009)	18–66	Mean 16 ng L^{-1}	<10–3700 ng L^{-1}
United Kingdom (25) (Jones et al., 2007)	20–59	–	1–10.6 ng L^{-1}
Germany (87)	18–65	(GM) 4 ng L^{-1}	LOQ-20 ng L^{-1}
Germany (72) (Heitland and Köster, 2006)	2–17	(GM) 4 ng L^{-1}	LOQ-3 ng L^{-1}
Japan (168) (Tolmachev et al., 2006)	–	(M ± SD) 5.6 ± 4.4 ng L^{-1}	0.8–35.6 ng L^{-1}
Finland (205) (Karpas et al., 2005b)	18–81	Median 64 ng L^{-1}	1–8450 ng L^{-1}
USA (2627) (NHANES, 2009)	>6	(GM) 7 ng L^{-1}	–
Italy (38) (Galletti et al., 2003)	20–50	(M ± SD) 10 ± 7 ng L^{-1}	1–44 ng L^{-1}
Germany (>200) (Roth et al., 2001)	7–84	Mean 17.5 ng L^{-1}	2–50 ng L^{-1}
USA (499) (Ting et al., 1999)	6–88	(GM) 7 ng L^{-1}	–
Slovenia (10) (Byrne and Benedik, 1991)	–	(M ± SD) 12.8 ± 13.2 ng L^{-1}	3–49 ng L^{-1}

4. Conclusion

This study was aimed at gaining better knowledge on the excretion of natural uranium of male and female subjects living and working in the south-western region of Nigeria. The data can be considered as baseline values of urinary uranium in unexposed persons in a non-mining area. The results were comparable to reference values reported from other countries with low level of urinary uranium, and low environmental uranium. The median of daily excreted uranium was estimated to be 14.2 ng d^{-1} for adults and of 45.1 ng d^{-1} for children, respectively. Data on body weights, urine volumes and urinary creatinine values partly differed from the ICRP reference values; this may be explained by the race differences in our Nigerian study group living in a tropical climate in comparison to e.g. Caucasians or Afro-Americans.

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