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INVESTIGATION OF THE CONSISTENCY OF EXPOSURE INDEX VALUES OF DIGITAL RADIOGRAPHY SYSTEMS IN NORTH-CENTRAL NIGERIA

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ABSTRACT

Background: The introduction of digital radiography has revolutionized radiography practice. The manufacturers of digital radiography have incorporated a numerical parameter called exposure index (EI) which is a direct estimate of entrance surface dose (ESD) on the imaging plate to allow for control of exposure factors and to mitigate against overexposure. However, the consistency of the exposure index values is uncertain.
Aim: The aim of this study was to investigate the consistency of exposure index values of digital radiography systems in repeated exposures under similar clinical conditions.
Materials and Methods: In this experimental study, five (5) computed radiography (CR) and seven (7) direct digital radiography (DDR) units which met the inclusion criteria were used to investigate the consistency of EI values. The X-ray tube voltage output and entrance surface dose were determined directly with multipurpose digital dosimeter, Cobia Smart R/F, while polymethylmethacrylate (PMMA) glass was used as phantom. The reproducibility of voltage output and entrance surface dose were initially established before data collection for consistency of EI values. For the consistency tests, 1cm thick glass was placed on the X-ray table and exposure parameters for hand was set. Six (6) exposures were taken, the EI, X-ray tube voltage output and ESD recorded each time.
Results: The results showed exposure index value status in computed radiography (CR) units as 43%, 28% and 29% for consistent, inconsistent and undefined respectively. For direct digital radiography (DDR) units, the exposure index status was 45%, 33% and 22% for consistent, inconsistent and undefined respectively. Fujifilm CR-IR 392 produced the least variation of EI values (1.91%), while Fujifilm FCR Capsula XL II produced the highest variation of EI values (58.47%). Vacutec VacuDAP compact DDR produced the least variation of EI values (0.66%), while EASYDR CXD1401G compact produced the highest variation of EI values (39.67%).
Conclusion: There was no overall difference in the performances of computed radiography (CR) and direct digital radiography (DDR) systems in this study and the inconsistencies in the EI values of CR and DDR systems remained significant. The pattern of variations of EI values between CR and DDR were similar in the study. The reasons for the observed inconsistencies of EI values could be due several factors such as variations in system calibration, the condition of the imaging equipment, and operator issues. Others are inadequate equipment maintenance and lack of standardized protocols.

1. Introduction

The introduction of digital radiography over the past four decades has revolutionized radiography practice. Technological advances in image acquisition led to the introduction of the first Fuji 101 computed radiography (CR) system in 1983. Subsequently, other manufacturers joined the CR imaging system [1]. Computed radiography is one form of digital radiography (DR) systems. The other form is the direct digital radiography (DDR) system. There are many advantages of digital radiography imaging systems. These include: wide exposure latitude, ability for post processing, DICOM compartible, electronic transfer and digital storage options [2]. However, ensuring consistency in the performance of these systems is crucial, particularly in terms of the Exposure Index (EI), which serves as an indicator of the amount of radiation used to capture an image. Maintaining consistent EI values is essential not only for producing high-quality diagnostic images but also for optimizing patient safety by minimizing unnecessary radiation exposure [3]. The EI values are numerical parameters introduced by digital radiography manufacturers as a direct estimate of entrance surface dose (ESD) on the imaging plate [4]. The exposure index/indicator (EI) is calculated with an algorithm provided by its manufacturer and named accordingly. The manufacturers recommended range (MRR) of exposure index is provided as a feedback to radiographers for optimum detector dose [5]. When EI values vary significantly across similar exposures, it raises concerns about the reliability of the system and the potential for radiation dose discrepancies, which can lead to suboptimal image quality or unnecessarily high patient doses. Ensuring the consistency of EI values in DR systems has become a priority in clinical settings worldwide, as it directly influences diagnostic accuracy and patient outcomes. Various factors can contribute to inconsistencies in EI values, including variations in system calibration, the condition of the imaging equipment, and operator techniques [6]. Studies have shown that DR systems, particularly in resource-constrained settings like North-Central Nigeria, may be prone to inconsistencies due to inadequate equipment maintenance, lack of standardized protocols, or operator training issues [7][8].

Despite the multifactorial determinants of patient dose, the concept of EI is implemented to serve as feedback to radiographers on the radiation to image detector and indirect indicator of dose to the patient, [9]. Some other authors have reported inconsistent EI values while using the same clinical conditions [10][11], and others reported consistent EI values [12]. Hence, the consistency of EI values across different manufacturers of digital radiography systems is uncertain. In Nigeria, digital radiography systems have increasingly become the standard in medical imaging; however, there is limited research evaluating the consistency of exposure index values in different clinical settings. North-Central Nigeria, which comprises a mix of urban and rural healthcare facilities, offers a unique environment to study this issue. This study aims to investigate the consistency of EI values in CR and DDR systems during repeated exposures under similar clinical conditions in the region. By identifying any significant variations in exposure indices, the study will contribute to understanding whether current practices meet international standards for radiographic quality assurance and patient safety as well as performance status of available digital radiography systems.

2. Materials and Methods

This experimental study was conducted in sixteen (16) digital radiography centres across hospitals and diagnostic centres in North-Central Nigeria from April, 2024 to June, 2024. Five (5) computed radiography (CR) units and seven (7) direct digital radiography (DDR) units met the inclusion criteria in the study. The inclusion criteria were basically centres with reproducible X-ray tube voltage and entrance surface dose (ESD) as measured with Cobia Smart R/F, multi-purpose digital dosimeter. A photostimulable phosphor plate (35 x 43cm) for CR units or a flat panel detector (35 x 43cm) for DDR units is placed on the X-ray couch. One plate of the polymethylmetacrylate (PMMA) glass phantom is placed on the centre of the imaging plate. The size of the phantom glass is 30cm x 30cm and 1cm thick. The X-ray tube is positioned, with a vertical beam, at a focus-to-detector distance of 100cm and the central ray to the centre of the glass phantom. The beam collimated to the size of the glass. A radio-opaque screw nail placed at the centre of the glass and an L-shaped iron placed at the four (4) edges of the glass. The digital dosimeter is additionally placed on the glass phantom ensuring that the sensitive portion is within the X-ray field. The set-up is exposed to a medium radiation energy, that is, exposure factors for an adult's hand, about 50kv and 2.5mAs depending on each centre. The imaging plate/detector is processed on CR/DDR unit as the case may be. The selected kv and mAs on the X-ray machines, the measured kv, mAs, ESD by the dosimeter as well as the exposure index (EI) are recorded. The above setups are repeated five (5) more consecutive times. The imaging plate/detector is processed after each exposure and all the stated parameters recorded. The exposure index (EI) as displayed on the computer screen is recorded without post-processing. In CR imaging, the plate is processed within two minutes of exposure to reduce effects of processing delay, while DDR system displays the image and EI automatically after exposure.

The reproducibility tests and the consistency of EI values are calculated with the coefficient of variation equation. The acceptable variation is 5% or less [13].

The consistency of EI values for CR units and DDR units are determined on centre basis. The results of both CR units and DDR units are compared.

3. Results

The data from seven (7) CR units that met inclusion criteria were analysed using Microsoft Excel. The results of the consistency of EI values in CR units were 43%, 28% and 29%, corresponding to consistent values, inconsistent values and undefined values respectively (Figure 1). Fujifilm CR-IR 392 produced the least variation of EI values (1.91%), while Fujifilm FCR Capsula II produced the highest variation of EI values (58.47%) (Table 1).

The data from nine (9) DDR units that met inclusion criteria were analysed using Microsoft Excel. The results of the consistency of EI values were 45%, 33% and 22%, corresponding to consistent values, inconsistent values and undefined values respectively (Figure 2). Vacutec VacuDAP compact DDR produced the least variation of EI values (0.66%), while EASYDR CXD1401G compact produced the highest variation of EI values (39.67%) (Table 2). In both digital radiography systems, Vacutec VacuDAP compact DDR produced the least EI values variation, while Fujifilm FCR Capsula XL II produced the largest variation.

The comparison of the EI values characteristics of CR and DDR showed similarity among the two digital radiography systems (Figure 3 and Figure 4). Table 3 showed categorized digital radiography systems according to the consistency of EI values in this study. There was wide variations of EI values amongst the digital radiography units.

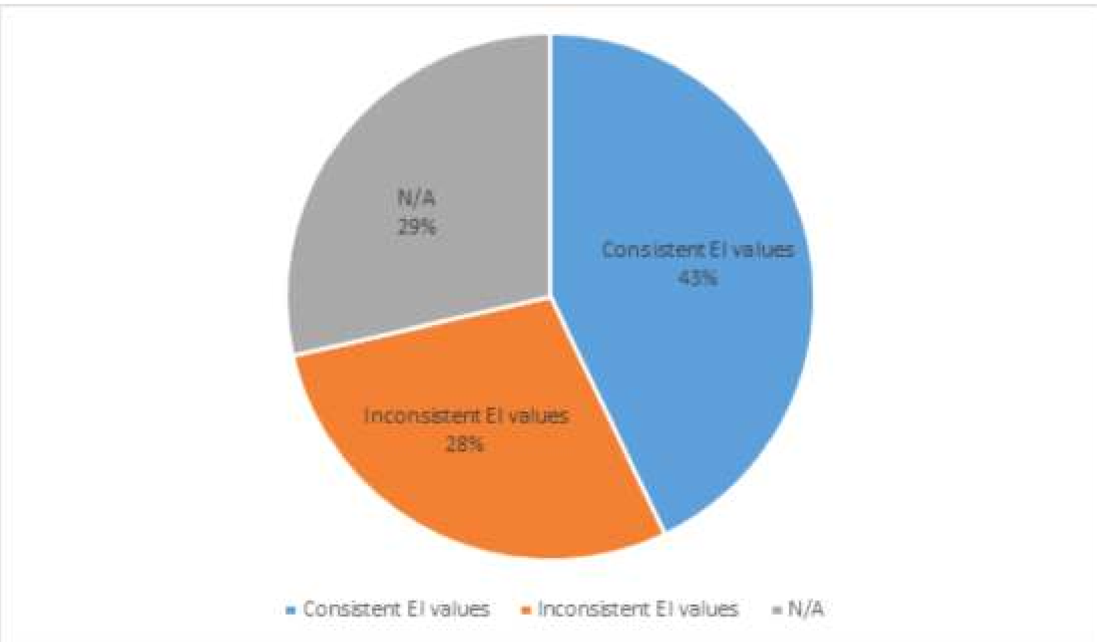

Figure1: Pie Chart showing the EI Consistency Status of CR Centres

Table 1: Consistency Test of Exposure Index Values in CR Centres 1 to 7, Using Coefficient of Variation (cv) Equation.

S/N	CENTRES/MAKES	CV (%) FROM EXPOSURE INDEX VALUES	INTERPRETATION
1	iCRco (iCR3600)	2.53	Consistent
2	Fujifilm (FCR Capsula XL II	58.43	Inconsistent
3	iCRco (3600)	N/A	N/A
4	Fujifilm (CR-IR 392)	1.91	Consistent
5	Fujifilm (CR-IR 393)	7.88	Inconsistent
6	CARESTREAM (Directview)	4.09	Consistent
7	AGFA (CR 12-X)	N/A (78.24)	N/A* Inconsistent ESD

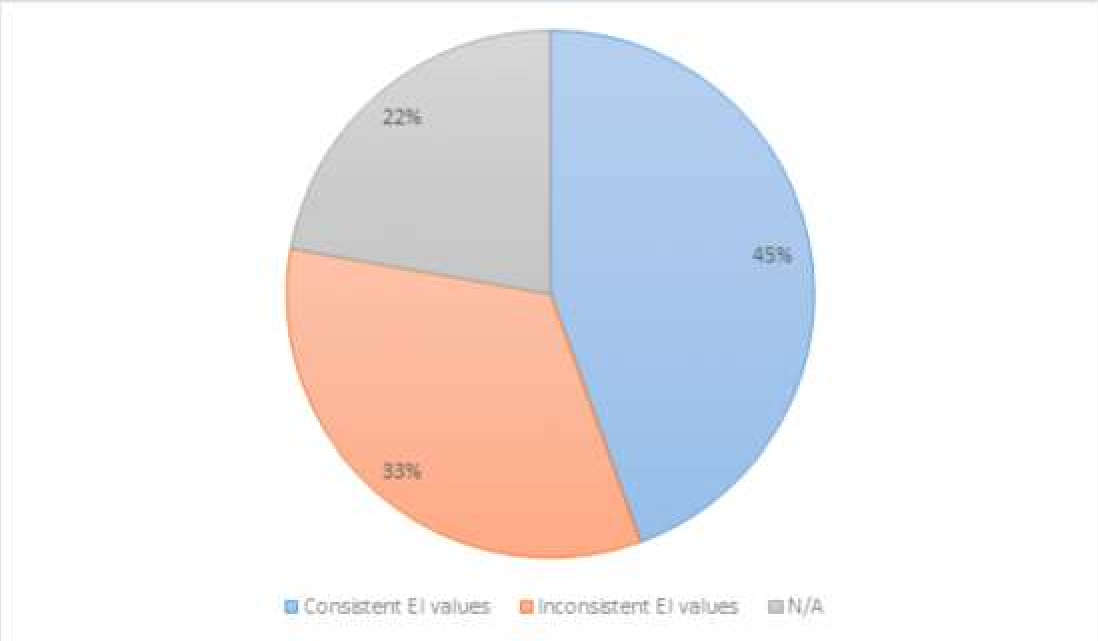

Figure 2: Pie Chart showing the EI Consistency Status of DDR Centres

Table 2: Exposure Index Values Consistency Test in DDR Centres 8 to 16, Using Coefficient of Variation Equation.

S/N	CENTRES/MAKES	Model/Type	CV (%) FROM EI VALUES	INTERPRETATION
1	Konica Minolta	AeroDR System 2	0.74	Consistent
2	Vieworks	Vivix-S1717v	N/A	N/A
3			N/A	N/A
4			2.89	Consistent
5	VACUTEC	VacuDAP Compact	0.66	Consistent
6	EASYDR	CXD1401G Compact	39.67	Inconsistent
7	Panascape	ScanPad/4343R	2.36	Consistent
8	iCRco	AIRDR/G3	8.09	Inconsistent
9	Vacutec	VacuDAP-OEM	14.47	Inconsistent

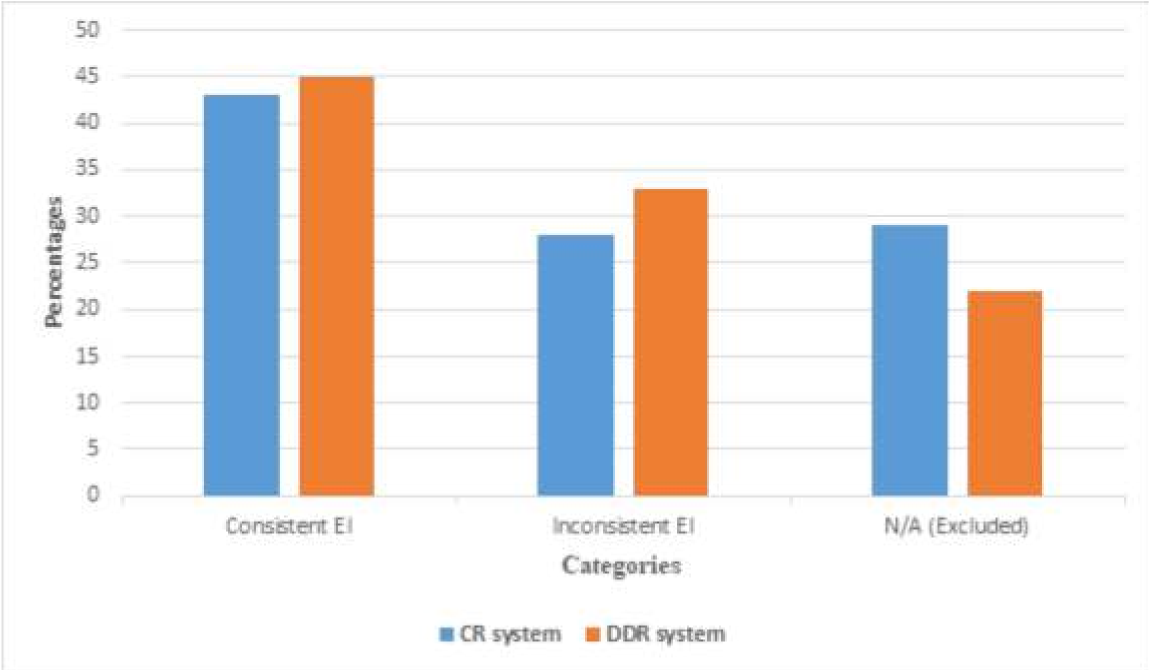

Figure 3: Bar Chart showing comparison of the Consistency of EI values in CR and DDR Centres

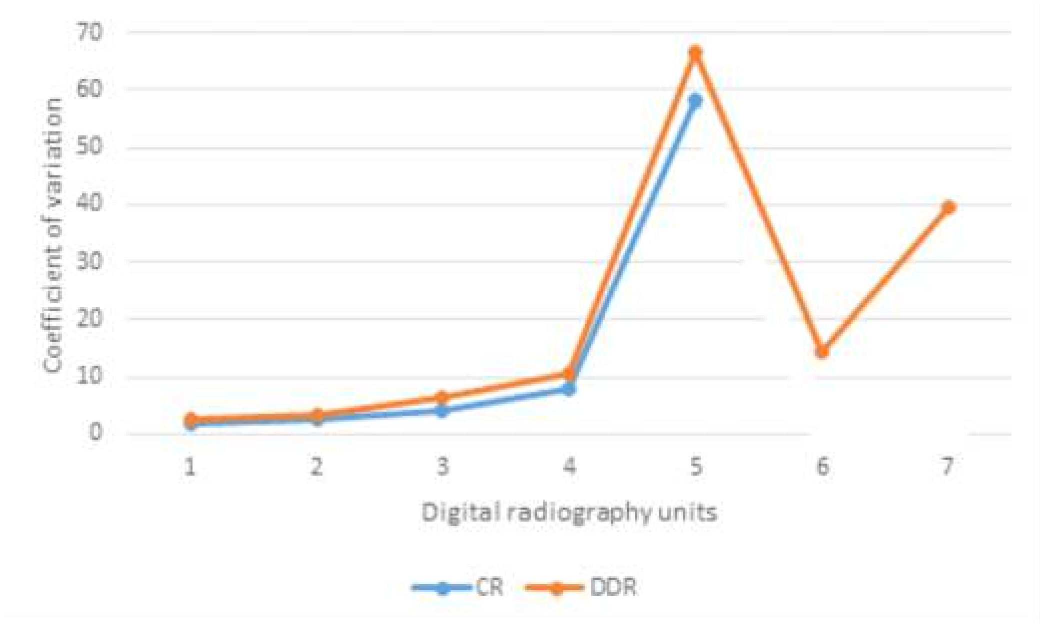

Figure 4: Line chart showing comparison of the Consistency of EI values in CR and DDR Centres

4. Discussion

The reproducibility of X-ray tube voltage in the centers used in this study ranged from 0.11%-1.42% which were all within the acceptable range of less than 5%. The manufacture dates of the X-ray tubes were between year 2010 and 2022. The high reproducibility rate of the X-ray tubes could be attributed to age of the machines which were 10 years or less, as well as the compliance with the local regulatory authority in Nigeria [14]. The X-ray tube reproducibility test was a key quality assurance test and prerequisite for inclusion of a facility into the study. Costa & Pelegrino [15] utilized a reproducibility range of less than 5.4%; Osman et al. [16] utilized a reproducibility range of less than 5% while Suleiman et al. [13] worked with reproducibility of within 4% or less.

The consistency of ESD, like the reproducibility test, was determined in the 16 centres for this study. Three (3) centres had inconsistent ESD values which were above 5% and were excluded from the study. The co-efficient of variation (cv) for the 12 centres used in this were in the range of 0.36% - 3.04%.

The consistency of EI values in CR centers showed that 43% were consistent, 28% were inconsistent and 29% had undefined values. There was significant inconsistent EI values in this study. Jamil et al. [10] and Butler et al. [12] also concluded that consistencies of EI values in CR systems were uncertain. There were no traceable similarities amongst the centers which were consistent or among those which were inconsistent in the current study. The largest variation was seen in the Fujifilm (FCR Capsula XL II). This was similar to the findings of Butler et al. [12] and the lowest variation seen in Fujifilm CR system (FCR Primax). Muhogora et al. [6] reported varied performances among CR systems in a quality assurance tests according to AAPM 93 recommendations. The variations were attributed to different detector formulations, plate reader characteristics and aging effects.

The consistency of EI values in DDR systems showed that 45% of the DDR systems were consistent, 33% were inconsistent while 22% had undefined EI values. The consistency of EI values in DDR systems in this study had significant variations. There were no traceable similarities amongst the DDR systems which were consistent or among those which were inconsistent. The largest variation was seen in centre 13 (Easy DR CXD1401G) and the lowest variation was seen in centre 8 (Vacutec VacuDAP compact0. Jamil et al. [10] concluded that the consistency of EI values in DDR were uncertain while Butler et al. [12] found that the DDR system of Siemens and Philips digital diagnostic systems to be perfectly consistent in their study. The current study had no Philips or Siemens systems for specific comparison.

In the comparison of CR system and DDR system in terms of EI consistency, inconsistency and excluded centres, the results were 43% and 45%; 28% and 33%; 29% and 22% respectively. Hence, there was no significant difference in the consistencies of EI values of CR system compared to DDR system. This finding was similar to Jamil et al. [10] and contrary to Butler et al. [12]. It was observed that the former authors studied similar makes of CR and DDR systems such as AGFA, Fujifilm, Carestream, Kodak etc, while the later authors studied DR systems made by Philips and Siemens which was not covered in the current study. In general, very few studies were done in this area.

5. Conclusion

The consistency of EI values in CR systems and DDR systems have been investigated and reported. The consistency of EI values in CR centres showed that 43% were consistent, 28% were inconsistent and 29% were undefined. The consistency of EI values in DDR systems showed that 45% were consistent, 33% were inconsistent while 22% had undefined EI values. Fujifilm CR-IR 392 produced the least variation of EI values (1.91%), while Fujifilm FCR Capsula II produced the highest variation of EI values (58.47%). Vacutec VacuDAP compact DDR produced the least variation of EI values (0.66%), while EASYDR CXD1401G compact produced the highest variation of EI values (39.67%). There was no overall differences in the performances of CR and DDR systems in this study and the inconsistencies in the EI values of CR and DDR systems remained significant.

6. Recommendations

The national and international regulatory authorities should streamline the implementation of the standardized exposure index values of digital radiography systems with a view to minimize the wide variations among manufacturers of digital radiography systems.

Consistency of exposure index values should be considered one of the acceptance tests for new product installations.

Routine quality assurance measures are recommended to identify digital radiography units with non-functional exposure index metrics.

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