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Assessment of natural radionuclides and health risk in pediatric toothpaste in Anambra State, Nigeria

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Abstract

Background: Pediatric toothpaste is an essential daily oral-care product and represents a potential chronic ingestion pathway for naturally occurring radionuclides, particularly in children who are biologically more sensitive to ionizing radiation. Despite widespread use, data on the radiological safety of pediatric toothpaste remain limited, especially in developing countries.

Objective: This study aims to assess the activity concentrations of naturally occurring radionuclides Potassium-40 (^{40}K), radium-226 (^{226}Ra), and thorium-232 (^{232}Th) in commonly consumed pediatric toothpaste brands in Anambra State, Nigeria, and to assess the associated radiological health risks to children using standard radiological hazard indices.

Methods: Five pediatric toothpaste brands were collected from retail outlets across Anambra State between December 2024 and January 2025. Gamma-ray spectrometry using a Nai(Tl) detector was employed to determine activity concentrations. Radiological hazard indices, annual effective dose equivalent (AEDE), and excess lifetime cancer risk (ELCR) were calculated using standardized equations for ingestion exposure.

Results: The activity concentrations of ^{40}K ranged from 55.76 ± 10.78 to 145.25 ± 22.51 Bq kg^{-1}, ^{226}Ra from 4.27 ± 1.44 to 4.80 ± 1.79 Bq kg^{-1}, and ^{232}Th from 2.44 ± 0.65 to 6.68 ± 1.69 Bq kg^{-1}. All values were below UNSCEAR reference limits. The total AEDE ranged from 0.00627 to 0.00825 mSv y^{-1}, and ELCR values ranged from 2.19 × 10^{-5} to 2.89 × 10^{-5}, indicating negligible radiological health risk.

Conclusion: This study establishes baseline radiological safety data for pediatric toothpaste in Nigeria, indicating that the analyzed products do not pose significant radiological risks under normal use. While the study is limited by the number of brands analyzed and standardized ingestion assumptions, the findings provide robust, protective upper-bound dose estimates and underscore the importance of periodic radiological monitoring of child-specific consumer products.

Keywords: Pediatric Toothpaste; Natural Radioactivity; Gamma-Ray Spectrometry; Radiological Health Risk; ELCR

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1. Introduction

Radiation is energy transmitted through space in the form of waves or particles. Ionizing radiation has sufficient energy to remove electrons from atoms or molecules, potentially causing damage to living tissues [1,2]. Human exposure to ionizing radiation occurs through both natural and anthropogenic sources, mainly via inhalation, ingestion, and dermal contact [3,4]. While external exposure contributes significantly to radiation dose, internal exposure resulting from ingestion of radionuclides in food, water, and consumer products remains an important public health concern, particularly for vulnerable populations such as children [5–7].

Naturally occurring radionuclides including potassium-40 (^{40}K), radium-226 (^{226}Ra), and thorium-232 (^{232}Th) are ubiquitous in the environment and may be incorporated into consumer products through raw materials and water used during manufacturing [8–10]. Once ingested, these radionuclides may interact with biological tissues at the cellular and molecular levels, potentially increasing long-term health risks [9,11]. Children are especially susceptible to ionizing radiation due to higher rates of cell division and longer post-exposure life expectancy, making risk evaluation in pediatric products particularly critical [12].

Toothpaste is a widely used oral-care product that is applied multiple times daily. Pediatric toothpaste, in particular, represents a unique exposure pathway because children are more likely than adults to inadvertently swallow toothpaste during brushing, and may also absorb its constituents through the oral mucosa, especially if the gums are inflamed or injured [13,14]. Despite its widespread use and recognized role in preventing dental caries, there is a notable lack of radiological safety assessments for toothpaste products intended for children, especially in developing countries.

Untreated dental caries remains among the most common health conditions affecting children worldwide, leading manufacturers to create toothpaste formulations with appealing flavors and packaging to encourage early adoption of oral hygiene practices [15-17]. Although the chemical composition and fluoride content of pediatric toothpaste have been well studied, there is a significant lack of data regarding the presence of naturally occurring radionuclides and the associated radiological health risks in these products.

In Nigeria, previous radiological studies have largely focused on environmental media, foodstuffs, building materials, and general consumer products [18, 19]. To the best of our knowledge, no published research has systematically evaluated the activity concentrations of natural radionuclides and radiological health risks associated with pediatric toothpaste consumed in Nigeria. Therefore, this study provides the first radiological assessment of pediatric toothpaste brands commonly consumed in Anambra State, Nigeria, and evaluates toothpaste as a chronic ingestion-related exposure pathway in children. It quantifies radiological risk using internationally accepted hazard indices, annual effective dose, and excess lifetime cancer risk, thereby establishing baseline data to support regulatory surveillance and consumer product safety in Nigeria. By addressing these gaps, the present study contributes to radiation protection, environmental health, and pediatric public health, and provides evidence to inform regulatory agencies, manufacturers, and healthcare professionals on the radiological safety of pediatric oral-care products.

2. Materials And Methods

2.1. Study Design and Area

This prospective cross-sectional study was conducted in Anambra State, southeastern Nigeria. The study focused on commonly consumed pediatric toothpaste brands available in retail outlets across the state.

2.2. Sample Collection

Five widely used pediatric toothpaste brands were purchased from major supermarkets and retail pharmacies between December, 2024, and January, 2025. Only products with valid National Agency for Food and Drug Administration and Control (NAFDAC) registration numbers were included.

2.3. Sample Preparation

Each toothpaste sample was air-dried, homogenized, and pulverized into fine powder. Approximately 200 g of each sample was transferred into radon-impermeable cylindrical plastic containers (7.6 cm × 7.6 cm). Containers were sealed hermetically using Vaseline jelly, candle wax, and adhesive tape to prevent radon escape. Samples were stored for at least 30 days to allow secular equilibrium between parent radionuclides and short-lived progenies.

2.4. Gamma-Ray Spectrometric Measurement

Activity concentrations were determined using a sodium iodide [Nai(Tl)] scintillation detector (3″ × 3″) coupled to an ORTEC multichannel analyzer. Energy and efficiency calibrations were performed using standard gamma sources (^{137}Cs and ^{60}Co) and IAEA reference materials (RGK-1, RGU-1, RGTh-1). Samples were counted for 18,000 s, with background correction applied.

2.5. Determination of Activity Concentration

The activity concentration Anisotropic Analytical Algorithm (AAA) Bq kg^{-1} of each radionuclide was calculated as:

A=Cε Pγ MA = \frac{C} {\varepsilon \, P_\gamma \, M} A=εPγMC

where CCC is the net count rate (counts s^{-1}), ε\varepsilonε is the detector efficiency, PγP_\gammaPγ is the gamma emission probability, and MMM is the mass of the sample (kg).

2.6. Radiological Hazard Assessment

2.6.1. Annual Effective Dose Equivalent (AEDE)

AEDE=A×IR×DCF\text {AEDE} = A \times IR \times DCFAEDE=A×IR×DCF

Were

- AAA = activity concentration (Bq kg^{-1})
- IRIRIR = ingestion rate (kg y^{-1})
- DCFDCFDCF = dose conversion factor (Sv Bq^{-1})

2.6.2. Dose conversion factors for children were adopted from UNSCEAR/ICRP

- ^{40}K = 6.2×10−96.2 \times 10^ {-9}6.2×10−9 Sv Bq^{-1}
- ^{226}Ra = 2.8×10−72.8 \times 10^ {-7}2.8×10−7 Sv Bq^{-1}
- ^{232}Th = 2.3×10−72.3 \times 10^ {-7}2.3×10−7 Sv Bq^{-1}

Total AEDE is the sum of contributions from all radionuclides.

2.6.3. Excess Lifetime Cancer Risk (ELCR)

ELCR=AEDE×DL×RF\text {ELCR} = \text {AEDE} \times DL \times RFELCR=AEDE×DL×RF

Were

- DLDLDL = duration of life expectancy (70 years)
- RFRFRF = fatal cancer risk factor (0.05 Sv^{-1})

2.7. Data Analysis

Data were analyzed using SPSS v20 and Microsoft Excel. Results are reported as mean ± standard deviation and compared with internationally recommended limits.

3. Results

Table 1 Radionuclide Activity Concentrations (Bq kg^{-1}) in Pediatric Toothpaste

S/N	Sample ID	^{40}K (Bq kg^{-1})	^{226}Ra (Bq kg^{-1})	^{232}Th (Bq kg^{-1})
1	Close Up	60.25 ± 12.42	4.80 ± 1.79	3.29 ± 0.84
2	Oral B	55.76 ± 10.78	4.27 ± 1.44	6.68 ± 1.69
3	Colgate	80.36 ± 13.24	4.71 ± 1.62	5.40 ± 1.72
4	Sensodyne	145.25 ± 22.51	4.52 ± 1.97	2.44 ± 0.65
5	MyMy	96.74 ± 18.93	4.33 ± 1.69	3.45 ± 0.86

3.1. AEDE and ELCR

Table 2 Annual Effective Dose Equivalent (AEDE) and Excess Lifetime Cancer Risk (ELCR) due to ingestion of pediatric toothpaste in Anambra State

S/N	Sample ID	AEDE ^{40}K (mSv y^{-1})	AEDE ^{226}Ra (mSv y^{-1})	AEDE ^{232}Th (mSv y^{-1})	Total AEDE (mSv y^{-1})	ELCR ($\times 10^{-4}$)
1	Close Up	0.00037	0.00403	0.00213	0.00653	0.229
2	Oral B	0.00034	0.00359	0.00432	0.00825	0.289
3	Colgate	0.00049	0.00396	0.00350	0.00795	0.278
4	Sensodyne	0.00089	0.00380	0.00158	0.00627	0.219
5	MyMy	0.00060	0.00364	0.00223	0.00647	0.226

All estimated AEDE and ELCR values are well below international safety thresholds, indicating negligible radiological risk

4. Discussion

This study provides one of the first systematic evaluation of natural radionuclide activity concentrations and associated radiological risks in pediatric toothpaste brands commonly consumed in Anambra State, Nigeria. The results show that potassium-40 (^{40}K) was the dominant radionuclide in all toothpaste samples, with measured activity concentrations ranging from 55.76 ± 10.78 to 145.25 ± 22.51 Bq/kg. Although ^{40}K is abundant, its relatively low radiotoxicity and small ingestion dose conversion factor resulted in minor contributions to the annual effective dose equivalent (AEDE: 0.00034–0.00089 mSv y^{-1}), indicating minimal risk from daily use.

Radium-226 (^{226}Ra) and thorium-232 (^{232}Th) were detected at lower concentrations (4.27 ± 1.44 to 4.80 ± 1.79 Bq/kg and 2.44 ± 0.65 to 6.68 ± 1.69 Bq/kg, respectively). Despite their higher radiotoxicity and dose conversion coefficients, their contribution to the total AEDE remained low, with combined values of 0.006–0.008 mSv y^{-1}, far below the reference limit of 1 mSv y^{-1} recommended by the International Commission on Radiological Protection [20]. Similarly, the excess lifetime cancer risk (ELCR), calculated using the standard formula ELCR = AEDE × LE × RF (where LE = life expectancy, RF = risk factor), ranged from 2.19×10^{-5} to 2.89×10^{-5}, well below the typical benchmark of 1×10^{-3} for acceptable risk. This concentration pattern was in line with similar work done by Nwodo et al [21], using other consumer products. These findings suggest that pediatric toothpaste contributes negligibly to chronic internal radiation exposure in children.

When compared to previous studies on toothpaste in other regions, the measured activity concentrations of ^{40}K, ^{226}Ra, and ^{232}Th are consistent with global patterns. For example, Ababneh and Samarah [22] reported similar ^{40}K levels in commercially available toothpaste, while the concentrations of ^{226}Ra and ^{232}Th were also comparable to values reported in consumer products in Nigeria [17,18]. This consistency may reflect similarities in raw material sourcing and manufacturing practices for products marketed for children.

A key novelty of this study lies in its focus on pediatric toothpaste as a chronic ingestion-related exposure pathway, which has been largely overlooked in prior radiological assessments. Children are particularly susceptible to ionizing radiation due to higher rates of cell division and longer post-exposure life expectancy, making even low-level exposures potentially significant over a lifetime [12]. By quantifying AEDE and ELCR specifically for pediatric toothpaste, this work provides baseline radiological safety data for a vulnerable population and underscores the importance of evaluating child-specific consumer products rather than assuming adult-based safety standards are sufficient.

Overall, this study demonstrates that, under normal usage conditions, commonly consumed pediatric toothpaste in Anambra State does not pose significant radiological health risks. The quantitative baseline data for AEDE and ELCR provided here serve as a practical resource for regulators, manufacturers, and healthcare professionals to help ensure the continued safety of child-oriented oral-care products.

Furthermore, this study highlights the value of periodic radiological surveillance of pediatric consumer products. While current findings indicate no immediate health concern, ongoing monitoring is needed because variations in raw material sourcing, manufacturing practices, or environmental contamination could alter radionuclide content over time, particularly in developing countries where regulatory oversight is limited.

Study Limitations: This study was limited by the number of toothpaste brands analyzed and the use of standardized ingestion assumptions and NaI(Tl) measurements, which may introduce minor uncertainties. Variations in ingestion rates, product formulations, or batch-to-batch differences could influence actual exposures. Nevertheless, the conservative approach adopted in this study yields protective upper-bound estimates, supporting the robustness of the results for regulatory and public health purposes.

5. Conclusion

This study presents one of the first systematic assessment of natural radionuclide activity concentrations and associated radiological risks in pediatric toothpaste brands commonly consumed in Anambra State, Nigeria. Measured activity concentrations of ^{40}K, ^{226}Ra, and ^{232}Th were all below UNSCEAR reference levels, and the calculated annual effective dose equivalent (0.006–0.008 mSv y^{-1}) and excess lifetime cancer risk ($2.19–2.89 \times 10^{-5}$) indicate negligible radiological health risk under normal usage conditions.

By focusing on pediatric toothpaste as a chronic ingestion-related exposure pathway, this study extends radiological risk assessment beyond traditional environmental and food matrices to include child-specific consumer products. This novel approach provides baseline quantitative data on radiological safety for a highly vulnerable population, offering valuable guidance for regulatory agencies, manufacturers, and healthcare professionals.

While the study provides supportive evidence, limitations include the restricted number of brands sampled, assumptions regarding ingestion rates, and analytical uncertainties associated with gamma spectrometry. Despite these constraints, the findings underscore the importance of periodic radiological surveillance of pediatric consumer products to detect potential variations in raw materials, manufacturing practices, or environmental contamination over time. Overall, the study delivers novel and actionable insights into pediatric oral-care product safety, contributing to radiation protection, environmental health, and public health policy in Nigeria and similar contexts.

Compliance with ethical standards

Disclosure of conflict of interest

There is no conflict of interest in this study whatsoever.

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