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Data Mining for Patient Safety: Comparative Evaluation of HRCT Radiation Dose in COVID-19 patients at Eastern Libya

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Abstract

This study compared radiation doses from fixed tube current and automatic exposure control (AEC) HRCT protocols in COVID-19 patients at Albyda Medical Center, Libya, and validated the findings using a controlled phantom experiment. A retrospective analysis was performed on 76 examinations acquired between January and June 2022. Scans were obtained a Fujifilm FCT SPEEDA scanner operating with fixed tube current and a Toshiba Aquilion scanner using AEC. Radiation dose metrics volume CT dose index (CTDIvol) and dose-length product (DLP) were extracted from the DICOM headers. Scan length was calculated as DLP/CTDIvol. As dose variables were non-normally distributed (Shapiro–Wilk test), non-parametric analyses were used. A complementary phantom study on the fixed-mAs scanner assessed four protocol variants for potential dose reduction. The AEC-equipped scanner produced significantly lower doses than the fixed-mAs system, with median CTDIvol values of 6.3 versus 12.1 mGy ($p < 0.001$) and median DLP values of 220.5 versus 418.7 mGy•cm ($p < 0.001$), representing a 47.3% DLP reduction. Scan lengths were comparable between systems ($p = 0.423$), indicating that dose savings were attributable to AEC rather than shorter scan lengths. In the phantom study, progressive protocol optimization on the fixed-mAs scanner achieved up to a 45.7% reduction in DLP. Dose substantially reduction for COVID-19 HRCT without effecting on image quality nor scan-length considerable reduction. In resource-limited settings such as Libya, using AEC-equipped systems and optimizing existing CT protocols can help maintain the ALARA principle while preserving diagnostic performance.

Keywords: Computed Tomography; Radiation Dose; Radiation Protection; Automatic Exposure Control; COVID-19; Chest CT; Libya

INTRODUCTION

Over subsequent decades, despite that CT has become integral to the diagnosis and management of diverse clinical conditions, including trauma, malignancy, vascular disease, and acute neurology. Its clinical value rests on a combination of high diagnostic accuracy, rapid acquisition, and broad availability. The extensive use raises a parallel responsibility: ensuring appropriate management of ionizing radiation exposure. The ALARA (As Low As Reasonably Achievable) principle has therefore become implanted in radiologic practice, driving technical innovations and protocol optimization efforts aimed at minimizing dose while preserving diagnostic information (Valentin, 2008).

These long-standing concerns were sharply amplified during the COVID-19 pandemic. High-resolution CT (HRCT) of the chest grew into a central role in the evaluation and follow-up of COVID-19 pneumonia, particularly in settings where access to reliable and timely RT-PCR testing was limited (Rubin et al., 2020; Salehi et al., 2020). In many developing regions, including Libya, limited logistics and laboratories' capacity led to a reliance on CT both for initial assessment and follow-up of disease progression. The resulting surge in imaging volume, although clinically justified, inevitably increased cumulative radiation exposure at the population level (C. H. McCollough et al., 2015). This situation highlighted monitoring of radiation dose and the need for robust, locally applicable optimization strategies.

By taking to account, patient attenuation, body habitus, and scan geometry; Automatic exposure control (AEC) represents a key technological step in this direction. On the other hand, fixed tube current (fixed mAs) protocols apply a uniform exposure to all patients (Kalra et al., 2004). By tailoring exposure on a projection-by-projection basis, AEC aims to maintain consistent image quality across different patients, while preserving dose in thinner or less attenuating regions(Singh et al., 2011). Studies, mainly from high-income countries assumed, following radiation protection guidelines, applying dose reductions with AEC in routine CT scans (Kalra et al., 2005; Mulkens et al., 2005). However, in resource-limited settings, less is known about its performance and implementation challenges, where heterogeneous equipment, maintenance issues, and limited training can deter optimal use (Vassileva & Rehani, 2015).

Our institution in eastern Libya presented a particular opportunity to investigate these questions. During the COVID-19 pandemic, two CT scanners operated in parallel: a Fujifilmfilm FCT SPEEDA system running a fixed-mAs protocol and a Toshiba Aquilion system equipped with AEC. This configuration effectively created a natural experiment environment, enabling direct comparison of dose metrics between two distinct scanning protocols applied to a similar clinical population.

This study had two main objectives. First, to quantitatively compare radiation dose metrics (CTDIvol, DLP, and derived scan length) for chest HRCT in COVID-19 patients imaged with fixed-mAs versus AEC protocols. Second, to complement the clinical analysis with a phantom-based experiment on the fixed-mAs scanner, designed to explore the extent to which protocol adjustments alone could replicate the dose reductions observed with AEC. Together, these data are intended to provide context-specific evidence to guide dose optimization and equipment planning in resource-constrained environments.

MATERIALS AND METHODS

Study Design and Setting

This retrospective, observational study was conducted at Albayda Medical Center, a major tertiary referral hospital in eastern Libya. The study period extended from January to June 2022, encompassing a pronounced local wave of COVID-19 cases. The study was approved by the institutional ethics committee and to eliminate bias and allow anonymization of all patient data.

Patient Selection and Characteristics

The initial cohort comprised 80 consecutive adult patients (≥18 years) referred for non-contrast chest HRCT with suspected or confirmed COVID-19 infection. Exclusion criteria were: (i) repeated examinations in the same patient, and (ii) incomplete or corrupted DICOM data preventing reliable dose extraction. Leaving a total of 76 patients.

Patients were grouped according to the CT system used: 50 examinations were performed on the Fujifilmfilm scanner (fixed mAs) and 26 on the Toshiba scanner (AEC). No additional matching or stratification was imposed. Demographic information, limited to age and gender, was retrieved from the radiology information system and is summarized in Table 2.

Scanner Characteristics and Technical Parameters

Two CT scanners operated concurrently during the study period:

- Toshiba Aquilion 160-slice scanner:
  Equipped with an AEC system providing real-time tube current modulation and using iterative reconstruction (AIDR 3D).
- FUJIFILMFILM FCT SPEEDA 128-slice scanner:
  Operating with a fixed tube current protocol and filtered back projection (FBP) image reconstruction.

Both scanners employed institutional chest HRCT protocols configured for COVID-19 imaging. Key acquisition parameters are presented in Table 1. These values were taken directly from the protocol presets displayed on the scanner consoles during the study period and represent the actual clinical settings used.

Table (1). HRCT Chest Scan Protocols for Clinical Scans

Parameter	Toshiba Aquilion (AEC)	Fujifilmfilm FCT SPEEDA (Fixed mAs)
Tube Voltage (kVp)	120	120
Tube Current (mAs)	Automatic modulation (30–250)	Fixed at 165
Rotation Time (s)	0.5	0.5
Pitch	1.0	1.0
Slice Thickness (mm)	1.0	1.0
Reconstruction Algorithm	AIDR 3D (iterative)	FBP

Phantom Study Design

To separate the effects of protocol configuration from AEC technology itself, a phantom experiment was carried out on the Fujifilmfilm scanner. A general-purpose acrylic CT body phantom (PMMA-Polymethylmethacrylate, Cylindrical, diameter 40cm & Height 10cm) was used as a reproducible surrogate for the thoracic region.

Four protocols were tested:

- Standard: Institutional default protocol (fixed mAs 165, standard field of view [FOV] which was subjected to Operating Technician at the time of study).
- Modified 01: Fixed mAs 165 with restricted FOV, tightly collimated to the phantom margins.
- Modified 02: Reduced fixed mAs (99.8) with standard [FOV] which was subjected to Operating Technician at the time of study).
- Modified 03: Combined approach with moderately reduced fixed mAs (113.3) and restricted FOV.

For each configuration, DLP was recorded, and percentage reduction relative to the standard protocol was calculated.

Data Extraction and Outcome Measures

For all clinical examinations, radiation dose descriptors CTDIvol (mGy) and DLP (mGy·cm) were automatically extracted from the DICOM headers using a custom Python script. Because scan length was not consistently stored as a DICOM tag in the archive, it was derived using the standard relationship recommended in international dosimetry guidance (C. McCollough et al., 2008):

Scan length (cm) = DLP (mGy·cm)/CTDI vol (mGy).

The derived scan length was used primarily to confirm that any observed dose differences were not due to truncation or extension of anatomical coverage between scanners. The primary outcome was the difference in median DLP between the AEC and fixed-mAs clinical protocols. Secondary outcomes included differences in CTDIvol and derived scan length, and the dose reduction achieved in the phantom study.

Statistical Analysis

Data analysis was performed in Python (version 3.8) using the SciPy and Pandas libraries. The distribution of CTDIvol, DLP, and scan length was assessed using the Shapiro–Wilk test, which confirmed non-normal distributions for all dose metrics. Accordingly, non-parametric tests were used throughout.

- Differences between the two independent clinical groups (fixed mAs vs. AEC) were evaluated using the Mann–Whitney U test.
- Paired comparisons within the phantom experiment (each modified protocol vs. standard) were analyzed using the Wilcoxon signed-rank test.

Continuous variables are reported as median and interquartile range (IQR). A two-sided p-value < 0.05 was taken as the threshold for statistical significance.

RESULTS

Patient Demographics

Baseline demographics of the 76 patients are presented in Table 2. The two scanner groups were comparable with respect to age and sex distribution. The median age was 65 years in both groups, with partially overlapping IQRs, indicating broadly similar age profiles.

Table (2). Patient Demographics

Characteristic	Fujifilmfilm (Fixed mAs) (n = 50)	Toshiba (AEC) (n = 26)
Male, n (%)	26 (52.0%)	15 (57.7%)
Female, n (%)	24 (48.0%)	10 (38.5%)
Age (years), Median (IQR)	65 (45–75)	65 (53–71)

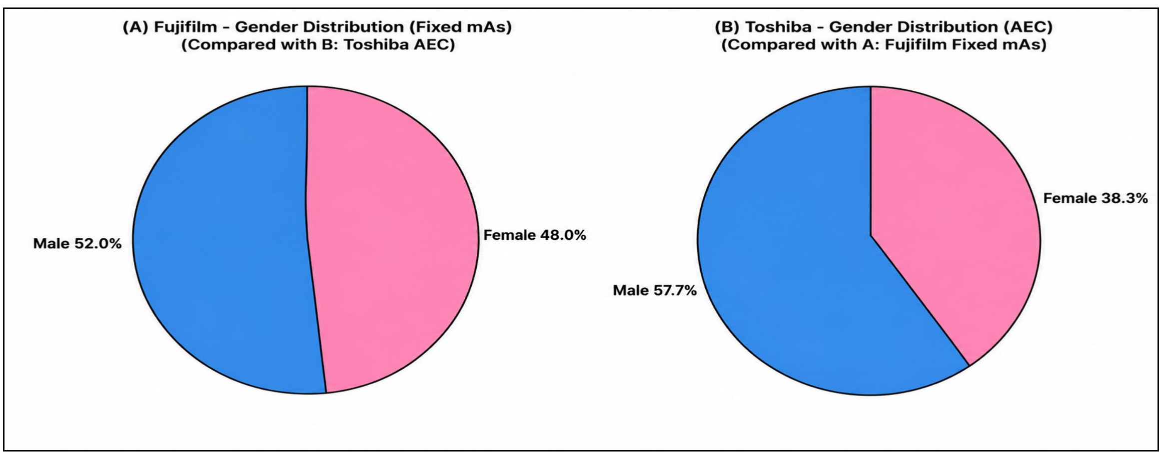

Figure (1). Pie charts illustrating gender distribution among patients examined on the Fujifilmfilm fixed-mAs scanner (A) and the Toshiba AEC-equipped scanner (B). The proportion of male and female patients is displayed for each scanner, allowing visual comparison of demographics.

Clinical Radiation Dose Analysis

Radiation dose metrics from clinical examinations are summarized in Table 3. The differences between the fixed-mAs and AEC protocols were marked. The Fujifilmfilm fixed-mAs scanner delivered a median CTDIvol of 12.1 mGy, with virtually no variability across patients (IQR: 12.1–12.1 mGy). In contrast, the Toshiba AEC system exhibited a lower median CTDIvol of 6.3 mGy (IQR: 4.0–8.4 mGy). This corresponds to a 48% reduction in median CTDIvol, and the difference was highly significant ($p < 0.001$). Correspondingly, median DLP decreased from 418.7 mGy·cm (IQR: 418.7–471.0 mGy·cm) for the fixed-mAs protocol to 220.5 mGy·cm (IQR: 156.4–322.3 mGy·cm) for the AEC protocol, a 47.3% reduction ($p < 0.001$).

The outcomes of scan-length showed that no noticeable connection with dose-reduction that was mentioned earlier. Derived scan lengths were comparable between groups: 34.6 cm (IQR: 34.6–38.9 cm) for the fixed-mAs scanner and 35.0 cm (IQR: 22.7–47.8 cm) for the AEC scanner ($p = 0.423$).

Table (3). Radiation Dose Metrics from Clinical Scans

Metric	Fujifilmfilm (Fixed mAs) (n = 50)	Toshiba (AEC) (n = 26)	p-value
CTDIvol (mGy), Median (IQR)	12.1 (12.1–12.1)	6.3 (4.0–8.4)	< 0.001
DLP (mGy·cm), Median (IQR)	418.7 (418.7–471.0)	220.5 (156.4–322.3)	< 0.001
Scan Length (cm)*	34.6 (34.6–38.9)	35.0 (22.7–47.8)	0.423

** Derived as DLP/CTDIvol.*

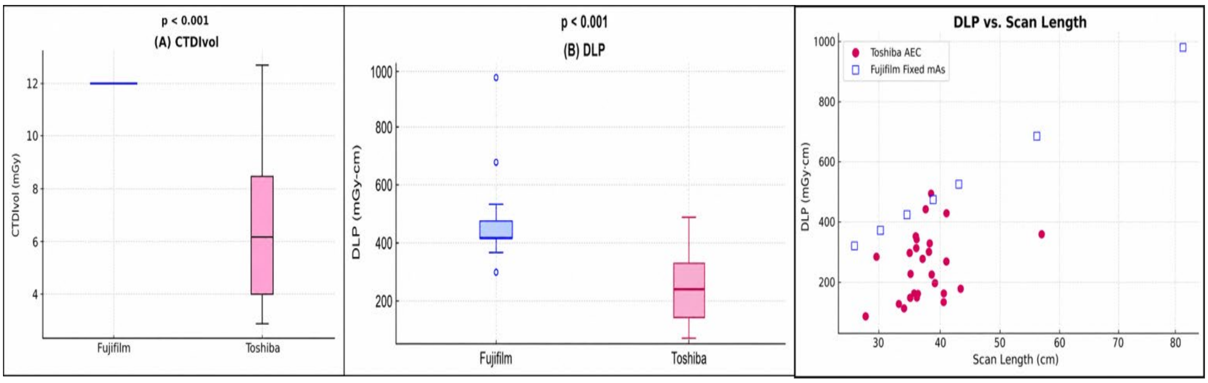

Figure (2). Scatter plot showing the relationship between dose–length product (DLP) and scan length for all clinical examinations performed using the Fujifilm fixed-mAs scanner and the Toshiba AEC system. The full dataset demonstrates the broader spread and higher DLP variability of fixed-mAs scanning, while AEC maintains consistently lower DLP values for comparable scan lengths. Abbreviation: DLP, dose–length product.

Phantom Study: Protocol Optimization on the Fujifilm Fixed-mAs Scanner

Phantom study results are summarized in Table 4. Starting from the standard protocol (DLP = 727.7 mGy·cm), sequential modifications produced a clear, stepwise reduction in dose:

- Restricting the FOV alone (Modified 01) reduced DLP to 575.7 mGy·cm (20.9% reduction).
- Reducing fixed mAs to 99.8 by activating AEC option (Modified 02) achieved a more substantial decrease to 411.3 mGy·cm (43.5% reduction).
- The combined strategy (Modified 03) with moderately reduced mAs (113.3) by activating AEC option and restricted FOV resulted in the lowest DLP of 395.2 mGy·cm (45.7% reduction compared with standard).

These reductions reflect, in magnitude, the dose savings observed clinically with AEC.

Table (4). Phantom Study: Dose Reduction through Protocol Optimization on the Fujifilmfilm Scanner

Protocol	Description	DLP (mGy·cm)	Reduction from Standard
Standard	Fixed mAs 165, standard FOV	727.7	–
Modified 01	Fixed mAs 165, restricted FOV	575.7	20.9%
Modified 02	AEC 99.8, standard FOV	411.3	43.5%
Modified 03	AEC mAs 113.3, restricted FOV	395.2	45.7%

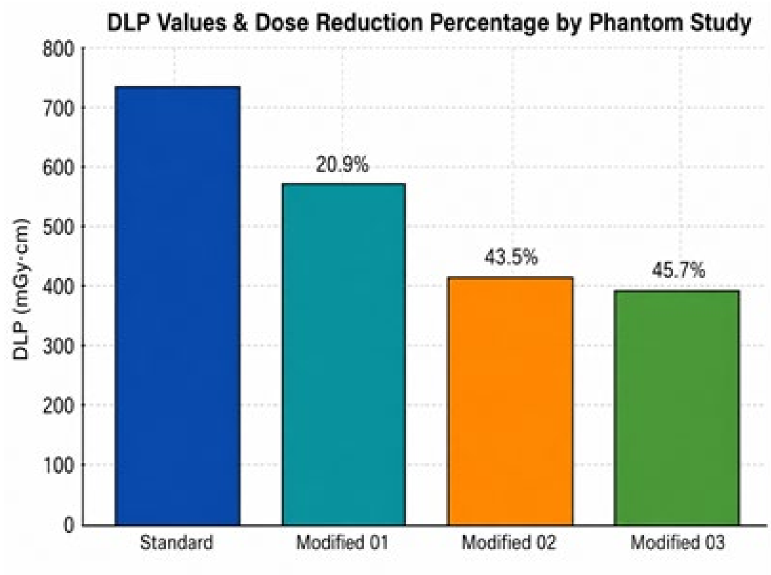

Figure (3). DLP values and corresponding percentage dose reduction across the phantom study protocols. Displayed are the standard protocol and three optimization variants (Modified 01–03), showing progressive reduction in radiation output with restricted FOV, reduced mAs, and combined optimization strategies.

DISCUSSION

This study provides a quantitative comparison of radiation dose from two contrasting CT operating strategies fixed tube current and AEC used contemporaneously for chest HRCT in COVID-19 patients at a Libyan tertiary center. The findings are straightforward but carry important implications: (i) the AEC-equipped scanner consistently delivered nearly 50% lower radiation doses than the fixed-mAs system, and (ii) a substantial proportion of this reduction can be replicated on older, non-AEC equipment through systematic protocol optimization.

The magnitude of dose reduction achieved in our cohort approximately 47–48% in CTDIvol and DLP approaches, and in fact slightly surpasses, the upper threshold reported in prior evaluations of AEC in thoracic CT, where reductions in the range of 20–50% are typically cited (Kalra et al., 2005; Mulkens et al., 2005). What distinguishes the present study is the context is much of the published evidence originates from highly standardized environments, often in high-income countries with optimized workflows and routine access to medical physics support. In contrast, our data are derived from a resource-limited setting during a pandemic, where operational pressures and infrastructure constraints complicate adherence to idealized protocols.

The fixed-mAs data illustrate this point clearly. The CTDIvol for all 50 patients was identical at 12.1 mGy, reflecting a rigid, one-size-fits-all exposure strategy that does not account for individual variation in patient size or anatomy. This uniformity implies not only a higher overall dose level but also systematic overexposure of smaller or less attenuating patients. The AEC system, conversely, adjusted tube current according to patient attenuation, thereby preventing this structural overexposure.

An important methodological feature of this study is the explicit consideration of scan length. Because DLP is proportional to both CTDIvol and scan length, any comparison of DLP alone can be misleading if one group routinely scans shorter regions. By deriving scan length from DLP/CTDIvol and demonstrating no significant difference in median values between groups, we confirm that the observed dose savings were not achieved by trimming anatomical coverage. The broader spread of scan length in the AEC group likely reflects a wider range of clinical indications, but for the typical patient receiving similar coverage, dose savings can reasonably be attributed to exposure modulation rather than coverage reduction.

The phantom results complement and extend the clinical findings. They show that on the fixed-mAs scanner, significant physical dose reductions up to 45.7% are achievable simply by reducing mAs and tailoring the FOV. This is an important proof-of-principle for centers that lack AEC capability. However, it is crucial to avoid over-interpreting these results. Phantom-based dose reduction does not equate to preserved diagnostic performance. An AEC system can increase tube current locally when needed (for example, in regions of dense consolidation or in large patients), whereas a fixed, uniformly low mAs protocol cannot. Any institutional move toward lower dose protocols must therefore be accompanied by careful clinical validation, including image quality assessment and diagnostic performance evaluation.

Our findings are broadly aligned with previous work emphasizing the role of AEC and protocol optimization in CT dose management. Kalra et al. described general strategies for dose optimization, including the potential of AEC to tailor exposure to patient attenuation(Singh et al., 2011). Reviews such as that by Kubo et al. have highlighted the particular suitability of the thorax for low-dose imaging because of the high inherent contrast of lung parenchyma(Kubo et al., 2014). Furthermore, our demonstration of achievable dose reduction through protocol adjustment is consistent with recommendations from bodies such as the AAPM, which stress regular protocol review and the establishment of diagnostic reference levels (DRLs) as part of a structured quality assurance program (Boone et al., 2011).

Strengths and Limitations

Several limitations must be acknowledged. Initially, the retrospective design limited available patient data. Height and weight were not consistently recorded, precluding calculation of size-specific dose estimates (SSDE), which would have provided a more individualized characterization of patient dose(Boone et al., 2011). Subsequently, the study was conducted at a single center, which may limit generalizability. Nonetheless, the consistency of our findings with international literature suggests that the underlying principles are broadly applicable.

Moreover, the two scanners differed not only in exposure control (AEC vs. fixed mAs) but also in reconstruction algorithms (iterative reconstruction vs. FBP). This could influence image noise and perceived image quality, even though it does not directly affect the dose metrics reported. A comprehensive evaluation of image quality would require a separate, dedicated analysis incorporating subjective radiologist assessment and objective noise measurements.

Finally, derived scan length, while mathematically sound, is an indirect measure. A direct measurement from the DICOM geometry would be preferable but was not uniformly available in our archive.

Despite these limitations, the study has notable strengths. It addresses an under-represented context: COVID-19 chest CT imaging in a resource-limited setting. It combines real-world clinical data with a controlled phantom experiment, thereby linking the observed problem (high and uniform dose from a fixed protocol) with a reasonable pathway to improvement (protocol optimization). The statistical analysis is transparent, and the numerical results provide a practical benchmark for dose levels achievable in similar environments.

CONCLUSION

Implementation of AEC in chest HRCT for COVID-19 patients at our institution nearly halved radiation dose compared with a long-standing fixed-mAs protocol, without evidence of reduced scan coverage. In practice, the AEC system functioned as a safeguard against systematic overexposure inherent to the fixed protocol, operationalizing the ALARA principle in daily clinical work.

For resource-limited settings, two complementary strategies emerge:

1. Strategic: When acquiring new CT equipment, the presence of robust AEC capability should be treated as a core requirement, not an optional feature.
2. Pragmatic and immediate: On existing non-AEC scanners, structured, physics-guided protocol optimization focusing on tube current and FOV can yield dose reductions comparable in magnitude to those achieved with AEC, provided that any new protocols are subjected to rigorous clinical validation.

In summary, even under constrained conditions, substantial improvements in patient radiation safety are achievable through a combination of appropriate technology and systematic protocol review.

RECOMMENDATIONS

Based on these findings, we propose the following actions for similar institutions:

1. Clinical validation of low-dose protocols:
   Use the phantom-derived protocols as a starting point to design prospective clinical audits that compare optimized low-dose settings against current standards on fixed-mAs scanners, with explicit assessment of diagnostic adequacy for COVID-19 and other thoracic indications.
2. Dose monitoring and development of local DRLs:
   Establish routine dose tracking for CT examinations and derive institution-specific diagnostic reference levels. Integrate periodic protocol review and dose audits into the hospital's quality management system.
3. Training and operational guidelines:
   Provide targeted training for radiologists, medical physicists (where available), and technologists on the principles, operation, and limitations of AEC systems and on low-dose protocol design. Incorporate dose optimization responsibilities into departmental policies.
4. Equipment procurement policy:
   In future capital planning, prioritize CT systems with advanced dose-management tools, including AEC and iterative reconstruction, as essential rather than optional features.

5. Future research:
   Conduct prospective, multi-center studies that include anthropometric data, enabling SSDE calculation. Focus on task-specific validation of optimized protocols (e.g., detection of post-COVID fibrotic changes), with standardized image quality and diagnostic performance end-points.

Duality of interest: The authors declare that they have no duality of interest associated with this manuscript.

Author contributions: Azmi B. A. Mekaiel contributed to the conception and design of the study, data collection, data extraction and curation, provision of data and analysis tools, formal analysis and interpretation of data, drafting of the manuscript, revision for important intellectual content, and approval of the final version of the manuscript. Ahmed M. Elhain contributed to the conception and design of the study, provision of data and/or analysis tools, analysis and interpretation of data, revision of the manuscript for important intellectual content, and approval of the final version of the manuscript. Saleh Boharara contributed to the conception and design of the study, provision of data and/or analysis tools, analysis and interpretation of data, revision of the manuscript for important intellectual content, and approval of the final version of the manuscript. All authors read and approved the final manuscript and agreed to be accountable for the accuracy and integrity of the work.

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