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Assessment of Organ-Specific Absorbed Dose, Effective Dose, and Radiation-Induced Cancer and Mortality Risk for Gastrointestinal Contrast Radiographic Procedures in North Western Nigeria

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Abstract

Background: Conventional gastrointestinal (GI) contrast radiography remains an essential diagnostic modality in many low- and middle-income countries where fluoroscopic facilities are unavailable or limited. Repeated radiographic acquisitions during barium examinations may increase radiation exposure to radiosensitive organs and contribute to stochastic radiation risks. However, comprehensive organ dosimetry and radiological risk data for these procedures remain scarce in Northwestern Nigeria. **Objective:** To evaluate organ-specific absorbed doses, effective dose, and radiation-induced lifetime cancer incidence and mortality risks associated with barium swallow, barium meal, and barium enema examinations performed using conventional radiographic systems in selected hospitals in Northwestern Nigeria. **Methods:** A multicentre prospective cross-sectional study was conducted among adult patients undergoing clinically indicated gastrointestinal contrast examinations at Yauri General Hospital, Usmanu Danfodiyo University Teaching Hospital (UDUTH), and MedStop Diagnostic and Clinical Centre. Patient demographics and exposure parameters, including tube potential (kVp), tube current–time product (mAs), focus-to-skin distance (FSD), focus-to-detector distance (FDD), beam area, and number of acquired images, were prospectively recorded. Organ absorbed doses, effective dose, and lifetime cancer incidence and mortality risks were estimated using Monte Carlo-based CALDose_X version 5.0, employing the MASH and FASH voxel phantoms. Statistical analyses were performed using IBM SPSS Statistics version 26.0. **Results:** Significant inter-procedural and inter-centre variations were observed. MedStop recorded the highest exposure settings for a barium swallow (88.08 kVp; 39.04 mAs), whereas a barium enema required the greatest number of radiographic acquisitions (8.35 images). During barium swallow, the thyroid received the highest absorbed dose (6.81 mGy), followed by the thymus (4.84 mGy), while the maximum skin entrance dose reached 12.07 mGy. A barium enema produced the highest doses to the gallbladder wall (3.31 ± 0.75 mGy), colon wall (1.96 ± 0.47 mGy), pancreas (1.70 ± 0.43 mGy), and skin entrance (6.73 ± 1.31 mGy). Effective doses ranged from 0.32 ± 0.09 mSv (female barium swallow, UDUTH) to 1.06 ± 0.43 mSv (male barium swallow, MedStop), whereas barium enema and barium meal recorded 0.74 ± 0.18 mSv and 0.50 ± 0.17 mSv, respectively. The highest lifetime cancer incidence (9.56 ± 4.52 per 100,000) and mortality risk (6.87 ± 3.05 per 100,000) occurred among male barium swallow patients at MedStop. Effective doses were 17.0–84.13% lower than previous African reports. **Conclusions:** Conventional gastrointestinal contrast radiography in Northwestern Nigeria was associated with relatively low effective doses but considerable variability in organ absorbed doses, particularly in the thyroid, skin, gallbladder, colon, and pancreas. Although estimated radiation-induced cancer risks remained low, institutional differences indicate opportunities for further optimization. These findings support the establishment of regional diagnostic reference levels (DRLs), standardized imaging protocols, and strengthened quality assurance programs to improve patient radiation protection.

Keywords: Gastrointestinal contrast radiography, organ absorbed dose, effective dose, radiation-induced cancer risk, barium swallow, barium meal, barium enema, CALDose_X. 5.0

Introduction

Gastrointestinal (GI) disorders remain a significant cause of morbidity and mortality worldwide and constitute a major public health concern across both developed and developing countries. Diseases such as dysphagia, oesophageal strictures, gastroesophageal reflux disease (GERD), peptic ulcer disease, gastric carcinoma, inflammatory bowel disease, intestinal obstruction, diverticular disease, colorectal polyps, and colorectal cancer require timely and accurate diagnosis for effective clinical management. While advances in computed tomography (CT), magnetic resonance imaging (MRI), capsule endoscopy, and conventional endoscopy have considerably improved gastrointestinal imaging, contrast-enhanced radiographic examinations using **barium sulphate** continue to play an indispensable role in evaluating both the structural integrity and physiological function of the gastrointestinal tract. In many low- and middle-income countries (LMICs), including Nigeria, conventional barium examinations remain the first-line diagnostic investigations because they are relatively inexpensive, readily available, and less technically demanding than advanced imaging modalities (International Atomic Energy Agency, 2014; International Commission on Radiological Protection, 2007).

In high-income countries, most barium studies are performed using digital fluoroscopic systems that provide continuous real-time imaging, automatic exposure control, pulsed fluoroscopy, last-image hold, and dose monitoring capabilities, thereby facilitating optimization of patient radiation exposure (ICRP, 2009; IAEA, 2014). However, in many resource-constrained healthcare settings across sub-Saharan Africa, fluoroscopy units are either unavailable, obsolete, or nonfunctional because of high acquisition costs, inadequate maintenance, irregular electricity supply, and shortages of skilled personnel. Consequently, many hospitals continue to perform **barium swallow**, **barium meal**, and **barium enema** examinations using conventional radiographic equipment, where diagnosis relies on a sequence of static radiographs acquired at predetermined time intervals following administration of contrast media. Although this approach remains clinically valuable, it frequently requires multiple radiographic exposures to compensate for the absence of continuous fluoroscopic visualization, thereby potentially increasing cumulative patient radiation dose while limiting opportunities for real-time optimization (Muhogora et al., 2008; IAEA, 2014).

The continued reliance on conventional X-ray systems for gastrointestinal contrast examinations in many African countries reflects disparities in healthcare infrastructure between developed and developing nations. Surveys conducted by the International Atomic Energy Agency have shown that many diagnostic radiology departments in Africa operate ageing analogue radiographic equipment with limited quality assurance programs, inadequate dosimetry services, and the absence of automatic dose monitoring systems, all of which contribute to substantial variability in patient radiation exposure (IAEA, 2014). Similar observations have been reported in multinational studies involving Asia, Africa, and Eastern Europe, where patient doses varied considerably because of differences in radiographic technique, equipment performance, operator experience, and optimization practices (Muhogora et al., 2008).

Unlike routine chest or skeletal radiography, conventional barium examinations often require serial radiographs obtained during different phases of contrast transit through the gastrointestinal tract. For example, a **barium swallow** typically involves multiple radiographs of the cervical and thoracic esophagus during swallowing; a **barium meal** includes sequential images of the stomach and duodenum, whereas a **barium enema** requires several abdominal and pelvic projections before, during, and after evacuation of contrast medium. The cumulative radiation exposure from these repeated radiographic acquisitions depends on tube potential (kVp), tube current-time product (mAs), focus-to-skin distance (FSD), focus-to-detector distance (FDD), field size, patient body habitus, number of radiographs, and operator experience. Consequently, significant inter-hospital and inter-operator variations in radiation dose have been reported for gastrointestinal contrast procedures (Ruiz-Cruces et al., 2000; Hart et al., 2012).

Assessment of patient radiation exposure has therefore become an essential component of quality assurance in diagnostic radiology. Radiation dose quantities commonly used in gastrointestinal imaging include Entrance Surface Dose (ESD), Kerma-Area Product (KAP/DAP), organ-specific absorbed dose, equivalent dose, and effective dose. While ESD and DAP provide useful indicators of radiation output from the X-ray system, they do not adequately quantify the biological risk associated with irradiation of radiosensitive organs. Organ-specific absorbed dose provides a more accurate estimate of the energy deposited in individual tissues such as the esophagus, stomach, colon, liver, lungs, bone marrow, gonads, bladder, and kidneys. Effective dose further incorporates tissue weighting factors to estimate the overall stochastic detriment from non-uniform irradiation and has become the internationally accepted quantity for comparing radiation burden among different diagnostic procedures (ICRP, 2007; ICRP, 2022).

Radiation-induced carcinogenesis remains the principal long-term concern associated with diagnostic X-ray examinations. Although individual doses from conventional barium studies are generally lower than those associated with computed tomography, repeated examinations and multiple radiographic acquisitions may increase cumulative organ doses, particularly in patients requiring follow-up investigations. Based on the Linear No-Threshold (LNT) model, the probability of stochastic effects, including cancer incidence and cancer mortality, increases proportionally with radiation dose without an assumed threshold. Consequently, international radiation protection organizations recommend optimization of all diagnostic procedures according to the **As Low As Reasonably Achievable (ALARA)** principle while ensuring adequate diagnostic image quality (ICRP, 2007; United Nations Scientific Committee on the Effects of Atomic Radiation, 2020; Samaila et al.2024).

Several studies have quantified radiation doses associated with gastrointestinal contrast examinations. Ruiz-Cruces et al. (2000) reported substantial variation in effective dose among different barium procedures, demonstrating that patient exposure depended largely on examination complexity and imaging technique. Similarly, Sulieman et al. (2011) reported effective doses ranging from approximately **0.2 mSv** for a barium swallow to **1.4 mSv** for a barium enema, emphasizing that optimization of exposure parameters and reduction of unnecessary radiographs significantly lowered patient dose. More recently, the United

Kingdom's national patient dose review confirmed continued reductions in radiation dose following implementation of digital imaging systems, optimized imaging protocols, and regular quality assurance programs (Hart et al., 2012; UK Health Security Agency, 2023).

In Africa, however, published evidence on organ-specific absorbed dose and radiation-induced cancer risk from gastrointestinal contrast radiography remains limited. Most available studies have focused on general radiography or fluoroscopic dose surveys rather than patient-specific organ dosimetry. In Nigeria, although several investigators have evaluated entrance surface dose and diagnostic reference levels for conventional radiographic examinations, comprehensive assessments of **organ absorbed dose, effective dose, radiation-induced cancer incidence, and cancer mortality risk for barium swallow, barium meal, and barium enema** examinations performed with **conventional X-ray equipment** are scarce. This knowledge gap is particularly evident in northwestern Nigeria, where many healthcare facilities continue to depend on conventional radiographic systems because fluoroscopic equipment is unavailable or inaccessible. The absence of locally generated dosimetric and radiological risk data limits the development of evidence-based optimization strategies, regional diagnostic reference levels, and patient radiation protection policies. Therefore, the present study aims to assess organ-specific absorbed dose, effective dose, and radiation-induced cancer and mortality risks associated with conventional gastrointestinal contrast radiographic procedures in Northwestern Nigeria, thereby providing baseline data for optimization of clinical practice and strengthening radiation protection in resource-constrained healthcare environments.

2.0 Material and Method

2.1 Study Area

This multicentre study was conducted in selected hospitals located in Kebbi and Sokoto States in Northwestern Nigeria, where gastrointestinal contrast radiographic examinations are routinely performed. The study sites comprised one secondary healthcare facility in Kebbi State and two referral centres in Sokoto State, selected based on the availability of functional radiographic equipment, regular performance of gastrointestinal contrast procedures, and the presence of qualified radiologists and radiographers. The selected facilities were Yauri General Hospital (YGH), Yauri, Kebbi State; Usmanu Danfodiyo University Teaching Hospital (UDUTH), Sokoto; and MedStop Clinic and Diagnostic Centre, Sokoto, Sokoto State.

Yauri General Hospital is a major secondary healthcare institution located in Yauri, Kebbi State, northwestern Nigeria, at approximately 12.4719° N, 4.2336° E. The hospital serves as a referral centre for the Yauri Emirate and neighboring communities within Kebbi, Niger, and Zamfara States, providing conventional radiography and fluoroscopic imaging services, including routine gastrointestinal contrast examinations.

Usmanu Danfodiyo University Teaching Hospital (UDUTH) is a tertiary referral hospital situated along Garba Nadama Road in the Sokoto metropolis at approximately 13.0383° N, 5.2235° E. As the principal teaching hospital in Northwestern Nigeria, UDUTH provides specialized diagnostic and therapeutic services and receives referrals from Sokoto, Kebbi, Zamfara, Katsina, and the neighboring Niger Republic. The Department of Radiology is equipped with fluoroscopic imaging facilities where gastrointestinal contrast procedures are

routinely performed. MedStop Clinic and Diagnostic Centre is a private specialist diagnostic facility located in the Sokoto metropolis at approximately 13.0301° N, 5.2493° E. The centre offers comprehensive diagnostic imaging services, including digital radiography, fluoroscopy, computed tomography (CT), magnetic resonance imaging (MRI), ultrasonography, and mammography and serves as one of the major private referral centres for gastrointestinal contrast radiographic examinations in Sokoto State.

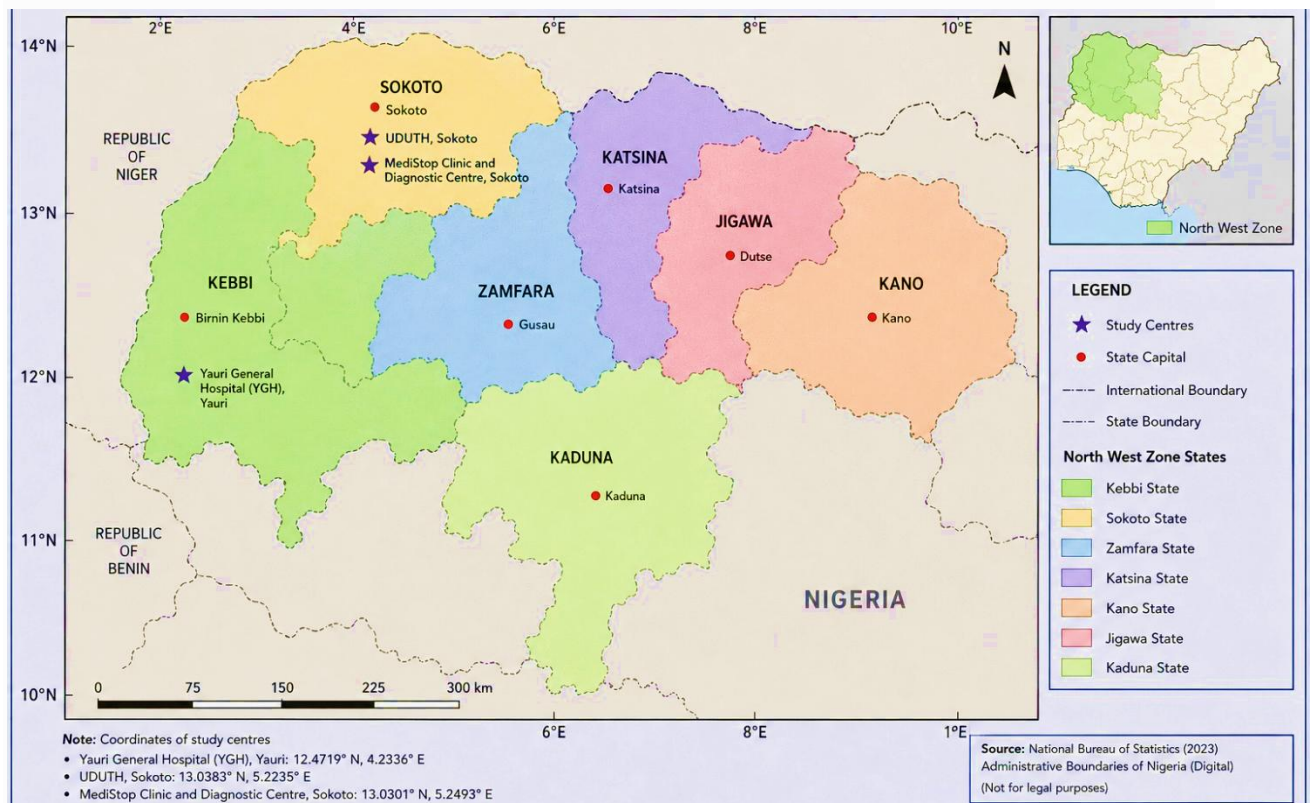


Figure 1: **Map of Northwestern Nigeria Showing the study areas**

2.2 Study Design

This study employed a multicentre prospective cross-sectional study design involving patients undergoing routine gastrointestinal contrast radiographic examinations at the selected healthcare facilities. All examinations were performed according to the participating institutions' standard clinical protocols without any modification to imaging procedures or exposure settings for research purposes. Radiation exposure parameters were prospectively collected during routine clinical practice, and no additional radiation exposure was incurred as a result of participation in the study.

2.3 Sample Size and Data Collection

The study population consisted of all consecutive patients referred for clinically indicated gastrointestinal contrast radiographic examinations, including barium swallow, barium meal, and barium enema, at the selected hospitals during the study period. A consecutive sampling technique was adopted, whereby every eligible patient who satisfied the inclusion criteria and provided informed consent was recruited until the predetermined sample size for each

procedure was achieved. This approach minimized selection bias and ensured that the study population was representative of patients routinely undergoing gastrointestinal contrast radiographic examinations at the participating centers.

Data were collected prospectively using a standardized data collection pro forma during routine clinical examinations without altering the established imaging protocols. Patient demographic characteristics (age, sex, weight, and height); examination details (clinical indication, type of gastrointestinal procedure, radiographic exposure time, and number of acquired images); and exposure parameters (tube potential [kVp], tube current-time product [mAs], focus-to-skin distance [FSD], focus-to-detector distance [FDD], and irradiated beam area) were recorded directly from the X-machine console and patients' radiological records. These parameters served as input variables for the estimation of organ-specific absorbed dose, effective dose, and radiation-induced lifetime cancer incidence and mortality risks using validated Monte Carlo-based dosimetric software. The collected data were verified for completeness and consistency before statistical analysis.

2.4 Data Analysis

Patient-specific organ absorbed doses, effective doses, radiation-induced cancer incidence risks, and cancer mortality risks were estimated using **CALDose_X version 5.0**, a validated Monte Carlo-based dosimetry software for diagnostic radiology (Kramer et al., 2008; Khoury et al., 2014). The software employs anthropomorphic voxel phantoms representing reference adult male (MASH) and female (FASH) anatomies together with pre-calculated Monte Carlo conversion coefficients to estimate organ doses from examination-specific radiation output while accounting for patient characteristics, X-ray beam geometry, and exposure conditions. For each patient, demographic data (age, sex), and examination parameters, including tube potential (kVp), tube current-time product (mAs), total filtration (mm Al), focus-to-detector distance (FDD), standard field size, projection & examination type, were entered into CALDose_X to estimate organ-specific absorbed doses, effective dose, and the corresponding lifetime radiation-induced cancer incidence and mortality risks.

2.4.1 Tube output and dose estimations by software

The software estimates radiation doses to radiosensitive organs based on patient anatomical characteristics and examination-specific exposure parameters. The following input parameters were entered into CALDose_X.5.0 for each patient: patient age, sex, height, weight, tube voltage (kVp), tube current-time product (mAs), focus-to-detector distance, examination type, and standard beam dimensions. Prior to patient dose estimation, the radiation output **for** each procedure were estimated using the slope of the graph generated by the CalDose X_5.0 software from tube loading and voltage. The expression used was given as

$$Y = S(kV)^2 \quad 1$$

Where S is the slope obtained from the Monte Carlo simulation software.

The calculated tube output was used to calculate the Entrance Surface Air Kerma (ESAK) for each exposure, which served as the normalization quantity required by CALDose_X (IAEA,

2007; Dance et al., 2014). The ESAK for each patient was determined from the calculated tube output (Y) using:

$$\text{ESAK} = Y(d) \times \text{mAs} \times \left(\frac{d}{\text{FSD}}\right)^2 \times \text{BSF} \quad 2$$

Where ESAK= Entrance Surface Air Kerma (mGy); Y(d)= measured X-ray tube output at calibration distance d(mGy mAs⁻¹); mAs= tube loading; FSD= focus-to-skin distance (cm); d= calibration distance (usually 100 cm); BSF= backscatter factor.

The calculated ESAK values together with patient and examination parameters were entered into CALDose_X version 5.0. The software automatically selected either the MASH or FASH reference voxel phantom according to patient sex and matched the recorded projection with the appropriate Monte Carlo conversion coefficients.

2.4.2 Estimation of Absorbed and Effective Dose

For each exposure, CALDose_X estimates the organ-absorbed dose by multiplying the measured normalization quantity (ESAK) by the organ-specific normalized conversion coefficient generated from Monte Carlo simulations:

$$D_T = \text{ESAK} \times CC_T \quad 3$$

Where "Where" D_T = absorbed dose to organ T(mGy), "ESAK" ESAK= Entrance Surface Air Kerma (mGy), and "μ" CC_T = Monte Carlo conversion coefficient relating ESAK to absorbed dose in organ T.

The weighted dose for each phantom is computed internally by CALDose_X using the ICRP tissue weighting factors according to:

$$WD = \sum_T w_T H_T \quad 3$$

where: WD= Total weighted dose (mSv); w_T = Tissue weighting factor for tissue or organ T; H_T = Equivalent dose to tissue T(mSv).

Because diagnostic X-rays have a radiation weighting factor of one ($w_R = 1$), the equivalent dose is numerically equal to the absorbed dose:

$$H_T = D_T \times w_R = D_T \quad 4$$

where: D_T = Absorbed dose to tissue or organ T(mGy).

Effective dose was estimated using **CALDose_X version 5.0**, a Monte Carlo-based patient dosimetry software developed for diagnostic radiology. The software employs the adult male (**MASH**) and adult female (**FASH**) voxel computational phantoms to estimate organ-absorbed doses and tissue-equivalent doses for a specified radiographic examination. Following Monte Carlo simulation of the examination geometry, CALDose_X applies the tissue-weighting factors recommended in **ICRP Publication 103** to calculate the **Weighted MASH Dose** and **Weighted FASH Dose**, representing the male and female contributions to the effective dose, respectively.

According to **Equation (5) of ICRP Publication 103**, the effective dose for a reference population is defined as the tissue-weighted average of the male and female equivalent doses. Consequently, CALDose_X computes the effective dose as the arithmetic mean of the total weighted doses obtained from the MASH and FASH phantoms:

$$E = \sum_T w_T \left[\frac{H_T^{\text{Male}} + H_T^{\text{Female}}}{2} \right] \quad 5$$

Where E= Effective dose (mSv), w_T = Tissue weighting factor for tissue or organ T, H_T^{Male} = Equivalent dose to tissue T calculated using the MASH phantom, and H_T^{Female} = Equivalent dose to tissue T calculated using the FASH phantom

Since CALDose_X already determines the weighted tissue contributions separately for the two reference phantoms, the above relationship is implemented internally as

$$E = \frac{F+M}{2} \quad 6$$

Where "FASH" F= Total Weighted FASH Dose (mSv) and "MASH" = Total Weighted MASH Dose (mSv).

Thus, the effective dose reported in this study was obtained by averaging the weighted female dose and weighted male dose generated automatically by CALDose_X version 5.0. This approach is fully consistent with the recommendations of **ICRP Publication 103** for estimating the effective dose of the reference adult population and is the methodology implemented within the CALDose_X software.

2.4.3 Cancer and mortality risk estimation

CALDose_X estimates radiation-induced cancer incidence by combining organ absorbed doses with age- and sex-specific lifetime attributable cancer risk coefficients derived from the Biological Effects of Ionizing Radiation (BEIR) VII report. For each radiosensitive organ, the excess lifetime cancer incidence was calculated as:

$$R_{\text{inc},T} = D_T \times RC_T \quad 7$$

Where "Where" $R_{\text{inc},T}$ = lifetime attributable cancer incidence risk for organ T; D_T = absorbed dose to organ T(Gy); RC_T = BEIR VII organ-specific cancer incidence risk coefficient.

The total lifetime cancer incidence risk for each patient was obtained by summing the organ-specific risks across all exposed organs. CALDose_X reports these values as excess cancer cases per 100,000 exposed individuals (National Research Council, 2006; Kramer et al., 2008).

Similarly, radiation-induced cancer mortality risk was estimated using BEIR VII organ-specific mortality coefficients incorporated into CALDose_X:

$$R_{\text{mort},T} = D_T \times RM_T \quad 8$$

Where "Where" $R_{\text{mort},T}$ = lifetime attributable cancer mortality risk for organ T; RM_T = the organ-specific mortality risk coefficient.

Overall cancer mortality risk was obtained by summing mortality estimates across all irradiated organs and was expressed as projected excess cancer deaths per 100,000 exposed persons. The

software automatically accounts for differences in age, sex, and tissue radiosensitivity during the risk calculations (National Research Council, 2006; ICRP, 2007; Kramer et al., 2008).

2.4.4 Percentage Effective Dose Reduction (%)

The percentage in effective dose reduction as compared with other literature findings were estimated using equation (10) below:

$$\% \text{Reduction} = \left(\frac{ED_{\text{Reference}} - ED_{\text{This Study}}}{ED_{\text{Reference}}} \right) \times 100 \quad 9$$

The negative sign of estimated values simply indicates that the effective dose measured in this study is lower than that reported in the literature. Similarly, the positive values indicate that the effective dose is higher than the literature findings.

2.4.5 Statistical Analysis

Statistical analyses were performed using **IBM SPSS Statistics for Windows, Version 26.0** (IBM Corp., Armonk, NY, USA). Descriptive statistics, including the **mean, standard deviation (SD), median, minimum, and maximum values**, were computed to summarize patients' demographic characteristics, examination and exposure parameters, organ-specific absorbed doses, effective doses, and radiation-induced cancer incidence and mortality risk estimates for the gastrointestinal contrast radiographic procedures.

2.5 Inclusion and Exclusion Criteria

Eligible participants were consecutive adult patients (≥ 20 years) who underwent clinically indicated gastrointestinal contrast radiographic examinations, including barium swallow, barium meal, and barium enema, at the selected study centres during the study period. Only patients with complete demographic and exposure parameter records who underwent examinations using standard X-ray imaging protocols and provided written/oral informed consent were included in the study. Patients were excluded if they were pregnant; had incomplete clinical or exposure data; underwent repeat examinations due to technical or procedural errors; had conditions or metallic implants that necessitated substantial modification of the standard imaging protocol; or declined to participate in the study.

2.6 Ethical Considerations

Ethical approval for the study was obtained from the Health Research Ethics Committees of the participating hospitals before commencement of data collection. Administrative permission was also obtained from the heads of the Radiology Departments of Yauri General Hospital, Usmanu Danfodiyo University Teaching Hospital, and MedStop Clinic and Diagnostic Centre. Written informed consent was obtained from all participants prior to enrolment. Patient confidentiality was maintained by anonymizing all collected data, and no identifying information was included in the analysis or reporting. The study complied with the ethical principles outlined in the Declaration of Helsinki for research involving human participants.

3.0 Results and Discussion

3.1 Demographic Characteristics, Procedural, and Exposure Parameters

Table 1 presents the demographic characteristics, procedural variables, geometric parameters, and X-ray exposure parameters of patients who underwent barium swallow, barium meal, and barium enema examinations at the selected hospitals in Northwestern Nigeria. Variations were observed across the three procedures, reflecting differences in patient characteristics, clinical indications, and institutional imaging protocols. Patients undergoing barium meal at Yauri General Hospital were the oldest (40.65 years), whereas those undergoing barium enema at UDUTH had the lowest mean age (27.55 years). The highest mean body weight was recorded among patients who underwent barium swallow at UDUTH (73.35 kg), while the greatest mean height was observed at MedStop Diagnostic Centre (172.80 cm). Similar variations in patient demographics have been reported in fluoroscopic studies, where age and anthropometric characteristics were shown to influence exposure factors and patient dose optimization (ICRP, 2007; Vaño et al., 2008; Vassileva & Rehani, 2015). These demographic differences are clinically relevant because patient size and anatomical characteristics directly influence the selection of exposure parameters required to maintain diagnostic image quality while minimizing radiation exposure.

Procedure-specific differences were also evident in the imaging and exposure parameters. Barium swallow performed at MedStop Diagnostic Centre utilized the highest contrast medium volume (111.60 mL), tube potential (88.08 kVp), and tube loading (39.04 mAs), whereas barium meal at Yauri General Hospital employed the lowest tube loading (20.03 mAs). In contrast, barium enema required the highest number of radiographic images (8.35), reflecting the greater anatomical coverage and procedural complexity associated with lower gastrointestinal fluoroscopic examinations. The focus-to-detector distance remained relatively constant (100–103.18 cm) across all procedures, indicating compliance with standard fluoroscopic practice, while the focus-to-skin distance varied modestly between 69.00 and 79.96 cm. Notably, the irradiated beam area was substantially larger during barium meal (1400.00 cm²) than during barium swallow (54.71–111.60 cm²) and barium enema (408.55 cm²), suggesting wider field collimation during upper gastrointestinal examinations. These findings are consistent with previous reports demonstrating that procedure-specific optimization of tube voltage, tube loading, beam collimation, and imaging geometry contributes significantly to variations in patient radiation dose during fluoroscopic examinations (IAEA, 2014; European Commission, 2018; Seeram, 2019). Consequently, the observed differences in exposure parameters among the participating centres are expected to influence organ absorbed doses, effective doses, and the corresponding estimates of radiation-induced cancer incidence and mortality risks evaluated in the subsequent sections of this study.

Table 1: Demographic, Procedure, Geometric, and Exposure Parameters for Barium Swallow, Barium Meal, and Barium Enema in the Selected Study Centres

Procedure	Centre	Age (years)	Weight (kg)	Height (cm)	VCA (mL)	T. I	N. I	FDD (cm)	FSD (cm)	kVp	mAs	BA (cm ²)	XOP
Barium Swallow	UDUTH	36.51	73.35	168.63	54.71	100.00	6.35	100.00	70.67	72.06	30.59	54.71	0.08
	MSDC	26.76	63.64	172.80	111.60	100.00	5.80	100.00	74.40	88.08	39.04	111.60	0.04
Barium Meal	YGH	40.65	66.40	152.15	91.65	64.50	3.15	103.18	79.96	74.88	20.03	1400.00	0.09
Barium Enema	UDUTH	27.55	66.90	165.85	60.00	20.35	8.35	100.00	69.00	74.25	28.65	408.55	0.09

Abbreviations: VCA = Volume of Contrast Agent; T.I = Time Interval; N.I = Number of Images; FDD = Focus-to-Detector Distance; FSD = Focus-to-Skin Distance; BA = Beam Area; XOP = X-ray Output

3.2 Barium Swallow Organ Absorbed Doses

The organ absorbed doses for patients undergoing Barium Swallow examinations in the two hospitals, MSDC and UDUTH 9 (table 2), show considerable variability, both between organs and across institutions. **MSDC** recorded the highest absorbed doses in radiosensitive organs such as the **thyroid (6.81 mGy, 3.37–10.06)**, **thymus (4.84 mGy, 2.25–7.33)**, and **skin entrance (12.07 mGy, 6.18–17.58)**. This indicates that, in MSDC, superficial and glandular tissues are exposed to relatively high radiation, likely due to machine output parameters and positioning during fluoroscopy. Conversely, lower doses were observed in the **colon wall (0.02 mGy, 0.01–0.03)**, **small intestine wall (0.02 mGy, 0.01–0.03)**, and **oral mucosa (0.26 mGy, 0.12–0.39)**, reflecting the limited direct exposure of these organs to the primary X-ray beam during the procedure. In **UDUTH**, dose variations were more pronounced between male and female patients. For instance, the **thyroid dose** was markedly lower in males (0.96 mGy, 0.13–4.59) compared to MSDC, but higher in females (3.74 mGy, 2.87–4.59), suggesting differences in patient anatomy, positioning, or exposure technique. Similarly, **pancreas and small intestine doses** were significantly elevated in male patients at UDUTH (4.28 mGy, 0.01–6.80 for the small intestine), whereas female patients received minimal exposure (0.01 mGy, 0.01–0.01). These disparities may reflect operator-dependent factors such as radiographic time, beam collimation, and patient body habitus.

Glandular organs such as the **breasts** showed moderate doses in MSDC (0.33 mGy, 0.15–0.49), but interestingly, UDUTH female patients recorded higher doses (0.46 mGy, 0.35–0.58), indicating potential variability in patient positioning or procedural technique. Organs with naturally lower radiosensitivity, including the **colon wall, kidneys, and gall bladder wall**, generally received lower doses across both centers, highlighting that the primary beam is carefully directed away from these areas during routine examinations. Maximum absorbed doses to **red bone marrow (RBM)** and **bone surface cells (BSC)** also reflect institution-dependent variations. MSDC recorded a **maximum RBM dose of 6.49 mGy (3.10–9.73)** and **BSC dose of 8.37 mGy (3.95–12.64)**, significantly higher than male patients at UDUTH (RBM: 2.79 mGy, BSC: 0.44 mGy), but comparable to UDUTH female patients (RBM: 2.71 mGy, BSC: 3.39 mGy). The **weighted MASH dose**, representing a composite estimate of organ doses, was similar across institutions (0.93 mGy MSDC vs. 0.52 mGy UDUTH), suggesting that despite variations in individual organ doses, the overall effective exposure remains moderate. These findings highlight the critical importance of procedure-specific optimization of radiographic parameters. The considerable differences between hospitals and between sexes at UDUTH underline the need for **institutional Diagnostic Reference Levels (DRLs)** tailored to patient demographics and examination protocols. Such measures can minimize unnecessary radiation exposure while maintaining diagnostic image quality, particularly for radiosensitive organs like the thyroid, thymus, and breast tissue.

Table 2: Barium Swallow Organ Absorbed Doses (mGy)

Organs	MSDC	UDUTH Male	UDUTH Female
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ADRENALS	0.78 (0.32–1.22)	0.27 (0.18–0.42)	0.32 (0.22–0.42)
ORAL MUCOSA	0.26 (0.12–0.39)	0.11 (0.07–0.20)	0.15 (0.11–0.20)
COLON WALL	0.02 (0.01–0.03)	0.02 (0.01–0.12)	0.02 (0.01–0.03)
BREASTS, glandular	0.33 (0.15–0.49)	0.14 (0.08–0.58)	0.46 (0.35–0.58)
KIDNEYS	0.35 (0.15–0.55)	0.17 (0.08–0.50)	0.14 (0.10–0.19)
LIVER	1.76 (0.83–2.66)	0.75 (0.54–1.00)	0.79 (0.58–1.00)
LUNGS	1.67 (0.78–2.54)	0.73 (0.51–1.05)	0.83 (0.61–1.05)
OESOPHAGUS	1.94 (0.88–2.96)	0.71 (0.04–1.27)	1.00 (0.73–1.27)
PANCREAS	0.25 (0.10–0.39)	0.77 (0.06–5.80)	0.17 (0.11–0.22)
SMALL INTESTINE WALL	0.02 (0.01–0.03)	4.28 (0.01–6.80)	0.01 (0.01–0.01)
SKIN ENTRANCE 7.2×7.2 cm	12.07 (6.18–17.58)	1.30 (0.06–7.39)	5.58 (4.36–6.80)
SPLEEN	0.27 (0.12–0.42)	0.26 (0.09–0.38)	0.11 (0.08–0.15)
STOMACH WALL	0.86 (0.39–1.32)	0.36 (0.05–1.97)	0.50 (0.35–0.64)
SALIVARY GLANDS	0.17 (0.08–0.26)	1.80 (0.08–3.22)	0.09 (0.07–0.12)
THYMUS	4.84 (2.25–7.33)	2.70 (0.28–3.58)	2.08 (1.52–2.61)
THYROID	6.81 (3.37–10.06)	0.96 (0.13–4.59)	3.74 (2.87–4.59)
EXTRATHORACIC AIRWAYS	0.41 (0.20–0.62)	0.88 (0.20–1.30)	0.24 (0.18–0.30)
HEART WALL	2.89 (1.33–4.40)	0.47 (0.03–1.58)	1.25 (0.89–1.58)
LYMPHATIC NODES	0.72 (0.34–1.10)	0.16 (0.05–0.39)	0.30 (0.23–0.38)
GALL BLADDER WALL	0.20 (0.08–0.32)	0.59 (0.08–2.73)	0.18 (0.13–0.23)
SKELETON AVERAGE	0.81 (0.38–1.22)	2.47 (0.39–3.47)	0.47 (0.35–0.59)
MAXIMUM RBM ABSORBED DOSE	6.49 (3.10–9.73)	2.79 (0.36–4.04)	2.71 (2.00–3.39)
MAXIMUM BSC ABSORBED DOSE	8.37 (3.95–12.64)	0.44 (0.29–0.64)	3.39 (2.47–4.26)
WEIGHTED MASH DOSE	0.93 (0.44–1.41)	0.52 (0.38–0.74)	0.52 (0.38–0.64)

Kim et al. (2021) observed similar thyroid doses (5–7 mGy) during conventional fluoroscopy. Given the radiosensitivity of the thyroid gland, protective shielding and high-kVp, low-mA exposure settings are essential. Using **flat-panel detectors** and **dose-reduction algorithms** can reduce exposure without compromising image quality (Lanca & Silva, 2022).

3.3 Barium Enema (BE), and Barium Meal Organ Absorbed Dose

Table 3 presents the absorbed doses for various organs during **Barium Enema (BE)** and **Barium Meal** examinations across different hospitals in Northwestern Nigeria. The doses are expressed as mean $\pm$ standard deviation (SD) with corresponding ranges, highlighting both the central tendency and variability of radiation exposure. Among the organs evaluated, the **skin entrance dose** recorded the highest values across all procedures, with Barium Enema at **6.73 $\pm$ 1.31 mGy (4.29–8.11)**, Colostography at **6.51 $\pm$ 1.70 mGy (3.61–9.57)**, and Barium Meal at **2.88 $\pm$ 1.96 mGy (0.85–7.12)**. This is expected, as the skin is directly exposed to the primary X-ray beam during radiographic examinations. Similarly, radiosensitive organs such as the **gall bladder, pancreas, colon wall, and stomach wall** recorded relatively higher doses compared to organs like the **heart, lungs, and testes**, reflecting their proximity to the irradiated region during contrast studies. The **pancreas** received **1.70 $\pm$ 0.43 mGy** during BE, whereas the dose during Barium Meal was significantly lower (**1.02 $\pm$ 0.44 mGy**), likely due to the smaller irradiated volume and lower beam intensity in upper gastrointestinal studies. The **spleen** and **liver** also exhibited a notable difference, with Barium Meal showing higher variability in absorbed dose (**2.61 $\pm$ 2.09 mGy** for the spleen and **0.56 $\pm$ 0.39 mGy** for the liver), indicating that patient-specific factors such as body habitus and organ positioning significantly influence dose deposition.

Low-dose organs, including the **adrenals, oesophagus, and testes**, consistently recorded minimal absorbed doses across all procedures (<0.25 mGy), reflecting both their anatomical position away from the primary beam and partial shielding by overlying tissues. The **maximum red bone marrow (RBM) and bone surface (BSC) absorbed doses** remained within expected limits, with RBM doses ranging from 0.38 ± 0.12 mGy for BE to 0.52 ± 0.59 mGy for Barium Meal, and BSC doses between 0.49 ± 0.15 mGy and 0.38 ± 0.15 mGy, indicating relatively low systemic exposure despite localized high-dose regions. The **weighted MASH dose for males**, representing a composite measure of effective dose, further supports that these procedures deliver modest whole-body radiation, although attention should be given to organs receiving higher localized exposure.

Table 3: Barium Enema (BE), and Barium Meal Organ Absorbed Dose [mGy]

Organs	Barium Enema [UDUTH]	Barium Meal [YGH]
ADRENALS	0.21 ± 0.06 (0.11–0.27)	0.21 ± 0.08 (0.11–0.32)
BLADDER WALL	0.80 ± 0.21 (0.45–1.03)	0.75 ± 0.26 (0.43–1.08)
COLON WALL	1.96 ± 0.47 (1.15–2.45)	1.44 ± 0.42 (0.92–2.46)
KIDNEYS	0.36 ± 0.10 (0.19–0.48)	0.16 ± 0.15 (0.03–0.54)
LIVER	1.20 ± 0.30 (0.69–1.51)	0.56 ± 0.39 (0.18–1.50)
LUNGS	0.03 ± 0.01 (0.02–0.05)	0.50 ± 0.47 (0.02–1.07)
OESOPHAGUS	0.04 ± 0.01 (0.02–0.06)	0.04 ± 0.02 (0.02–0.06)
TESTES	0.07 ± 0.02 (0.03–0.09)	0.05 ± 0.02 (0.03–0.10)
PANCREAS	1.70 ± 0.43 (0.97–2.16)	1.02 ± 0.44 (0.50–2.24)
SMALL INTESTINE WALL	1.85 ± 0.47 (1.05–2.35)	1.15 ± 0.45 (0.59–2.39)
SKIN ENTRANCE $7.2\text{cm} \times 7.2\text{cm}$	6.73 ± 1.31 (4.29–8.11)	2.88 ± 1.96 (0.85–7.12)
SPLEEN	0.69 ± 0.18 (0.39–0.88)	2.61 ± 2.09 (0.37–4.95)
STOMACH WALL	1.90 ± 0.46 (1.11–2.38)	0.98 ± 0.55 (0.39–2.42)
PROSTATE	0.23 ± 0.07 (0.12–0.31)	0.75 ± 0.57 (0.13–1.45)
HEART WALL	0.04 ± 0.01 (0.02–0.06)	0.27 ± 0.29 (0.01–0.68)
LYMPHATIC NODES	0.77 ± 0.19 (0.44–0.96)	0.34 ± 0.32 (0.03–0.98)
GALL BLADDER WALL	3.31 ± 0.75 (1.98–4.08)	1.40 ± 1.15 (0.07–4.07)
SKELETON AVERAGE	0.41 ± 0.11 (0.22–0.53)	1.06 ± 0.83 (0.21–2.18)
MAXIMUM RBM ABSORBED DOSE	0.38 ± 0.12 (0.19–0.51)	0.52 ± 0.59 (0.20–2.25)
MAXIMUM BSC ABSORBED DOSE	0.49 ± 0.15 (0.25–0.65)	0.38 ± 0.15 (0.21–0.75)
WEIGHTED MASH DOSE MALE	0.67 ± 0.16 (0.39–0.84)	0.47 ± 0.15 (0.27–0.86)

Overall, Table 3 underscores the importance of **procedure-specific dose optimization**, particularly for high-exposure organs such as the skin, colon, and gall bladder. The data demonstrate that **Barium Enema tend to impart higher localized doses**, whereas **Barium Meal generally produces lower and more variable organ doses**, likely reflecting differences in beam collimation, exposure time, and patient anatomy. These findings highlight the necessity of adhering to **radiation protection principles** such as ALARA (As Low As Reasonably Achievable) and suggest that regular **dose monitoring and protocol optimization** could effectively reduce patient radiation burden in gastrointestinal contrast studies. These findings agree with Tapiovaara and Siiskonen (2023), who identified gastrointestinal fluoroscopy as among the most dose-intensive diagnostic procedures. Optimizing exposure parameters and adopting **digital radiographic systems** can substantially reduce patient dose (Lanca & Silva, 2022).

3.4 Effective Dose [mSv]

Examinations involving barium-based studies displayed diverse doses depending on procedure type and hospital availability. For **Barium Swallow**, male patients received the highest dose at **Medi Stop Diagnostic and Clinical Centres (1.06 ± 0.43 mSv) (table 4)**, while female patients at Usmanu Danfodiyo University Teaching Hospital had relatively low exposure (0.32 ± 0.09 mSv). Similarly, **Barium Enema** and **Barium Meal** doses were moderate, with the Barium Enema at Usmanu Danfodiyo University Teaching Hospital measuring 0.74 ± 0.18 mSv, suggesting procedural differences and radiographic technique adjustments significantly impact patient dose. The close similarity between male and female mean values indicates that procedural technique, rather than patient sex, was the main determinant of dose consistent with the work of Damilakis et al. (2020), who noted procedural standardization as a major dose-reduction factor. Interestingly, many hospitals did not report doses for these specialized procedures, highlighting either limited utilization or data collection gaps. Overall, the table highlights significant inter-hospital and inter-procedural variability in effective doses. **Medi Stop Diagnostic and Clinical Centres** frequently recorded the highest doses. These findings suggest the need for standardization of exposure protocols and optimization of radiographic parameters to ensure patient safety and adherence to diagnostic reference levels (DRLs). Differences may also be attributed to equipment age, calibration status, and operator expertise, reinforcing the importance of regular quality control programs in all radiology centers.

Table 4: Effective Dose [mSv]

Procedures	Yauri General Hospital, Yauri	Usmanu Danfodiyo University Teaching Hospital, Sokoto	Medi Stop Diagnostic & Clinical Centres, Sokoto
Barium Swallow [Male]	---	0.50 ± 0.08 (0.36–0.72)	1.06 ± 0.43 (0.50–1.60)
Barium Swallow [Female]	---	0.32 ± 0.09 (0.22–0.42)	---
Barium Enema	---	0.74 ± 0.18 (0.42–0.93)	---
Barium Meal	0.50 ± 0.17 (0.28–0.95)	---	---

Kim et al. (2021) reported comparable values (0.5–2.5 mSv) for similar procedures. These findings fall within international diagnostic thresholds but highlight variability linked to equipment performance. Implementing **dose management systems (DMS)** and **routine quality assurance** will improve patient safety (IAEA, 2018).

3.5 Radiation-Induced Cancer Incidence Risk

The present study revealed substantial inter-procedural and inter-centre variations in the estimated lifetime radiation-induced cancer incidence risk associated with gastrointestinal contrast radiographic examinations. As presented in Table 5, the highest estimated cancer incidence risk was observed among male patients undergoing Barium Swallow examination at Medi Stop Diagnostic and Clinical Centres, with a mean value of 9.56 ± 4.52 , ranging from 4.08 to 16.21. In contrast, the same examination performed at Usmanu Danfodiyo University Teaching Hospital (UDUTH) produced a markedly lower mean risk of 0.50 ± 0.08 (0.36–0.72), representing almost a nineteen-fold reduction compared with Medi Stop. Female patients undergoing Barium Swallow at UDUTH demonstrated a mean cancer incidence risk of $5.76 \pm$

1.58 (3.93–7.44), which was substantially higher than the corresponding male value recorded at the same institution. Similarly, Barium Enema examinations performed at UDUTH yielded a mean risk of 4.90 ± 1.20 (2.95–7.56), whereas Barium Meal examinations undertaken at Yauri General Hospital (YGH) recorded the lowest overall cancer incidence risk of 2.97 ± 0.69 (2.00–4.39).

These findings clearly demonstrate that radiation-induced cancer incidence risk varies considerably among healthcare institutions despite evaluating comparable gastrointestinal fluoroscopic procedures. Such variability is expected because patient radiation dose during fluoroscopically guided examinations depends strongly on technical and operational factors, including fluoroscopy duration, pulse rate, tube potential (kVp), tube current-time product (mAs), number of acquired spot images, field size, beam collimation, image receptor efficiency, patient body habitus, and operator experience. Hart et al. (2012) reported more than a ten-fold variation in patient doses among hospitals participating in the United Kingdom National Patient Dose Database, attributing these differences primarily to inconsistencies in examination protocols and fluoroscopic practice. Likewise, the European Commission (2018) identified substantial variations in fluoroscopic doses across European healthcare facilities and emphasized optimization and Diagnostic Reference Levels (DRLs) as the most effective strategies for harmonizing patient radiation exposure.

The exceptionally high cancer incidence risk observed for male Barium Swallow examinations at Medi Stop Diagnostic and Clinical Centres (9.56 ± 4.52) strongly suggests comparatively higher patient effective doses during these procedures. This may reflect prolonged fluoroscopy times, increased image acquisition, larger irradiation fields, or differences in equipment performance and operator-dependent imaging techniques. By comparison, the considerably lower value reported at UDUTH (0.50 ± 0.08) indicates more optimized imaging practices, potentially including shorter fluoroscopy times, effective beam collimation, pulsed fluoroscopy, lower exposure settings, and adherence to standardized examination protocols. Similar observations were reported by Chen and D’Costa (2022), who demonstrated that optimization of fluoroscopic exposure parameters significantly reduced effective dose during Barium Swallow examinations without compromising diagnostic image quality.

An important finding of the present study is the higher estimated cancer incidence risk among female patients undergoing Barium Swallow examinations at UDUTH (5.76 ± 1.58) compared with their male counterparts (0.50 ± 0.08). This observation is biologically plausible and consistent with the Biological Effects of Ionizing Radiation (BEIR VII) report, which concluded that females generally possess a higher lifetime attributable risk of radiation-induced cancer than males exposed to equivalent radiation doses because of increased radiosensitivity of tissues such as the breast, thyroid, lungs, and ovaries, combined with longer life expectancy (National Research Council, 2006). Consequently, even when patient doses are similar, the projected stochastic risk remains higher among female patients.

The moderate cancer incidence risk associated with Barium Enema (4.90 ± 1.20) is consistent with the relatively larger irradiated anatomical region and the longer fluoroscopic screening typically required for evaluation of the large intestine. Barium Enema examinations frequently involve repeated spot radiographs and prolonged visualization of the colon, resulting in greater

radiation exposure to radiosensitive pelvic organs, including the colon, bladder, gonads, and bone marrow. Conversely, the lower cancer incidence risk observed during Barium Meal examinations at YGH (2.97 ± 0.69) likely reflects the comparatively shorter examination duration and more limited irradiation of radiosensitive organs.

The present findings are broadly consistent with international dosimetric investigations. Alsalem (2025) reported considerable variation in effective dose and estimated cancer risk during Modified Barium Swallow examinations performed in Saudi Arabia, identifying fluoroscopy time and operator experience as the principal determinants of patient radiation exposure (Samaila, 2026; Samaila et al., 2024). Similarly, UNSCEAR (2022) emphasized that optimization practices remain one of the major determinants of stochastic radiation risk associated with diagnostic imaging worldwide. Although the absolute cancer incidence risks estimated in the present study remain relatively small at the individual level, the cumulative public health impact becomes increasingly important because gastrointestinal fluoroscopic examinations are frequently performed. In accordance with the Linear No-Threshold (LNT) model adopted by the International Commission on Radiological Protection (ICRP), any incremental radiation exposure is assumed to proportionally increase the probability of stochastic effects, reinforcing the need for continuous optimization of fluoroscopic practice (ICRP, 2007).

Table 5: Risk of Cancer Incidence

Procedures	Yauri General Hospital, Yauri (A)	Usmanu Danfodiyo University Teaching Hospital, Sokoto (B)	Medi Stop Diagnostic and Clinical Centres, Sokoto (C)
Barium Swallow [Male]	—	0.50 ± 0.08 (0.36–0.72)	9.56 ± 4.52 (4.08–16.21)
Barium Swallow [Female]	—	5.76 ± 1.58 (3.93–7.44)	—
Barium Enema	—	4.90 ± 1.20 (2.95–7.56)	—
Barium Meal	2.97 ± 0.69 (2.00–4.39)	—	—

3.6 Radiation-Induced Cancer Mortality Risk

The estimated lifetime radiation-induced cancer mortality risk exhibited a pattern similar to that observed for cancer incidence, with considerable variation among hospitals and examination types (Table 6). The highest mortality risk was recorded among male patients undergoing Barium Swallow examinations at Medi Stop Diagnostic and Clinical Centres, with a mean value of 6.87 ± 3.05 , ranging from 3.05 to 11.08. Conversely, the corresponding examination performed at UDUTH produced a substantially lower mortality risk of only 0.49 ± 0.09 (0.34–0.71). Female patients undergoing Barium Swallow examinations at UDUTH demonstrated a mortality risk of 3.59 ± 0.87 (2.61–4.52), while patients undergoing Barium Enema recorded a mean mortality risk of 2.39 ± 0.58 (1.45–3.62). The lowest mortality risk among all evaluated procedures was observed for Barium Meal examinations at Yauri General Hospital, with a mean value of 1.50 ± 0.29 (1.11–2.09).

The close correspondence between cancer incidence and mortality risks observed in this study is expected because both parameters are derived from organ absorbed doses and effective dose estimates using the BEIR VII risk projection model. Consequently, healthcare facilities delivering comparatively higher patient doses inevitably produce higher estimates of both cancer incidence and cancer mortality. The nearly fourteen-fold difference between Medi Stop (6.87 ± 3.05) and UDUTH (0.49 ± 0.09) for male Barium Swallow examinations strongly indicates substantial differences in fluoroscopic practice and radiation dose optimization between the two institutions.

Several procedural factors may account for these observed differences. Increased fluoroscopy time, repeated image acquisition, inadequate collimation, higher exposure factors, suboptimal equipment calibration, and limited implementation of dose-saving technologies such as pulsed fluoroscopy and last-image hold have all been identified as major contributors to increased patient dose during gastrointestinal fluoroscopic procedures. Miller et al. (2010) demonstrated that systematic implementation of optimized fluoroscopic protocols significantly reduced patient radiation dose while maintaining adequate diagnostic image quality, findings that support the lower mortality estimates observed at UDUTH.

The higher mortality risk estimated for female Barium Swallow examinations (3.59 ± 0.87) compared with males at the same institution (0.49 ± 0.09) is also consistent with internationally recognized radiation risk models. BEIR VII reported that females generally exhibit greater lifetime susceptibility to radiation-induced malignancies because of increased tissue radiosensitivity and differences in baseline cancer incidence (National Research Council, 2006). Nevertheless, mortality risk remains lower than cancer incidence because not every radiation-induced malignancy results in fatal disease, and risk coefficients incorporate cancer-specific survival probabilities.

The intermediate mortality risks associated with Barium Enema (2.39 ± 0.58) and Barium Meal (1.50 ± 0.29) further reflect differences in examination complexity and irradiated anatomical volume. Barium Enema examinations generally require longer fluoroscopic observation and expose multiple pelvic organs, whereas Barium Meal examinations are relatively shorter and predominantly involve the upper gastrointestinal tract. These observations agree with ICRP Publication 121 (2013), which identified fluoroscopy duration and examination complexity as primary determinants of patient radiation dose during gastrointestinal imaging.

The present findings are comparable with those reported by Chen and D'Costa (2022), who demonstrated substantial reductions in effective dose following optimization of Barium Swallow imaging protocols, and by Alsalem (2025), who found that patient radiation risk during Modified Barium Swallow examinations was highly dependent on fluoroscopy time and operator expertise. Similarly, UNSCEAR (2022) concluded that although stochastic risks associated with diagnostic radiology remain relatively low for individual patients, significant inter-institutional variability persists globally owing to differences in optimization practices, equipment performance, and adherence to radiation protection principles.

From a clinical and radiation protection perspective, the elevated cancer mortality risk observed at Medi Stop Diagnostic and Clinical Centres highlights the necessity for routine patient dose audits, periodic quality assurance testing, optimization of exposure parameters, implementation of local and national Diagnostic Reference Levels, and continuous professional training of radiologists and radiographers. These measures are fully consistent with recommendations issued by the ICRP (2007), the International Atomic Energy Agency (IAEA, 2018), and the World Health Organization, all of which advocate optimization of fluoroscopically guided procedures to minimize stochastic radiation effects while maintaining diagnostic image quality.

Overall, the present study demonstrates that radiation-induced cancer incidence and mortality risks associated with gastrointestinal contrast examinations remain low in absolute terms but vary markedly across healthcare institutions. The observed variability underscores significant opportunities for dose optimization and supports the urgent establishment of procedure-specific Diagnostic Reference Levels for gastrointestinal fluoroscopy in Nigeria and other resource-constrained healthcare systems.

Table 6: Risk of Cancer Mortality

Procedures	Yauri General Hospital, Yauri (A)	Usmanu Danfodiyo University Teaching Hospital, Sokoto (B)	Medi Stop Diagnostic & Clinical Centres, Sokoto (C)
Barium Swallow [Male]	--	0.49 ± 0.09 [0.34–0.71]	6.87 ± 3.05 [3.05–11.08]
Barium Swallow [Female]	--	3.59 ± 0.87 [2.61–4.52]	--
Barium Enema	--	2.39 ± 0.58 [1.45–3.62]	--
Barium Meal	1.50 ± 0.29 [1.11–2.09]	--	--

3.7 Comparison of Effective Doses

Table 7 demonstrates that the effective doses (EDs) estimated in the present study were consistently lower than those reported in previous investigations conducted in Ghana, Cameroon, and Nigeria across all evaluated contrast-enhanced radiographic examinations. The observed reductions ranged from 17.0% to 84.1%, indicating a systematic decrease in patient radiation exposure relative to published regional data. Although these findings suggest improved dose optimization, direct comparisons should be interpreted cautiously because differences in patient characteristics, imaging equipment, fluoroscopy protocols, dosimetric methodologies, and institutional practices may contribute substantially to inter-study variability.

For barium swallow examinations, the present study yielded an ED of 0.64 mSv, representing a 23.81% reduction compared with the 0.84 ± 0.13 mSv reported by Ngaile (2014). Similarly, comparison with the Nigerian study by Adejoh et al. (2016) showed a more modest reduction of 17.0% relative to the reported ED of 1.00 mSv. The relatively small differences observed between these studies may reflect comparable procedural complexity and similar fluoroscopic imaging requirements. Nevertheless, the lower ED reported in the present investigation may indicate incremental improvements in optimization practices, including more appropriate selection of exposure parameters, tighter beam collimation, increased utilization of digital

detector technology, and greater adherence to radiation protection principles. These findings are consistent with the recommendations of the International Commission on Radiological Protection (ICRP) and the International Atomic Energy Agency (IAEA), which emphasize continuous optimization of patient doses while maintaining diagnostic image quality (ICRP, 2007; IAEA, 2014).

The greatest reductions were observed for barium meal examinations. Compared with the 3.15 ± 0.44 mSv reported by Ngaile (2014), the ED obtained in the present study (0.50 mSv) was approximately 84.13% lower. Likewise, comparison with the 2.5–3.2 mSv reported by Moifo et al. (2017) (using the midpoint of the reported range) demonstrated an 82.46% reduction, while comparison with Adedokun et al. (2014) showed an 83.87% reduction. Such substantial differences may reflect advances in radiographic technology over the past decade, particularly the widespread transition from conventional fluoroscopic systems to digital flat-panel detectors, implementation of automatic exposure control, improved detector efficiency, and more rigorous optimization protocols. Furthermore, increasing awareness of radiation protection, regular quality assurance programmes, and improved operator training may have contributed to reducing unnecessary fluoroscopy time and repeat image acquisition. However, because none of the comparator studies assessed image quality using standardized objective criteria, it cannot be concluded unequivocally that lower radiation doses translated into equivalent or superior diagnostic performance. Consequently, dose reduction should be interpreted within the broader context of diagnostic efficacy rather than as an isolated indicator of optimization.

A similar pattern was observed for barium enema examinations, where the ED of 2.39 mSv obtained in the present study was substantially lower than values reported in previous African studies. Specifically, reductions of 61.70% and 60.17% were observed relative to the findings of Ngaile (2014) and Moifo et al. (2017), respectively, while comparison with Adedokun et al. (2014) also demonstrated a reduction of approximately 60%. Barium enema examinations typically involve prolonged fluoroscopic guidance and multiple image acquisitions, making them among the highest-dose conventional gastrointestinal procedures. Therefore, the observed reduction may indicate improved fluoroscopic dose management through optimization of pulse rates, reduced screening times, improved beam filtration, appropriate field collimation, and optimized patient positioning. These observations are consistent with international recommendations advocating justification and optimization as the two fundamental principles governing medical radiation exposure (ICRP, 2007).

Collectively, the comparisons presented in Table 7 suggest that the participating centres achieved lower patient radiation doses than those previously reported in comparable African studies. Although the precise factors responsible for these reductions cannot be identified from the available data, several plausible explanations exist. These include technological improvements associated with digital radiography systems, implementation of quality assurance and quality control programmes, greater compliance with diagnostic reference levels (DRLs), routine equipment calibration, optimization of exposure parameters, and increasing professional awareness of radiation safety. Similar reductions in patient dose following implementation of optimization strategies have been reported in international radiological

practice, where modernization of imaging systems and protocol standardization have contributed to substantial decreases in fluoroscopic radiation exposure (IAEA, 2014).

Despite these encouraging findings, several limitations should be acknowledged. First, the comparator studies were conducted over different time periods and under varying clinical conditions, making direct quantitative comparisons inherently challenging. Second, differences in patient body habitus, examination indications, fluoroscopy duration, imaging equipment, detector technology, and effective dose calculation methodologies may influence the reported ED values independently of optimization practices. Third, while effective dose provides a useful metric for population-level comparison of stochastic radiation risk, it does not account for patient-specific organ radiosensitivity or individual anatomical variation and should therefore not be interpreted as a measure of individual patient risk (ICRP, 2007).

Overall, the findings indicate that the participating hospitals have achieved comparatively low effective doses for contrast-enhanced radiographic examinations relative to previously published African data. These results provide additional evidence supporting the continued implementation of optimization strategies, establishment of locally derived diagnostic reference levels, and routine dose audits to promote safe and effective use of ionizing radiation in diagnostic imaging. Future multicentre studies employing standardized dosimetric methodologies and objective image quality assessment would further strengthen regional benchmarking and facilitate harmonization of optimization practices across healthcare institutions.

Table 7: Comparative Effective Doses for Contrast-Enhanced Radiographic Examinations Across

Author / Year	Country / Region	Centre / Institution	Procedure	Reported ED (mSv)	This Study (mSv)	% Deviation
Ngaile (2014)	Ghana	Korle-Bu Teaching Hospital	Barium Swallow	0.84 ±0.13	0.64	-23.81%
Ngaile (2014)	Ghana	Korle-Bu Teaching Hospital	Barium Meal	3.15 ±0.44	0.50	-84.13%
Moifo et al. (2017)	Cameroon (Yaoundé)	YUTH	Barium Meal	2.5–3.2	0.50	-82.46%
Ngaile (2014)	Ghana	Korle-Bu Teaching Hospital	Barium Enema	6.24 ±0.70	2.39	-61.70%
Moifo et al. (2017)	Cameroon (Yaoundé)	YUTH	Barium Enema	5.0–7.0	2.39	-60.17%
Adedokun et al., 2014	-	-	Barium Meal	3.10	0.50	-83.87%
Adedokun et al., 2014	-	-	Barium Enema	6.00	2.39	-60.17%
Adejoh et al., 2016	-	-	Barium Swallow	1.00	0.83	-17.00%

4.0 Conclusion and Future Research

This multicentre prospective study provides comprehensive evidence on organ-specific absorbed doses, effective dose, and radiation-induced cancer risks associated with conventional gastrointestinal contrast radiographic examinations in Northwestern Nigeria. The findings

demonstrate significant inter-centre and inter-procedural variations in radiation exposure, primarily attributable to differences in imaging protocols, exposure parameters, and institutional practices. Among the investigated procedures, barium swallow performed at MedStop Diagnostic and Clinical Centre produced the highest effective dose (1.06 ± 0.43 mSv) together with the greatest estimated lifetime cancer incidence (9.56 ± 4.52 per 100,000 exposed persons) and mortality risk (6.87 ± 3.05 per 100,000 exposed persons). Conversely, female patients undergoing barium swallow at UDUTH received the lowest effective dose (0.32 ± 0.09 mSv), while barium enema and barium meal produced intermediate effective doses of 0.74 ± 0.18 mSv and 0.50 ± 0.17 mSv, respectively. These findings indicate that procedural complexity and radiographic technique exert greater influence on patient radiation burden than patient sex alone. Organ-specific dose assessment revealed that the thyroid (6.81 mGy), skin entrance (12.07 mGy), thymus (4.84 mGy), gall bladder wall (3.31 ± 0.75 mGy), colon wall (1.96 ± 0.47 mGy), and pancreas (1.70 ± 0.43 mGy) received the highest radiation doses during gastrointestinal contrast examinations, highlighting the importance of organ dosimetry in evaluating patient radiation burden and stochastic risk. Although effective doses remained within internationally acceptable diagnostic ranges, localized organ exposures emphasize the need for continued optimization of radiographic techniques to minimize unnecessary irradiation of radiosensitive tissues.

A notable finding of this study is that effective doses were **17.0–84.13% lower** than those reported in previous studies from Ghana, Cameroon, and Nigeria. These reductions likely reflect improvements in equipment performance, beam collimation, protocol optimization, routine quality assurance, and increasing adherence to international radiation protection recommendations. Nevertheless, the variability observed among participating centres suggests that further harmonization of examination protocols remains necessary to achieve consistent optimization across healthcare facilities. Overall, the estimated lifetime radiation-induced cancer incidence and mortality risks were low, supporting the continued clinical use of gastrointestinal contrast radiographic examinations when clinically justified. However, optimization should remain a fundamental component of clinical practice. Establishing **locally derived diagnostic reference levels (DRLs)**, implementing routine patient dose monitoring, strengthening quality assurance and quality control programmes, standardizing imaging protocols, and promoting continuous professional training are recommended to further reduce radiation exposure while maintaining diagnostic image quality. The present study provides important baseline dosimetric and radiological risk data for Nigeria and contributes evidence to support the development of national DRLs for gastrointestinal contrast radiography. Future multicentre investigations incorporating larger patient cohorts, standardized dosimetric methodologies, objective image-quality assessment, and optimization audits are warranted to strengthen regional benchmarking and improve radiation protection practices across sub-Saharan Africa.

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Data availability

The datasets are available upon request

Declarations

Ethical approval

The research was approved by Health Research Ethics Committee of Kebbi State Ministry of Health [**KESHREC Reg No: 107:061/2023**], UDUTH Health Research Committee, Sokoto State [**UDUTH/HREC/2024/1437/V1**] and Verbal communication of approval was obtained from **MedStop Clinic and Diagnostic Centre** after presentation of the research proposal before the Health Research Committee in accordance with the Helsinki Declaration on human data.

Consent to participate

The patients were informed prior to the data collection [measurement of his/her weight, height and age] and verbal consent of each patient were obtained.

Consent to publish

All the articles included in the study were cited and referenced, and all the authors of the paper consented to publication.

Clinical Trial Number

Not applicable

Competing interests

The authors declare no competing interests.

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