RESEARCH ARTICLE

Prediction of mortality in adult COVID-19 patients using chest CT severity scoring systems: A comparative analysis of different scores

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Abstract: Purpose: To compare the accuracy of mortality prediction of four CT severity scoring systems for COVID-19: CT severity score three levels, CT severity score, Total severity score, and Chest CT score. **Methods:** This was a retrospective study of 278 patients hospitalized with COVID-19 confirmed by a positive polymerase chain reaction (PCR) and in whom a CT scan was performed to assess the severity of lung involvement. This assessment was performed using four different scoring systems, including the CT severity score three levels, the CT severity score, the Total severity score, and the Chest CT score. **Results:** A total of 278 COVID-19 patients had chest CT scans, of whom 59 (21.22%) died and 219 (78.78%) survived. The ROC curves showed outstanding performance for the four chest CT severity scoring systems: 0.9580 for the CT severity score; 0.9532 for the CT severity score three levels; 0.9474 for the Total severity score; and 0.9327 for the Chest CT score. The comparison of these four ROC curves revealed no statistically significant difference between the four scoring systems ($X^2 = 3.89$; $p = 0.2740$). **Conclusion:** The four chest CT severity scoring systems used predicted mortality in COVID-19 patients with excellent agreement and outstanding performance.

Keywords: COVID-19, prognosis, mortality, ROC curve, computed tomography, CT severity score

1 Introduction

Since its outbreak in Wuhan, China, in December 2009, the COVID-19 pandemic has spread rapidly around the world [1]. Because the disease is highly transmissible, a rapid and accurate diagnosis plays a key role in treatment [2]. This is an unusual and unprecedented challenge, with clinical presentations ranging from asymptomatic carriers to patients who require assisted ventilation and admission to intensive care units (ICU), with a high mortality rate [3]. These patients often have acute respiratory distress syndrome (ARDS), which can lead to death. In a recent review of the literature by Dessie and Zewotir [4] of 42 studies that include 423,117 patients, the mortality rate for hospitalized patients with COVID-19 was 17.62% (95% CI: 14.26 - 21.57%) and was significantly higher in male patients and those with comorbidities such as chronic obstructive pulmonary disease (COPD), cardiovascular disease, diabetes mellitus, obesity, hypertension, acute kidney injury, and cancer.

The reverse transcription polymerase chain reaction (RT-PCR) performed on a nasopharyngeal swab is the standard diagnostic test to confirm the disease. Although this is a powerful tool, a significant proportion of false negatives have been reported, influenced by the stage of the disease (low sensitivity in the early stages) [5–7]. For early detection of the disease, particularly in patients with false negative RT-PCR results, and for proper management and monitoring of disease progression, chest computed tomography (CT) imaging plays an essential and fundamental role [8].

Chest CT has been shown to detect COVID-19 at an early stage with a sensitivity of 56-98% [5, 9, 10]. Although chest CT has a high sensitivity for the diagnosis of COVID-19, its specificity is low because it is difficult to distinguish COVID-19 from other viral diseases on chest CT [11, 12]. The chest CT findings in patients with COVID-19 are variable, with the most common images being multifocal ground-glass opacities that may present with or without consolidation and are usually distributed peripherally. Other notable features are unsystematized consolidation, crazy-paving patterns, pleural effusion, and bronchial wall thickening [13–16].

Particularly in thoracic imaging, it is recognized that the results of radiological examinations may vary from one radiologist to another [16]. As a result, several chest CT severity scoring systems have been developed for COVID-19 to standardize radiological reports [17–21]. The present study aims to compare the accuracy of mortality prediction of four CT severity scoring systems for COVID-19: CT severity score three levels, CT severity score, Total severity score, and Chest CT score.

2 Materials and methods

2.1 Type, period, and population of the study

This was a retrospective multicenter cross-sectional study conducted from 1 January 2021 to 31 December 2022. The Clinique de Médecine Internationale Avancée (CIMAK), Hôpital de la Charité Maternelle, and Hôpital HEAL Africa were selected for this study. These are the three reference health facilities for the appropriate management of COVID-19 patients in Goma city, in North Kivu province of the Democratic Republic of the Congo (DRC). Please note that the only hospital in the city with a CT scanner is CIMAK.

Patients who met all the following inclusion criteria were included in this study: patient over 18 years of age; a case of COVID-19 confirmed by RT-PCR, suspected pulmonary embolism complicating COVID-19; or a case of COVID-19 diagnosed based on a clinical picture (cough, respiratory distress, fever) and chest CT imaging compatible with COVID-19. Patients under 18 years of age or with incomplete medical records were excluded.

The CT scan reports provided radiological data. Data were extracted from administrative databases and medical records of the hospitals mentioned above. Age, sex, chest CT findings, and in-hospital mortality were variables extracted from these databases.

2.2 Chest CT scan acquisition technique

Chest CT scans were performed without intravenouscontrast injection, with the patient supine and at the end of inspiration when pulmonary embolism was not suspected. Chest CT scans were performed with intravenouscontrast injection followed by a bolus if pulmonary embolism was suspected, with the patient supine and in neutral inspiration.

A 16-slice SOMATOM Scope CT scanner (Siemens Healthineers, Germany) was used to perform various chest CT scans. The low-dose protocol was used. Each chest CT scan was performed at 120 kV and 100 to 150 mAs. The collimation measurement was 0.6mm. Each of the sections taken was 2.5mm thick before being reconstructed with a collimation of 1.25mm. By including the latero-thoracic soft tissues, the topo-scan made it possible to delimit the field of examination from the apex to below the costo-phrenic sinuses.

The patients and technicians wore masks and personal protective equipment according to the protocol of the World Health Organization, and complete decontamination was performed after each examination.

2.3 Chest CT imaging analysis

The visual scale recommended by the Société Française de Radiologie and the European Society of Radiology was used [22, 23] as it is simple, quick, and effective. According to the following estimates, the right and left lower lobes each represent 25% of the total lung parenchyma, while the right and left upper lobes and the middle lobe each represent 15% of the parenchyma. The categories defined were minimal (< 10%), moderate (10-25%), widespread (26-50%), severe (51-75%), and critical (> 75%). All patients underwent chest CT scans, which were independently evaluated by two experienced radiologists (with more than 10 years of experience). The characteristics evaluated were consistent with Fleischner Society nomenclature guidelines and similar studies [24–26]. These included ground-glass opacities, consolidation, nodules, crazy paving, subpleural lines, bronchial wall thickening, enlargement of lymph nodes, and pleural effusion. The descriptive elements were classified in a standardized form, adapted from the chest CT scan report, and developed based on the recommendations of the Société

Française de Radiologie using the visual scale [23].

Quantification of the extent of abnormalities was attempted using four chest CT severity scoring systems to assess the degree of lung parenchymal involvement in COVID-19 patients. These four scores are summarized in Table 1.

Table 1 Four chest CT severity scoring systems used in the present study [16–20]

Scoring systems	Segmentation	Severity score based on the percentage of lung parenchymal involvement for each segment studied	Maximum score
Chest CT severity score [17]	18 anatomical segments of the lung with a further division of the apico-posterior segment of the left upper lobe into apical and posterior divisions and of the antero-medial segment of the left lower lobe into anterior and medial segments.	0 = no involvement; 1 = $<$ 50% involvement; 2 = $\geq$ 50% involvement.	40
Total severity score [18]	Five anatomical lobes of the lungs	0 = no involvement; 1 = 1–25% involvement; 2 = 26–50% involvement; 3 = 51–75% involvement; 4 = 76–100% involvement.	20
CT severity score three levels [19]	Three levels should be considered in assessing the extent and nature of pulmonary involvement: (i) above the carina (upper level), (ii) below the carina to the upper border of the inferior pulmonary vein (middle level), (iii) below the inferior pulmonary vein (lower level).	**Extent**: 0 = no involvement; 1 = $<$ 25% involvement; 2 = 25-49% involvement; 3 = 50-74% involvement; 4 = $\geq$ 75% involvement. **Nature**: (1) normal lung parenchyma; (2) at least 75% ground-glass opacities/crazy paving; (3) combination of ground-glass opacities /crazy paving and consolidation, provided that the involvement is less than 75% in both cases; (4) at least 75% consolidation.	96
Chest CT score [20]	Five anatomical lobes of the lungs	0 : no involvement; 1 : $<$ 5% involvement; 2 : 5-25% involvement; 3 : 26-50% involvement; 4 : 51-75% involvement; 5 : $>$ 75% involvement.	25

2.4 Statistical analysis

Absolute frequencies and percentages of qualitative variables were presented, while mean and standard deviation were used to present quantitative variables. In addition, the median and percentiles of the observed distribution were calculated and represented by violin graphs. Bivariate analyzes were performed using the Pearson test and mean comparisons were performed using the Student t test with a significance level of the p-value of less than 0.05. A receiver operating characteristic (ROC) curve and an area under the ROC curve (AUC) calculation were used to assess the performance of each scoring system in predicting mortality. The AUCs were then classified as unsatisfactory (AUC $<$ 0.7); acceptable (0.7 $\leq$ AUC $<$ 0.8); excellent (0.8 $\leq$ AUC $<$ 0.9), and outstanding (AUC $\geq$ 0.9) [27]. Patient outcome during hospitalization, marked by death or survival, was the independent variable in the main analysis. STATA version 16 software was used to perform all statistical analyzes and graphs.

2.5 Ethical considerations

This study was approved by the Medical Ethics Committee of the University of Goma (approval no. UNIGOM/CEM/009/2023). Confidentiality was ensured during data analysis.

3 Results

3.1 Patient characteristics and chest CT findings

A total of 278 COVID-19 patients had chest CT scans, of whom 59 (21.22%) died and 219 (78.78%) survived.

Table 2 presents demographic characteristics and chest CT findings of the 278 patients included, according to their course during hospitalization. The mean age was 51.71 ± 12.93 years; this mean was 58.12 ± 11.92 years for non-survivors and 50.01 ± 12.70 years for survivors. The comparison of these two means shows a statistically significant difference ($p < 0.0001$). Sixty-eight-point seven percent of the patients were male; this proportion was 76.27% in non-survivors and 66.67% in survivors; we did not observe statistical difference between these two proportions (p=0.1580). Table 2 shows that ground-glass opacities (93.88%), consolidations (44.96%), subpleural lines (21.22%), and crazy-paving patterns (12.95%) were the most common chest CT findings. Regarding the chest CT findings and the clinical course of the patients, we observed significantly higher proportions of bilateral involvement, consolidations, crazy-paving patterns, and pleural effusion in non-survivors than in survivors ($p < 0.0001$). We also noted that 83.05% of non-survivors had a severe/critical degree (> 50%) of lung parenchymal involvement compared to 6.39% of survivors ($p < 0.0001$).

Table 2 Age, sex, and chest CT findings of 278 COVID-19 patients

Variable	Total (n = 278), *n (%)*	Non-survivors (n = 59), *n (%)*	Survivors (n = 219), *n (%)*	p-value
Age (years), *mean±SD*	51.71±12.93	58.12±11.92	50.01±12.70	< 0.0001
Sex				0.1580
Male	191 (68.71)	45 (76.27)	146 (66.67)	
Female	87 (31.29)	14 (23.73)	73 (33.33)	
Bilateral lung invlovement	230 (82.73)	58 (98.31)	172 (78.54)	< 0.0001
Ground glass opacities	261 (93.88)	56 (94.92)	205 (93.61)	0.7100
Consolidations	125 (44.96)	44 (74.58)	81 (36.99)	< 0.0001
Subpleural lines	59 (21.22)	5 (8.47)	54 (24.66)	0.0070
Crazy-paving	36 (12.95)	16 (27.12)	20 (9.13)	< 0.0001
Pleural effusion	12 (4.32)	8 (13.56)	4 (1.83)	< 0.0001
Lung involvement according the Société Française de Radiologie				< 0.0001
Minimal (< 10%)	110 (39.57)	1 (1.69)	109 (49.78)	
Moderate (10-25%)	63 (22.66)	1 (1.69)	62 (28.31)	
Widespread (26-50%)	42 (15.11)	8 (13.56)	34 (15.53)	
Sévère (51-75%)	53 (19.06)	39 (66.10)	14 (6.39)	
Critical (> 75%)	10 (3.60)	10 (16.95)	0 (0.00)	

3.2 Chest CT severity scoring systems

The distribution of values for the four chest CT severity scoring systems according to the clinical course of the COVID-19 patients is shown in Figure 1. We note that non-survivors have very significantly higher values than survivors ($p < 0.0001$).

The means of the CT severity score were 31.53±5.99 in non-survivors and 11.78±8.40 in survivors. For the Total severity score, the means were 13.34±3.72 and 4.90±3.31 for non-survivors and survivors respectively. The mean of the Chest CT score was 17.39±4.69 for non-survivors and 6.45±4.78 for survivors. The means of the CT severity score three levels were 49.61±17.49 for non-survivors and 14.00±11.28 for survivors. Comparison of these different means between non-survivors and survivors shows a highly significant difference ($p < 0.0001$) (Table 3).

Table 3 Means and standard deviations of the values of four chest CT severity scoring systems used according to the clinical course of 278 COVID-19 patients

Scoring systems	Total (n = 278)	Non-survivors (n = 59)	Survivors (n = 219)	p-value
CT severity score	15.97±8.40	31.53±5.99	11.78±8.40	< 0.0001
Total severity score	6.69±4.84	13.34±3.72	4.90±3.31	< 0.0001
Chest CT score	8.77±6.53	17.39±4.69	6.45±4.78	< 0.0001
CT severity score three levels	21.56±19.41	49.61±17.49	14.00±11.28	< 0.0001

For each of the four scoring systems, a separate ROC curve was constructed to differentiate between non-survivors and survivors; the four ROC curves showed outstanding performances for all scoring systems: 0.9580 for the CT severity score; 0.9532 for the CT severity score three levels; 0.9474 for the Total severity score; and 0.9327 for the Chest CT score (Table 4 and Figure 2). Comparison of these four ROC curves revealed no statistically significant differences between the four scoring systems ($X^2 = 3.89$; $p = 0.2740$).

The four chest CT severity scoring systems showed exceptional performance in predicting

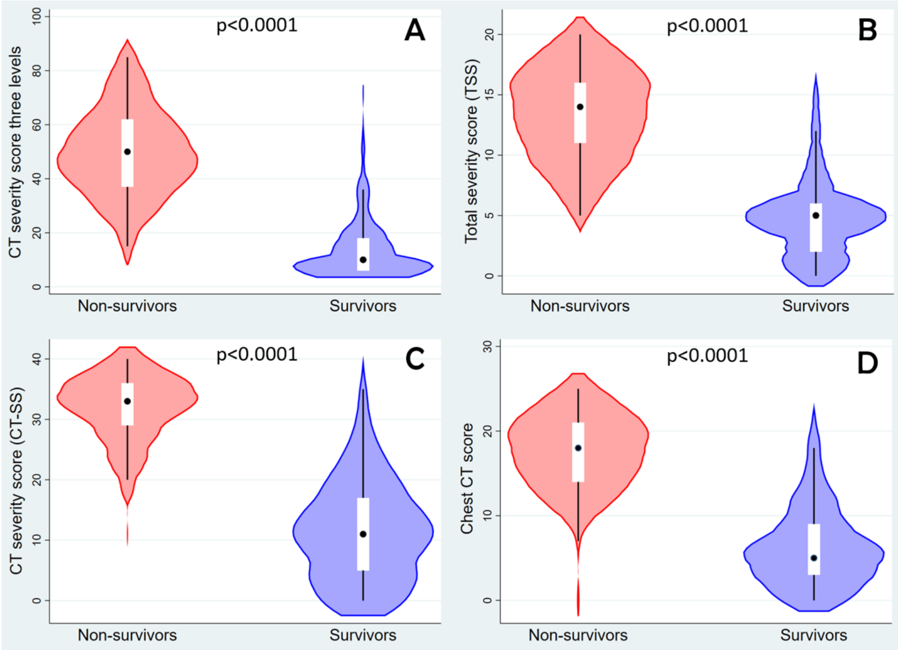

Figure 1 Distribution of values for the four chest CT severity scoring systems used according to the clinical course of 278 COVID-19 patients

Table 4 ROC areas for the four chest CT severity scoring systems used according to the clinical course of 278 COVID-19 patients

Scoring systems	Area under ROC	Std. Err.	95% CI	p-value
CT severity score	0.9580	0.0125	0.9335-0.9825	< 0.0001
CT severity score three levels	0.9532	0.0126	0.9286-0.9778	< 0.0001
Total severity score	0.9474	0.0129	0.9220-0.9727	< 0.0001
Chest CT score	0.9327	0.0199	0.8937-0.9717	< 0.0001

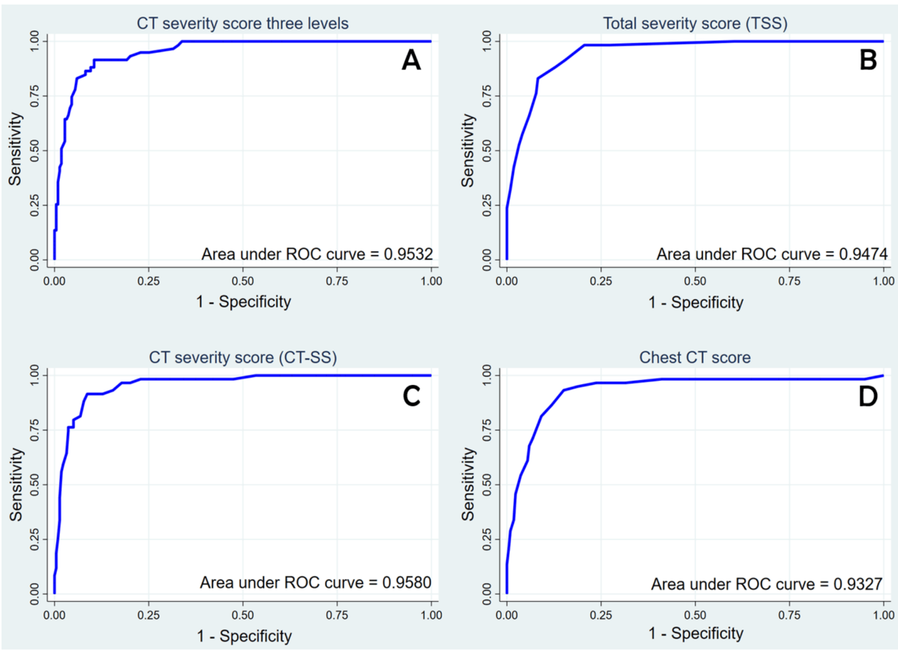

Figure 2 ROC curves showing the performance of the four chest CT severity scoring systems used according to the clinical course of 278 COVID-19 patients

mortality in COVID-19 patients. The threshold values at which each of these four scoring systems simultaneously showed high sensitivity and specificity are presented in Table 5.

Table 5 Cut-off values for the four chest CT severity scoring systems used

Scoring systems	Sensitivity	Specificity	Patients correctly classified	Positive likelihood ratio	Negative likelihood ratio
Chest CT score $\geq$ 12	93.22%	84.93%	86.69%	6.19	0.80
CT severity score $\geq$ 24	91.53%	91.32%	91.37%	10.55	0.09
CT severity score three levels $\geq$ 29	91.53%	89.50%	89.93%	8.71	0.09
Total severity score $\geq$ 8	91.53%	84.47%	85.97%	5.89	0.10

4 Discussion

The COVID-19 pandemic spread and caused variable morbidity and mortality throughout the world. Numerous chest CT severity scoring systems have been published to assess the severity of this disease. The present study is based on a quantitative visual analysis using different chest CT severity scoring systems for COVID-19. This study evaluated the performance of these four previously published scoring systems [16–18, 20, 21] in predicting mortality in COVID-19 patients and also to validate them in our population.

The chest CT findings in our study are consistent with previous studies [28–32] reporting a predominance of ground-glass opacities, consolidations, and crazy-paving patterns in COVID-19 patients. Chest CT findings show COVID-19 characteristics similar to those of viral pneumonia [33, 34], with multifocal ground-glass opacities and consolidation in a peripheral distribution being the most frequently observed characteristics [28–32]. Although these chest CT findings may be nonspecific, they are of strategic importance in the appropriate clinical setting. They confirm diagnosis, assess disease burden and severity, assess changes in severity, and help modify the treatment plan, thus inferring prognosis [35, 36].

Our results showed a statistically significant difference between non-survivors and survivors for consolidations, crazy-paving patterns, and pleural effusion; no statistical difference was found for ground-glass opacities. This finding is similar to that made in the study by Li *et al.* [29] who also found statistically higher proportions of consolidations, crazy-pavings, and pleural effusion in severe cases than in non-severe cases. Furthermore, the study by Elmokadem *et al.* [16] reported that, compared with non-severe cases, severe cases had statistically significantly fewer ground-glass opacities and more crazy-pavings. According to Tian *et al.* [37], severe cases develop consolidations, which could be caused by fibroblast proliferation, extracellular matrix formation, and interstitial thickening. These authors continued to point out that, in some patients, massive intra-alveolar neutrophil infiltration, possibly due to superimposed bacterial pneumonia, may cause radiographic consolidation [37].

In this study, the statistical comparison of the different mean values of the four scoring systems used between non-survivors and survivors showed a highly significant difference ($p < 0.0001$). An Italian study by Francone *et al.* [20] reported that the Chest CT score values were significantly higher in critically ill patients than in mildly ill patients, and in late-onset patients than in early-onset patients ($p < 0.0001$).

The present study showed that the scoring systems demonstrated outstanding performances (AUC > 0.9) in the prediction of mortality and that the cut-off values for the prediction of mortality were ≥ 12 for the Chest CT score, $\geq$ 24 for the CT severity score, ≥ 29 for the CT severity score three levels, and $\geq$ 8 for the Total severity score. In Kuwait, a recent study by Elmokadem *et al.* [16], comparing these four scoring systems in assessing diagnostic accuracy, reported cut-off values for detection of severe cases of > 22, > 17, > 12 and > 26 for the CT severity score, the Chest CT score, the Total severity score, and the CT severity score three levels. The performance of these four scoring systems used in the present study were outstandings (AUC > 0.9). The study by Elmokadem *et al.* [16] adopted a similar design comparing the performance of these four scoring systems and showed that the AUCs were 0.868, 0.904, 0.890, and 0.865 for the CT severity score, the Chest CT score, the Total severity score, and the CT severity score three levels respectively. As shown in the Kuwaiti study [16], there were no statistically significant differences between the four scoring systems when their AUCs were compared in the present study. Other studies have been conducted to evaluate the performance of different chest CT severity scoring systems to predict adverse outcomes (ICU admission and mortality) in COVID-19 patients and have reported acceptable performance [38, 39].

Predicting COVID-19-related mortality is an important issue in the clinical management of the disease. The use of different chest CT severity scoring systems has proven to be a promising approach. In the present study, the results of the four ROC curves indicate outstanding performances (AUC > 0.9) in predicting mortality for each of the scoring systems studied. Taken together, these scores demonstrate the effectiveness of CT-based assessments in predicting COVID-19-related mortality. However, it is important to note that despite this outstanding performance, these scores must be used in conjunction with other clinical and biological data for a complete risk assessment.

This study has several limitations. First, the identification of prognostic factors is relatively limited due to its retrospective design. Second, excellent reproducibility was observed compared to other studies. This may be attributed to the use of a single CT scanner and the strict application of laboratory-confirmed COVID-19 cases, which are believed to have positively influenced image interpretation. Third, there is a lack of precise information on when the symptoms started. However, despite the significant advances, it is important to note that CT-based mortality prediction is not infallible. Several factors, such as comorbidities, patient age, and other clinical variables, also influence the prognosis. An integrated approach, which combine radiological and clinical data, can offer a more complete perspective in clinical decision making. This study validated these scores to optimize their usefulness in the management of COVID-19 patients in our setting.

5 Conclusion

The present study showed that the four chest CT severity scoring systems used predicted mortality in COVID-19 patients with excellent agreement and outstanding performance. For an accurate diagnosis, management and follow-up of COVID-19, severity assessment is very important. The use of these chest CT severity scoring systems can have important clinical implications. By quickly identifying high-risk patients, healthcare workers can intensify care and interventions, thus improving survival chances. We suggest incorporating the severity assessment into standard CT reports in COVID-19 patients.

Data Availability

The datasheet used to support the findings of this study is available from the corresponding author (OM) upon request.

Competing interests

The authors declare that they have no competing interests.

Ethics approval and consent to participate

This study was approved by the Medical Ethical Committee of the University of Lubumbashi (Approval No. UNIGOM/CEM/009/2023). Due to the retrospective nature of the study, informed consent was not sought from patients as data had been collected from medical records at the hospital. Data analysis was carried out anonymously and in confidence.

Author contributions

DNN, OM, CKK, SOW, and ZKT participated in the design of the study. DNN, OM, MLT, GLM, AMA, and JTM involved in data collection. DNN, OM, and CKK performed the statistical analysis and drafting of the manuscript with the support of SOW, and ZKT. All the authors were involved in finalizing the manuscript, read, and approved the final version.

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