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Determination of the Local Diagnostic Reference Level in Panoramic Radiography for the Evaluation of Radiation Doses in Dental Offices in Abidjan

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Abstract

Objective: To date, no data on Diagnostic Reference Levels (DRLs) have been recorded in Ivorian dental practice. Moreover, the determination of these DRLs still seems to be an area of research that remains insufficiently explored in the dental field in Africa, despite the fact that international bodies encourage each Nation to develop its dose reference levels adapted to the equipment used and their practice. The objective of this study was to establish Diagnostic Reference Levels in children and adults based on dental panoramic radiographs. **Material and Method:** Five radiographic devices installed in five dental offices were selected. Using a Diamentor M4KDK-type 11017 DAP meter, the values of Dose-Area Product in mGy·cm^2 were measured. In each dental office, thirty-five adult patients and twenty-five child patients were considered. The exposure parameters for each patient (voltage, current, and exposure time) were extracted. The third quartile values, considered as local diagnostic reference levels, were established. **Results:** A total of 300 children and adult patients were included in this study. The results showed that the third quartile values for children and adults varied respectively from 45.3 to 90.6 mGy·cm^2 and 106.3 to 160.9 mGy·cm^2. The local values of the Diagnostic Reference Levels established overall were 85.35 mGy·cm^2 for children and 149.6 mGy·cm^2 for adults. **Conclusion:** The Diagnostic Reference Levels obtained in this study were significantly higher compared to those in other countries. Nevertheless, these values remain lower than those reported in other countries. Hence, there is a need to raise awareness among professionals about the risks of ionizing radiation.

Keywords

Diagnostic Reference Level, Dose-Area Product, Panoramic Radiography, Radiation Protection

1. Introduction

The use of ionizing radiation is an aid in the diagnostic and therapeutic approach of the Dentist [1]. Nevertheless, the benefits of these ionizing radiations should not overshadow the potential risks associated with their uncontrolled use. The United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR) emphasized in its 2020/2021 report that the medical use of ionizing radiation remains the main artificial source of exposure to ionizing radiation [2].

Thus, healthcare professionals must have a culture of radioprotection in their radiological practice. This culture implies respect for the fundamental ALARA principle (as low as reasonably achievable) for the protection of the patient. From this fundamental principle, the justification of radiological examinations must determine whether or not the examinations are carried out [3].

Although the doses of radiation delivered by dental radiographic devices are relatively low, it is necessary not to underestimate the potential risks associated with their cumulative effect [4]. In the same radiology room, the doses delivered by the equipment can vary from one patient to another. Thus, the International Commission on Radiological Protection (ICRP) introduced the concept of Diagnostic Reference Levels (DRLs) in the 1990s [5]. The DRL is a tool predominantly used in the optimization process. It constitutes an excellent indicator of radiation protection. As a result, the establishment of DRLs has been recommended to all member states by the International Atomic Energy Agency (IAEA) [6].

Furthermore, various studies have been conducted following the IAEA's recommendations in several countries [7]-[9]. In Côte d'Ivoire, studies on the establishment of DRLs have also been conducted [10] [11]. The radiological examinations concerned included, among others, the chest and lumbar regions. To date, no data on DRLs have been recorded in Ivorian dental practice. Moreover, the determination of these DRLs still seems to be an area of research that remains insufficiently explored in the dental field in Africa, despite the fact that international bodies (ICRP and IAEA) encourage each Nation to develop its dose reference levels adapted to the equipment used and their practice.

Thus, the aim of this study is to establish DRLs reflecting current dosimetric practice from dental radiographic equipment through a dose survey.

2. Material and Method

Over a period of 11 months, we conducted a dosimetric study within dental offices in the city of Abidjan. This study focused on the doses of radiation emitted by dental radiographic devices. As the economic capital of Côte d'Ivoire and the main metropolis of the country, Abidjan represents a pivotal center in the Ivorian healthcare system. This city gathers a significant share of the human, health, and technological resources in the field of oral and dental care. It alone concentrates a substantial proportion of the dental offices in the country.

2.1. Dosimetry Equipment

The main equipment used for dosimetric measurements was the DAP meter type 11017 from the Diamentor M4KDK brand, manufactured in Germany by the company PTW (Physikalisch-Technische Werkstätten). It consists of a size B ionization chamber and an electrometer (device for reading DAP counters). The ionization chamber is placed at the tube output, at the level of the collimator, and the electrometer is placed at desk level, behind the lead screen. The ionization chamber and the electrometer are connected by two cords. The ionization chamber is the main instrument for measuring the dose received by a patient. It is a plastic box containing a gas (air) and two electrodes between which a potential difference is established. When the X-ray beam passes through the ionization chamber, it deposits energy there, which is transmitted through the cables to the electrometer. At this stage, this energy is converted into air dose (Dair) and Dose-Area Product (DAP) [12].

This device was provided by the Ivorian Authority for Radiation Protection, Nuclear Safety and Security (ARSN). According to the information provided by the regulatory authority, the DAP meter had previously been calibrated at the PTW laboratory in Freiburg, Germany. However, the calibration date and the associated measurement uncertainty were not available. To ensure better agreement between the values recorded by the DAP meter and those displayed by the radiological equipment, a paired agreement analysis, reporting the systematic bias and limits of agreement, was performed using radiological equipment that undergoes regular quality control by the competent radiation protection authority.

2.2. Selection Criteria

Based on the data from the Directorate of Private Establishments and Health Professions (DEPPS) and the National Oral Health Program (PNSBD), we conducted an inventory of dental offices that had a functional extra-oral radiographic device (panoramic unit or a CBCT system operating in panoramic mode) at the time of the study. A total of seven dental clinics were identified. The study included dental clinics that voluntarily agreed to participate and for which the characteristics of the X-ray equipment were accessible. Thus, five dental clinics were eligible for inclusion in the study. Among these five dental clinics, different digital imaging systems were installed: three dedicated panoramic units and two CBCT systems operated in panoramic mode.

In each dental office, we took into account thirty-five (35) adult patients and twenty-five (25) child patients in accordance with the recommendations of the International Commission on Radiological Protection [13].

Participants were divided into two age groups: children and adults. The pediatric group included participants aged 5 - 15 years, while the adult group included participants aged ≥18 years. The age distribution was reported separately for each group. To ensure compliance with radiation protection measures, the patient's position was carefully verified to avoid unnecessary radiation exposure.

2.3. Data Collection Method

Letters were sent to the selected offices for the conduct of the study. After receiving approval, we set up our equipment. Once the DAP meter was correctly positioned at the exit of the X-ray beam, as illustrated in **Figure 1**, we performed a test in the absence of a patient to ensure the proper functioning of the entire measurement system. Subsequently, we visited five (5) dental offices daily, one after the other, to collect data at each acquisition Panoramic.

The variables collected were the brand of the device, the age and sex of the patient, the voltage in kiloVolts (kV), the current in milliAmperes (mA), the exposure time in seconds (s), and the dose-area product or DAP in milligray square centimeters ($mGy \cdot cm^2$). We recorded two (2) values of the dose-area product. One value was collected directly from the radiographic device software and another value was recorded with the DAP meter. The exposure parameters were collected directly from the radiographic device software.

Figure 1. Attachment of the ionization chamber at the X-ray tube.

2.4. Statistical Analysis

The data were analyzed using R software, primarily employing the readxl libraries for importing Excel files. A descriptive analysis was conducted separately for each practice as well as at the overall level. For each quantitative variable and for each patient group (adults and children), the mean, minimum, maximum, median (P50), and third quartile (Q3 or P75) were calculated. The third quartile (Q3 or P75) was defined as the diagnostic reference level in accordance with the recommendations of the International Commission on Radiological Protection [13].

A Pearson linear correlation analysis was performed to study the relationship between the dose measured with the DAP meter and the dose collected with the radiographic device software. For each correlation concerning the relationship between exposure parameters and doses: the Pearson correlation coefficient (r), the p-value, the confidence interval, the direction of the correlation (positive or negative), and the strength of the correlation (weak, moderate, or strong) were determined.

Correlations were considered highly significant for $p < 0.001$, significant for $p < 0.05$, and not significant for $p \geq 0.05$.

3. Results

A total of 300 adult and child patients from 5 dental offices, that is, 60 patients per dental office where radiographic devices were installed, were included in this study.

The values of exposure parameters across all dental offices are presented in **Table 1**. In child patients, the voltage ranged from 67 to 68 kV with a current of 7 to 10 mA and an exposure duration of 8.82 to 12.8 s. In adult patients, the voltage ranged from 73 to 80 kV with a current of 7 to 12 mA and an exposure time of 10.78 to 13.8 s.

Table 1. Expositions of the parameters of dental offices.

	Child			Adult		
	Tension (kV)	Intensity (mA)	Time (s)	Tension (kV)	Intensity (mA)	Time (s)
Office 1	67	7	11.6	80	9	13.8
Office 2	68	8	8.82	73	12	10.78
Office 3	68	10	12.8	76	7	12.7
Office 4	67	8	9.77	73	10	11.76
Office 5	68	8	8.82	73	10	10.78
Mean	**67.6**	**8.2**	**10.36**	**75**	**9.6**	**11.96**

A paired agreement analysis that reports systematic bias and limits of agreement between the values of dose-area products measured with the DAP meter and those collected directly from the radiographic equipment software was noted. This correlation is illustrated in **Figure 2** and **Table 2**.

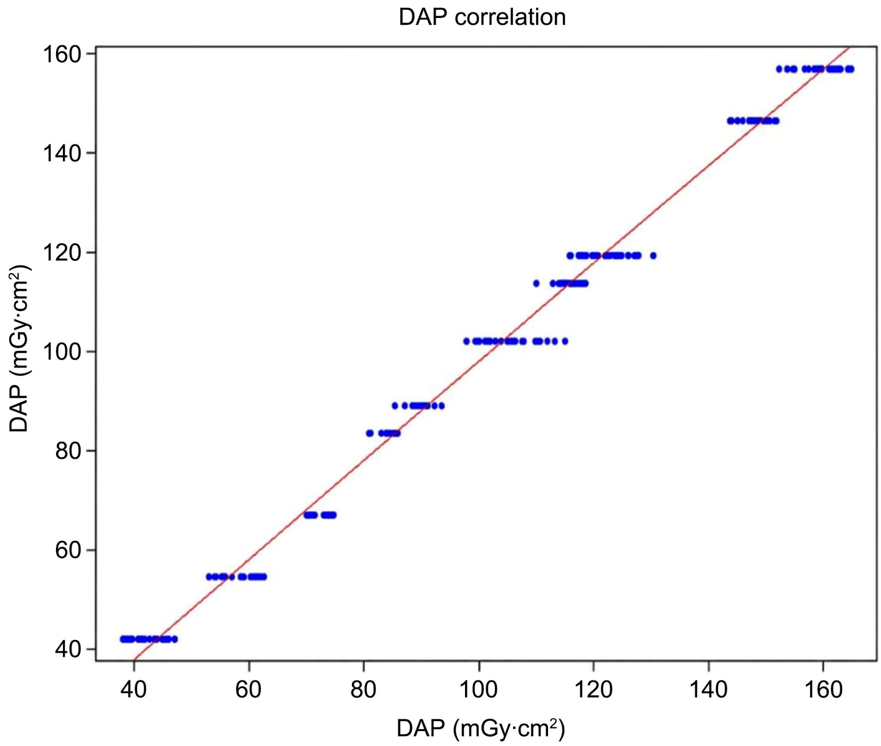

Figure 2. Correlation between measured and displayed dose-area product values.

Table 2. Comparison of measured and displayed dose-area product values.

Variables	Correlation	p-value	IC-inf	IC-sup	Interpretation
DAP1/DAP2	0.996	$p < 0.001$	0.995	0.997	Significant Correlation

In **Table 3**, presenting the dosimetric values for each unit, the CBCT units operated in panoramic mode showed higher dose values than the dedicated panoramic units.

Table 3. Dosimetric value for each unit.

X-units	Median (mGy·cm²)		Third quartile (mGy·cm²)	
	Child	Adult	Child	Adult
CBCT in panoramic mode (office 1)	84.4	157.2	85.3	160.9
Panoramic (office 2)	73.2	116.3	73.8	118
CBCT in panoramic mode (office 3)	89.9	147.6	90.6	149.6
Panoramic (office 4)	59	122.8	60.8	124.2
Panoramic (office 5)	42.1	102.7	45.3	106.3

The distribution of dose-area product values is presented in Table 4. The extreme values were: 38.2 mGy·cm^2 to 93.7 mGy·cm^2 for children and 97.7 mGy·cm^2 to 163.9 mGy·cm^2 for adults.

Table 4. Distributions of dose-area product values in mGy·cm^2.

Age	Mean	Minimum	Maximum	Median	Third quartile
CHILD	69.6	38.2	93.7	73.2	85.35
ADULT	129.85	97.7	163.9	122.8	149.55

Correlations were also observed between dose-area product values and exposure parameters, as illustrated in Table 5. These correlations were generally significant.

Table 5. Correlation between the values of dose-area products and exposure parameters.

Variables	Correlation	p-value	Interpretation	Evolution	Force
DAP/Tension	0.9186	5.34×10^{-123}	Verry significant correlation	Positive	Strong
DAP/Intensity	0.1146	0.04	Significant Correlation	Positive	Weak
DAP/Time	0.8208	5.98×10^{-75}	Verry Significant Correlation	Positive	Strong

DAP: Dose-Area Product.

The calculated Diagnostic Reference Level was 85.35 mGy·cm^2 for child patients and 149.55 mGy·cm^2 for adult patients. These values, compared to those of other countries, are presented in Table 6.

Table 6. Comparison of diagnostic reference levels.

Authors	Years	Country	DRL child (mGy·cm^2)	DRL Adult (mGy·cm^2)
Our study	2026	Côte d'Ivoire	85.35	149.55
Kim	2025	Coree du Sud	224	354
Al Shamsi	2024	Emirates	39.19	68.59
Amal	2020	Inde	82	-
Almohiy	2020	Arabie Saoudite	58.5	99
Suliman	2018	Soudan	70.4	103.4

A comparison of the medians by dental office relative to the established DRL is illustrated in **Figure 3** for child patients and in **Figure 4** for adult patients. The median values in child patients were higher compared to the DRL at dental office number 3. However, these values in adult patients were higher compared to the DRL at dental office number 1.

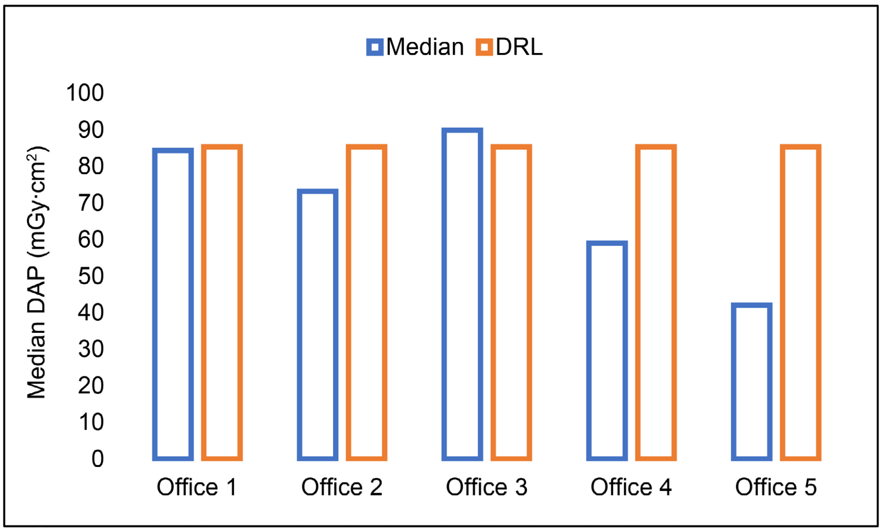

Figure 3. Comparison of medians relative to the DRL for children.

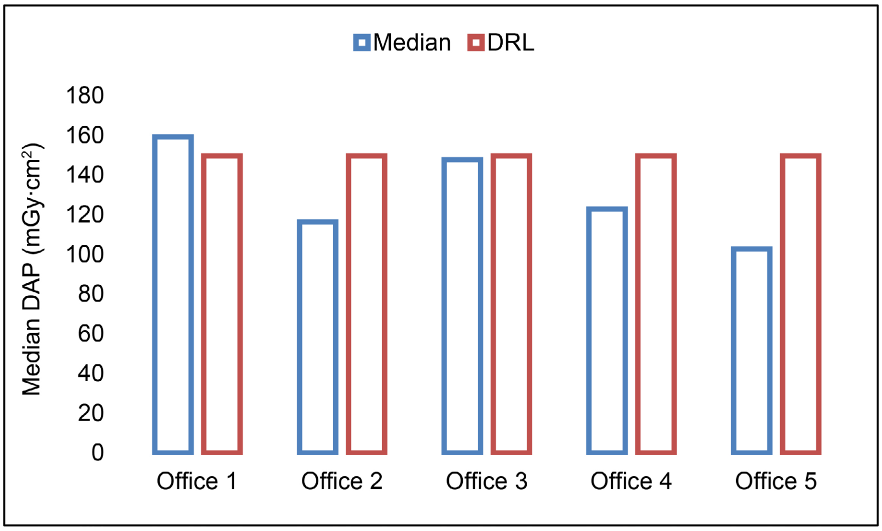

Figure 4. Comparison of medians relative to the DRL for adults.

4. Discussion

In this study, the exposure parameters used varied from one dental office to another. On average, the voltage was 67.6 kV with a current of 8.2 mA and an exposure time of 10.36 s for child patients. As for adult patients, the voltage was 75 kV with a current of 9.6 mA and an exposure duration of 11.96 s. In the literature, it has been reported for children that the parameters are generally around 60 to 70 kV, 8 to 10 mA, and 12 to 13 s. For adults, these parameters are around 70 to 80 kV, 8 to 12 mA, and 12 to 14 s [14] [15]. Comparing the parametric data from this study to those in the literature, we observe that our results fall within the reported range except for the time in children. At this level, the exposure time was below the range. However, the voltage values were closer to the upper limit of the range, unlike the current and duration.

In general, these parameters vary according to the characteristics of the devices and the patient's morphology. The goal is to obtain a quality image with minimal exposure, respecting the ALARA principle (As Low As Reasonably Achievable). The adjustment of parameters before any X-ray exposure is an important step. It significantly influences the radiation dose received by the patient, particularly in terms of the electric charge expressed in milliampere-seconds [16]. Thus, it is appropriate to take this step into account in the optimization process.

The correlation between the Dose-Area Product (DAP) values measured using the DAP meter and those directly displayed by the radiographic devices was assessed using a paired agreement analysis, which quantified the systematic bias and established the limits of agreement between the two measurement methods.

The distribution of the dose-area product values measured in pediatric patients ranged from 38.2 mGy·cm^2 to 93.7 mGy·cm^2. In adult patients, these values varied from 97.7 mGy·cm^2 to 163.9 mGy·cm^2. These variations highlight heterogeneous dosimetric practice. The main sources of these variations may be related to different manufacturers. The radiographic devices included in the study were different suppliers with different operating systems. Two (2) of the devices studied were three-dimensional Cone Beam Computed Tomography digital systems with a two-dimensional functionality allowing panoramic radiographs to be performed. However, three (3) of these devices were typically two-dimensional digital radiography systems. Indeed, Ludlow *et al.* [17] showed that the dosimetric fluctuations observed between radiographic devices could be related to the different design systems among manufacturers. Furthermore, Pauwels *et al.* [18] emphasized that the goal of manufacturers is to produce clinically usable images based on technical modifications with doses varying according to an optimization strategy specific to each system. These authors also noted that exposure parameters had a proportional influence on the dose delivered. This observation aligns with our findings in the study. We noted significant correlations between the measured Dose-Area Product (DAP) values and the exposure parameters. These highly significant correlations with the dose-area products concerned the voltage and exposure time parameters.

From the third quartile of DAP, the Diagnostic Reference Level (DRL) was 85.35 mGy·cm^2 for children and 149.55 mGy·cm^2 for adults. Our results are significantly lower than those of Kim *et al.* [7], who found 224 mGy·cm^2 in pediatric panoramic radiography and 354 mGy·cm^2 in adults. However, our results were higher compared to those reported in the United Arab Emirates [19], India [20], Saudi Arabia [21], and Sudan [22]. A summary of these comparisons is presented in **Table 5**. These variations in DRLs could be related to the equipment and practices specific to each country according to their clinical reality [7].

The DRL is a tool predominantly used in the optimization process. It constitutes an excellent radiation protection indicator. Following the determination of the DRL, we calculated the median in each dental office. As a statistical parameter, the median allows better expression of the central tendency of the distribution according to the dental offices.

For child patients, the median value ranged from 42.1 to 89.9 mGy·cm^2. For adults, it ranged from 102.7 to 159.1 mGy·cm^2. By comparing the median obtained in each dental office with respect to the DRL established overall, we observed that the median obtained in office 3 (89.9 mGy·cm^2) was higher than the established DRL (85.35 mGy·cm^2) for children. Also, for adults, the median in office 1 (159.1 mGy·cm^2) was higher than the established DRL (149.55 mGy·cm^2). These median values being higher than the established DRL suggest that the dosimetric practices carried out in these offices are not optimized. The dental offices where the medians were higher than the DRL concerned office number 3, shown in **Figure 3** for children and office number 1, shown in **Figure 4** for adults.

By observing the exposure parameters applied to children in **Table 1** at office number 3, the voltage was 68 kV with a current of 10 mA and an exposure time of 12.8 s. When compared to data from the literature [14] [15], we observed that these parameters were practically closer to the upper extreme values. Thus, it is necessary to minimize these parameters as much as possible for optimal practice because children have increased sensitivity to ionizing radiation [23].

For adults, in **Table 1** at office number 1, the applied parameters were: 80 kV; 9 mA; 13.8 s. Except for the current, the voltage and time were practically closer to the upper extreme values. It therefore seems necessary to adjust the voltage and duration before any exposure. The radiographic equipment used in this study had exposure parameters that could be adjusted manually, which would facilitate these corrective actions to reduce radiation risks.

This could be related to the experience of the operator [20]. Indeed, the operator encountered in dental office number 3 was a staff member trained on-site by the office manager. This person had only basic knowledge of image acquisition without any knowledge of radiation protection regarding the adjustment of exposure parameters according to the patient's presence. Thus, adult parameters were applied to children.

As for the operators encountered in dental office number 1, they were senior medical imaging technicians. They noted that the modules taught in their initial training were not applicable in the dental field. Similarly, the modules on exposure parameters that were taught were focused on the fundamental concepts without emphasizing the impact of these parameters on the dose through studies. As a result, this increase in dose could be related to these training deficiencies. Thus, it seems appropriate in this context to improve initial and continuing training programs for better practice of radiology. Another factor that could influence these observations is the regular quality control of radiographic equipment [24]. The information collected from most dental office managers reveals that the dosimetric checks they regularly receive from the national authorities concerned portable dosimeters. As for the equipment, they say they do not remember the last time maintenance and quality control actions were performed. Regular quality control of radiographic equipment constitutes a very important step in order to detect potential flaws that could be related to the X-ray generator.

Nevertheless, we noted from a cabinet official that he himself occasionally requested a private company for the calibration of these radiographic devices.

The maintenance and regular quality control of radiographic equipment constitute a very important step in order to detect potential flaws that could be related to the X-ray generator.

High dosimetric values compared with the Diagnostic Reference Level (DRL) do not necessarily indicate that practices are not optimized. Rather, they should serve as a warning signal prompting a local review of practices. Thus, it seems wise on the part of the authorities to strengthen the preventive and corrective actions integrated into a well-developed program.

Digital evolution with the Low Dose program at the level of new radiographic devices allows quality images with lower exposure to ionizing radiation. A pillar of the optimization principle, DRLs must be established as part of an effort to cultivate radiation protection in radiodiagnostic procedures.

5. Conclusions

In this dosimetric assessment study, the Diagnostic Reference Level established for panoramic radiography was 85.35 mGy·cm^2 for pediatric patients and 149.55 mGy·cm^2 for adult patients.

The comparison of the median obtained in each dental office with the established DRL for the group as a whole showed a high median value compared to the DRL in two dental offices. This highlights that the Dose-Area Products are not optimized in these offices. Therefore, corrective measures need to be taken. Specifically, smaller values should be used within the recommended range for voltage, current, and exposure time before any radiographic examination.

We have noted a considerable variation in doses between dental offices. It is therefore necessary to establish continuing education programs on the optimization of radiological practices for the well-being of exposed individuals. This suggests better collaboration between regulatory authorities and users of ionizing radiation.

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Author Contributions

All authors have approved the manuscript according to the defined role. BEK:

Conceptualization, data collection, and manuscript writing. IK: Methodology, results interpretation. ABAL and ASD: Supervision and manuscript writing. JBB: Study conception, supervision and validation.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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