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Assessment of Entrance Surface Dose and Effective Dose in Intravenous Urography (IVU) Procedure in Selected Hospitals in Yobe State, Nigeria

Joseph IAnas Muhammad Salisu, Joseph Istipanus Abaleni, Yusuf Abdullahi Ahmed, Nasiru Rabi'u

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Abstract: *The study aimed to assess radiation doses in patients undergoing Intravenous Urography (IVU) at selected hospitals in Yobe State, Nigeria, ensuring that exposure is justified and maintained as low as reasonably achievable (ALARA). A quantitative methodology was employed, utilizing Thermo-luminescent dosimeters (TLDs) to measure entrance surface doses (ESD) on patients, along with CALDose_X 5.0 software for effective dose estimation. A total of 50 patients (25 each from Yobe State University Teaching Hospital and Yobe State Specialist Hospital) were surveyed, recording exposure parameters such as peak kilovoltage (kVp) and current-time product (mAs). The results indicated mean ESD and ED in YSUTH was found to be (0.815±0.107 mGy and 0.028±0.005 mSv) at 0 min exposure and (0.865±0.121 mGy and 0.032±0.006 mSv) at 1 minute exposure, for YSSHD was recorded as 0.967±0.330 mGy and 0.038±0.007 mSv for 1 min exposure and 1.086±0.319 mGy and 0.048±0.012 mSv; at 0 minute exposure. Mean cumulative ESD values of 4.5708±0.808 mGy and 5.899±2.254 mGy for YSUTH and YSSHD; respectively. Effective doses ranged from 0.119 mSv to 0.474 mSv in the study and the m,ean ED for YSUTH and YSSHD are 0.163±0.031 mSv and 0.248±0.091 mSv. The risk assessment revealed that the cancer risk 3.663×10^{-5} estimated were significantly lower than the established international reference levels, suggesting that while radiation exposure is present, it remains within acceptable limits. In conclusion, the findings underscore the importance of optimizing radiation doses during IVU procedures and adherence to safety protocols to mitigate potential health risks associated with ionizing radiation. The study provides critical data for improving radiological practices in the region.*

Keywords: *Intravenous Urography (IVU), Thermo-luminescent dosimeters (TLDs), to measure entrance surface doses (ESD), CALDose_X 5.0 software*

Anas Muhammad Salisu*
Physics Department, Ahmadu Bello University, Zaria, Kaduna State, Nigeria
Email: abuumair399@gmail.com
https://orcid.org/0009-0002-6134-0511

Joseph Istipanus Abaleni
Department of Physics, Kaduna State College of Education, Gidan Waya, Kaduna State, Nigeria
Email: abaleni30@gmail.com
https://orcid.org/0009-0004-3789-4332

Yusuf Abdullahi Ahmed
Centre for Energy Research and Training, Ahmadu Bello University, Zaria, Nigeria
Email: yaahmed1@gmail.com
https://orcid.org/0000-0002-1904-3241

Nasiru Rabi'u
Physics Department, Ahmadu Bello University, Zaria, Kaduna State, Nigeria
Email: nrabiu@yahoo.com

1.0 Introduction

Medical diagnostic imaging using ionizing radiation has become indispensable in modern healthcare, particularly for the evaluation of diseases of the urinary system. Intravenous urography (IVU) remains a commonly employed radiographic procedure for investigating renal anatomy and function, especially in resource-limited settings where access to advanced imaging modalities such as computed tomography urography (CTU) may be restricted. IVU involves the administration of iodinated contrast media followed by multiple X-ray exposures at different time intervals, which inevitably subjects patients to ionizing radiation. Although the diagnostic benefits of IVU are well established, exposure to ionizing radiation carries a potential risk of stochastic effects, including radiation-induced malignancies, necessitating careful dose assessment and optimization in accordance with the As Low as Reasonably Achievable (ALARA) principle (Eddy *et al*., 2025a,b).

Patient radiation dose in diagnostic radiography is commonly assessed using quantities such as Entrance Surface Dose (ESD) and Effective Dose (ED). ESD provides an estimate of the radiation incident on the patient's skin, while ED accounts for the radiosensitivity of exposed organs and tissues and is widely used for estimating overall radiation risk. Accurate evaluation of these dose quantities is essential for comparing clinical practice with established diagnostic reference levels (DRLs), optimizing imaging protocols, and ensuring patient safety.

Several studies have investigated radiation doses associated with IVU and other diagnostic radiological procedures. Jambi *et al*. (2022) assessed radiation dose and radiogenic cancer risk in IVU examinations and reported mean entrance surface air kerma and effective dose values of 2.1 ± 0.64 mGy and 0.131 ± 0.04 mSv, respectively. Their findings indicated that radiation doses from IVU were significantly lower than those from CTU, highlighting IVU as a comparatively lower-dose imaging option when appropriately optimized. Similarly, Hamza *et al*. (2015) compared effective doses from renal scintigraphy, CTU, and IVU, demonstrating that IVU generally results in lower patient effective doses than CTU, although dose values varied depending on imaging protocols and patient characteristics.

In Nigeria and other developing countries, several studies have focused on patient dose assessment in conventional diagnostic radiography. Nworgu & Bamidele (2025) evaluated ESDs for common X-ray examinations in two Nigerian teaching hospitals and found that mean doses were generally within international reference limits. However, notable variations were observed between facilities, emphasizing the influence of equipment performance and exposure parameters. Shehu *et al*. (2026) reported elevated entrance skin doses for some conventional X-ray examinations in Sokoto Metropolis, suggesting potential patient overexposure and inadequate optimization practices. Similar concerns regarding dose variability and the need for regular quality control have been reported by Vatsa *et al*. (2022) and Rubai *et al*. (2018), who highlighted the importance of routine dose audits to minimize radiation risks to patients.

Despite the growing body of literature on patient dosimetry in diagnostic radiology, there remains a clear lack of published data on radiation doses associated with IVU procedures in Yobe State, Nigeria. Most Nigerian studies have focused on general radiographic examinations such as chest, spine, and abdominal imaging, with limited attention given to IVU, a procedure that involves multiple exposures and prolonged examination time. The absence of localized dose data makes it difficult to evaluate compliance with international reference levels, assess potential radiation risks, and implement effective dose optimization strategies within the region.

Therefore, the aim of this study is to assess the entrance surface dose and effective dose received by patients undergoing intravenous urography in selected hospitals in Yobe State, Nigeria. Specifically, the study seeks to quantify patient radiation exposure during IVU procedures, estimate the associated effective dose and cancer risk, and compare the measured values with internationally recommended reference levels.

The significance of this study lies in its contribution to establishing baseline patient dose data for IVU procedures in Yobe State. The findings will provide valuable information for radiologists, medical physicists, and healthcare policymakers to improve radiation protection practices, optimize imaging protocols, and enhance patient safety. Furthermore, the study will contribute to the limited national database on patient radiation doses in Nigeria and support ongoing efforts toward standardization and quality assurance in diagnostic radiology.

2.0 Materials and Methods

The materials and methods details the evaluation of Entrance Surface Dose (ESD) and Effective Dose (ED) in patients undergoing Intravenous Urography (IVU) at selected hospitals. The study utilized Thermo-luminescent dosimeters (TLDs) to directly measure ESD on patients' skin and CALDose_X 5.0 software to compute ED (Omer *et al*., 2022; Sherer, Visconti, Ritenour, & Haynes, 2018; Tsoulfanidis & Landsberger, 2021).

2.1 Materials

The materials employed in the study are:

(i) Medical X-ray machines: Fixed type rotanode (YSUTH) and mobile X-ray apparatus (YSSHD).
(ii) TLDs: Specifically, TLD-100 made of lithium fluoride doped with magnesium and titanium.
(iii) Phantoms: Anthropomorphic phantoms used to simulate human organs.

The technical specifications of the machines employed in the study were specified in Table 1.

Table 1: Technical Specifications of X-ray machines

Facility	Machine Type	Manufacturer	Model	Filtration	Focal Spot
YSUTH	Fixed Rotanode	Toshiba	E7239X	2.0 mm Al	2.0/1.0
YSSHD	Mobile X-ray apparatus	Ocean Med+	F100(XD4-2.9/100)	1.5 mm Al	4.3

Source: YSUTH and YSSHD radiography units

2.2 Methodology

This structured methodology ensures the reliability of dose estimates during IVU procedures, which is crucial for patient safety in radiological assessments.

TLD calibration: TLDs was annealed initially using TLD reader and are pre-irradiated by exposing to radiation to establish their calibration factor before use.

Patient setup: TLDs were placed on patients' skin at the specified locations during IVU procedures so that the TLD placed did not affect the diagnostic value of the image.

Data collection: Exposure parameters (kVp, mAs) and the focus-to-skin distance were recorded. At the end of every examination, the TLDs was removed from the patient and put in a black zip-lock bag to avoid other external contamination and annihilation of the recorded.

2.2.1 Estimation of ESD and ED

ESD was directly measured using Thermo-luminescent Dosimeters (TLDs) placed on the patients' skin and can be estimated mathematically using equation 2. Effective doses were calculated using the CALDose_X 5.0 software with the equation 1.

$$E = \sum W_T \left[H_{T(female)} + H_{T(male)}\right]/2 = {}^1/_2 \left[\sum W_T H_{T(female)} + \sum W_T H_{T(male)}\right] = {}^1/_2 \left[F + M\right] \quad (1)$$

and H_T is the average organ and tissue equivalent doses in tissues T.

The effective dose estimated by CALDose_X 5.0 and specified by the ICRP103 (ICRP, 2022) is therefore the average of the sex-**specific** weighted doses. The calculated weighted female dose (F) or weighted male dose (M) is given and recorded (Yacoob & Mohammed, 2017).

2.2.2 Mathematical Computation of ESD

Mathematical models using parameters such as kVp, mAs, and backscatter factors were employed to estimate doses. The formula used for ESD calculation was:

$$ESD = BSF \times Tube\ Output\ \left(\frac{mGy}{mAs}\right) \times \left[\frac{100cm}{FSD}\right]^2 \times mAs \quad (2)$$

Where kVp represents X-ray peak tube voltage, BSF is the backscatter factor; 1.37 was selected from an IAEA publication (IAEA, 1996, p. 282), Tube Output is beam output in mGy/mAs of the X-ray tube at different kVp settings at distance of 1 m, which was calculated using an ionization chamber, mAs is the tube current multiplied by exposure time; and FSD is the focus-to-skin distance (cm) (Alomairy *et al*., 2023).

2.2.3 Estimation of cancer risks

This is the probability that an individual would develop cancer from a radiological diagnostic procedure. CALDose_X 5.0 calculates this as the sum over risk-weighted organs and tissues equivalent doses using equation 3

$$R = \sum \Upsilon_T H_T \quad (3)$$

where Υ_T is the lifetime attributable tissue specific cancer risks per unit organ equivalent dose estimated as 5×10^{-2} Sv^{-1} (ICRP, 2022)

3.0 Results and Discussion

The present study evaluated the Entrance Surface Dose (ESD) and Effective Dose (ED) received by patients undergoing Intravenous Urography (IVU) procedures at Yobe State University Teaching Hospital (YSUTH) and Yobe State Specialist Hospital, Damaturu (YSSHD). A total of 50 patients (30 males and 20 females), aged between 20 and 75 years, participated in the study. Patients' body weight ranged from 40 to 72 kg, and the Body Mass Index (BMI) ranged from 15.78 to 28.12 kg/m². Key radiographic parameters recorded during IVU procedures included a focus-to-skin distance (FSD) of approximately 100 cm, tube voltage (kVp) between 60 and 80, and tube current-time product (mAs) adjusted according to patient size.

3.1 Patient Dose during IVU Procedures

Table 2 presents the ESD and ED for patients at 0- and 1-minute exposures, as well as cumulative values for each facility.

At YSUTH, the mean ESD was 0.815 ± 0.107 mGy at 0 min and 0.865 ± 0.121 mGy at 1 min, with corresponding ED values of 0.028 ± 0.005 mSv and 0.032 ± 0.006 mSv. At YSSHD, the mean 0 min ESD and ED were 1.086 ± 0.319 mGy and 0.048 ± 0.012 mSv, and at 1 min 0.967 ± 0.330 mGy and 0.038 ± 0.007 mSv, respectively. The cumulative mean ESD and ED were 4.570 ± 0.808 mGy and 0.163 ± 0.031 mSv for YSUTH, and 5.899 ± 2.254 mGy and 0.248 ± 0.091 mSv for YSSHD.

Table 2: Patient Dose During IVU Procedures

Facility	0 min ESD (mGy)	0 min ED (mSv)	1 min ESD (mGy)	1 min ED (mSv)	Cumulative ESD (mGy)	Cumulative ED (mSv)
YSUTH	min: 0.592	0.02	0.602	0.021	3.098	0.119
	mean: 0.815±0.107	0.028±0.005	0.865±0.121	0.032±0.006	4.570±0.808	0.163±0.031
	max: 0.976	0.038	1.004	0.042	7.386	0.25
YSSHD	min: 0.651	0.036	0.651	0.027	3.181	0.135
	mean: 1.086±0.319	0.048±0.012	0.967±0.330	0.038±0.007	5.899±2.254	0.248±0.091
	max: 1.712	0.079	1.869	0.058	13.083	0.474

The results indicate that doses at YSSHD were higher than at YSUTH, likely due to slightly higher kVp, mAs, and variations in focus-to-skin distance. Nonetheless, all recorded doses are well within international diagnostic reference levels (DRLs), with the European Commission (EC, 2008) recommending a reference ESD of 10 mGy for IVU procedures. Figure 1 can be inserted here to graphically show ESD and ED variations at 0 and 1 minute exposures for both hospitals, aiding visual comparison.

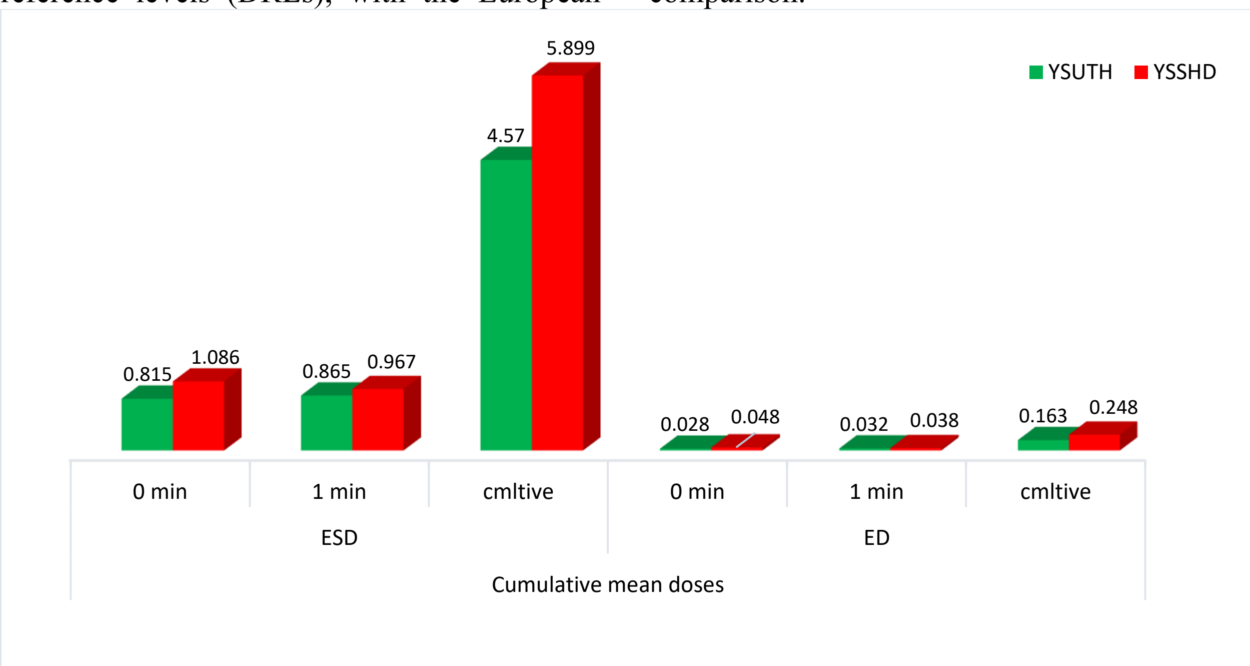

Fig. 1: Estimated ESD and ED

3.2 Comparison with Previous Studies

Table 3 compares the mean ESD, cumulative ESD, and estimated cancer risk from this study with prior investigations and DRL guidelines.

The ESD and cumulative ESD recorded in this study are lower than those reported in Suliman *et al.* (2010) and Odunayo (2021), indicating effective radiation optimization practices in the participating hospitals.

Table 3: Comparison of Mean ESD, Cumulative ESD, and Cancer Risk with Previous Studies

Dose (mGy)	This Study	Related Studies	DRLs (IVU)

	YSUTH	YSSHD	Suliman *et al*., 2010
ESD	0.815±0.107	0.967±0.330	3.21±1.20
Cumulative ESD	4.570±0.808	5.899±2.254	13.61±6.17
Cancer risk (M) x10^{-5}	1.586±0.50	2.23±1.24	2.70±1.01
Cancer risk (F) x10^{-5}	3.663±2.08	3.53±1.72	3.46±1.20

Furthermore, the cancer risk estimates (maximum 3.663 ± 2.083 × 10^{-5}) remain below the lifetime risk threshold suggested by ICRP (2022) and UNSCEAR (2008), where a 1 Sv exposure would result in a maximum of 35 cases per 1,000,000 people. Fig/2 can be inserted here to compare the mean ESD and cumulative ESD from this study against previous studies, visually highlighting the lower doses obtained in the current investigation.

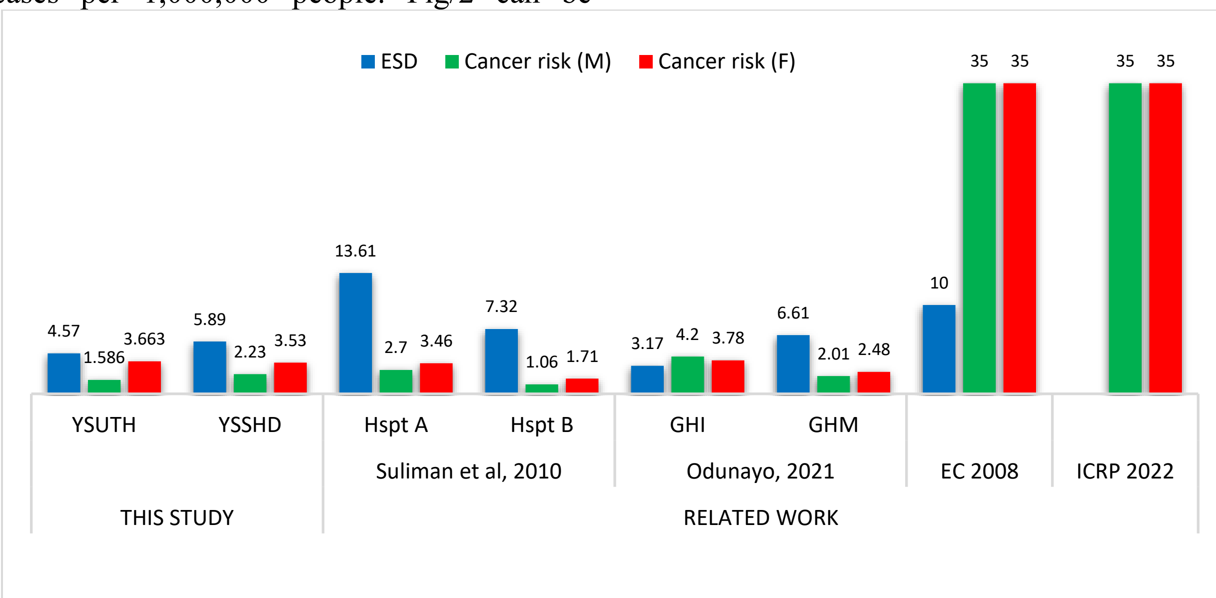

Fig. 2: Comparison of the study with previous work.

3.3 Technical Discussion

The observed higher radiation doses at YSSHD may be attributed to slightly increased exposure parameters, including tube voltage (kVp) and current-time product (mAs), as well as variations in focus-to-skin distance. According to ICRP (2022) and Hamza *et al*. (2015), both ESD and ED values are influenced by patient size, X-ray beam quality, and patient positioning, which helps explain the variability observed between the two hospitals. The cumulative ESD provides a more relevant measure for estimating the total radiation burden during the full IVU procedure, since multiple exposures are necessary to image the entire urinary tract. In this study, the cumulative ESD values were 4.57 ± 0.808 mGy at YSUTH and 5.899 ± 2.254 mGy at YSSHD, both substantially below the European Commission's recommended diagnostic reference level (DRL) of 10 mGy, demonstrating adherence to ALARA (As Low As Reasonably Achievable) principles.

Comparisons with previous studies indicate that Suliman *et al*. (2010) reported higher ESD values of 3.21 ± 1.20 mGy, likely due to differences in imaging protocols and machine calibration. Similarly, Odunayo (2021) reported an ESD of 1.60 ± 0.83 mGy, which is closer to the current findings and suggests that

Nigerian hospitals are gradually optimizing IVU radiation doses. International DRLs, as reported by EC (2008) and ICRP (2022), consistently recommend 10 mGy as the reference dose for IVU procedures, confirming that the doses measured in this study are safely within established limits.

The cancer risk assessment indicates a minimal radiogenic risk, with female patients exhibiting slightly higher estimated lifetime risk than male patients. This is consistent with ICRP tissue weighting factors, as radiosensitive organs in the female urinary system contribute to higher effective doses (Hamza *et al*., 2015; Jambi *et al*., 2022). Overall, these findings underscore that both hospitals are maintaining patient safety effectively while optimizing radiation exposure during IVU procedures.

The findings of this study highlight several important observations and implications. First, both hospitals successfully maintained radiation doses below international diagnostic reference levels, demonstrating effective dose management and adherence to recommended radiation safety standards. Second, the observed variability in doses between the two hospitals appears to be influenced by differences in machine type, exposure settings, and operator technique, indicating the need for standardized imaging protocols to further reduce inconsistencies. Third, despite the lower radiation doses, the quality of diagnostic images was not compromised, confirming that optimization of IVU procedures can be achieved without sacrificing clinical effectiveness. Finally, this study provides baseline data on patient radiation doses for IVU procedures in Yobe State, which can serve as a reference for hospital protocols and inform the establishment of national dose reference levels, thereby supporting policy decisions aimed at improving patient safety in diagnostic radiology.

4.0 Conclusion

This study assessed patient radiation exposure during Intravenous Urography (IVU) procedures at Yobe State University Teaching Hospital (YSUTH) and Yobe State Specialist Hospital, Damaturu (YSSHD), with a focus on Entrance Surface Dose (ESD), Effective Dose (ED), and associated cancer risk. The results demonstrate that the mean ESD and ED for both hospitals, as well as cumulative doses, remained well below internationally established diagnostic reference levels (DRLs), indicating effective radiation optimization in clinical practice. While slight variations in doses were observed between the two hospitals, these differences were attributable to variations in X-ray exposure parameters, focus-to-skin distance, and machine type, highlighting the importance of standardized imaging protocols to ensure consistent dose management. The estimated cancer risk, with a maximum of 3.663×10^{-5} for female patients, is minimal and remains substantially below the lifetime risk thresholds recommended by ICRP and UNSCEAR, confirming that patient safety is being effectively maintained. Importantly, these optimized dose levels did not compromise diagnostic image quality, demonstrating that adherence to the as low as Reasonably Achievable (ALARA) principle can be successfully implemented in routine IVU examinations. The findings provide critical baseline data for IVU procedures in Yobe State, offering a reference point for hospital protocols, national dose reference levels, and policy formulation aimed at improving radiological safety. Overall, this study underscores the value of systematic dose monitoring, patient-specific dose assessment, and continued optimization of radiographic techniques to minimize radiation exposure while maintaining high-quality diagnostic outcomes in resource-limited settings.

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Declaration

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Competing Statement

There are no competing financial interests in this research work.

Ethical considerations

Not applicable

Data availability

The microcontroller source code and any other information can be obtained from the corresponding author via email.

Authors' Contribution

Anas Muhammad Salisu conceptualized the study, conducted field measurements, and led data analysis and manuscript drafting. Joseph Istipanus Abaleni supervised the research design, methodology, and quality assurance. Yusuf Abdullahi Ahmed supported dosimetric analysis, software-based dose estimation, and interpretation of results. Nasiru Rabi'u contributed to data collection, statistical evaluation, literature review, and critical revision of the manuscript for intellectual content.