Role of cardiovascular computed tomography parameters and lungs findings in predicting severe COVID-19 patients: a single-centre retrospective study

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Abstract

**Background:** During the coronavirus disease 2019 (COVID-19) pandemic, most patients experienced various respiratory and cardiovascular problems, and their health suddenly deteriorated despite active treatment. Many parameters have been used to assess patient health status. However, few have considered chest computed tomography (CCT) and lung findings to predict patient outcomes. This single-centre retrospective observational study was conducted between December 2020 and March 2021 at the European Gaza Hospital to predict the mortality of COVID-19 patients based on their CCT parameters and lung involvement scores.

**Results:** A total of 152 patients with severe respiratory symptoms were admitted during the study period, of which 93 (61.2%) improved and 59 (38.8%) died. Deceased patients showed a significantly higher right pulmonary diameter, cardiothoracic ratio, and ground glass with crazy paving opacity ($p < 0.05$). A cardiothoracic ratio $\geq 0.49$ was associated with significantly higher mortality risk ($p < 0.05$) and a fourfold higher hazard ratio ($p < 0.05$) compared to $< 0.49$.

**Conclusions:** Assessing cardiac indices on CCT could provide prognostic information and guide physicians in patient management and risk stratification.

**Keywords:** COVID-19, Chest CT, Cardiovascular, Lung findings, Death predictor

**Background**

The 2019 coronavirus disease (COVID-19) pandemic has negatively influenced the cardiovascular system of patients and posed challenges to the global cardiovascular community [1]. About 40% of COVID-19 deaths are due to cardiovascular involvement [2], potentially reflecting direct or indirect effects such as myocardial injury, myocarditis, acute coronary syndrome, cardiac arrhythmias, heart failure, cardiogenic shock [3, 4], and pulmonary hypertension [5]. The disease severity and survival rates could be associated with demographic and clinical variables, including age, sex, and comorbidities such as cardiovascular conditions [6–9]. For example, cardiovascular risks such as myocarditis, acute myocardial infarction, and sudden onset of heart failure were noted in previous influenza epidemics, with a substantial increase in morbidity and mortality [10, 11].

There is currently a dearth of research on COVID-19 infection in patients with pulmonary hypertension and cardiovascular index, resulting in poor evidence-based guidance to manage this specific patient population and reliably predict their clinical course [12]. In addition,
further research is needed to investigate the cardiovascular parameters as predictors of morbidity and mortality. The dilatation of the main pulmonary artery is a sign of increasing pulmonary artery pressure, most often due to increased pulmonary artery resistance. Consequently, a pulmonary artery-to-ascending aorta (PA/AA) diameter ratio of >1 raises suspicion of pulmonary hypertension [13–16] and is associated with an unfavourable prognosis in patients with respiratory diseases [17, 18]. Chest computed tomography (CCT) has high sensitivity and clinical value in COVID-19 diagnosis [19–22]. Many cardiovascular parameters could be assessed with CCT, including the cardiothoracic ratio (CTR), referring to cardiomegaly [23], PA/AA ratio, and inferior vena cava (IVC) dimensions. In addition, CCT helps to assess the severity of lung involvement via calculating the total lung score in all zones (upper, middle, and lower), with higher scores associated with more severe COVID-19 disease [24, 25]. The clinical utility of cardiovascular parameters and lung involvement scores could be important in providing prognostic information and facilitating risk stratification among COVID-19 patients. Therefore, this study predicts the mortality of COVID-19 patients based on CCT cardiovascular parameters and lung involvement scores.

Methods
Study design, sample, and population
This retrospective observational study included 152 non-vaccinated COVID-19 patients admitted at the European Gaza Hospital in the Gaza Strip, Palestine. CCT data were collected between December 2020 and March 2021 during their hospitalization.

Eligibility criteria
Inclusion criteria
Patient inclusion criteria were: aged ≥ 18 years, confirmed COVID-19 infection, and availability of non-contrast CCT data.

Exclusion criteria
Patient exclusion criteria were a history of pulmonary emboli or oxygen-dependent chronic obstructive pulmonary disease and poor CT image quality due to respiratory or cardiac motion or metallic artefacts.

Image acquisition and analysis
CCT imaging was acquired for each COVID-19 patient using a Philips-Brilliance 64-slice CT Scanner in the supine position during end-inspiration. The CCT protocol used included scanning parameters such as a 1.5-s scan time, 0.60 mm × 64-detector array, a pitch of 1, table speed of 50 mm/rotation, 200 mAs, 120 kVp, and 5 mm slice thickness. A 1 mm reconstruction interval was used for sagittal and coronal image reconstruction.

CCT data were extracted from the Digital Imaging and Communications in Medicine network system. Two expert consultant radiologists with at least 10 years of experience independently interpreted the images, and a final decision was reached by consensus. In cases of disagreement, the opinion of a third arbitrator consultant radiologist was taken. The images were viewed in axial, sagittal, and coronal planes.

The radiological findings were defined as ground-glass opacification (GGO), consolidation, reticular, crazy-paving pattern, and mixed involvement patterns. Other associated features were observed, including pleural and pericardial effusion, pneumothorax, airway thickening/dilatation, pulmonary vessel dilatation, air bronchogram, traction bronchiectasis, and lymph nodes > 1 cm. The lung opacity distribution was divided into peripheral, central, and peripheral with central. Similarly, lung opacity locations were defined as the upper, middle, and lower lung zones.

Abnormal lung opacities in CCT images were scored by assessing all zonal lung involvements. Independently, each lung consists of three zones: the upper zone, which is located above the carina; the middle zone, which is located between the carina and the inferior pulmonary vein; and the lower zone, which is located below the inferior pulmonary vein. The percentage of severity scores for each lung involvement was calculated via the next classification (score 0: no involvement/normal lung zone; score 1: <25%; score 2: 26–50%; score 3: 51–75%; score 4: >75%). The overall lung score (maximum score = 24) was calculated by summing the scores of all three zones [9, 26, 27].

Cardiovascular parameters were assessed by measuring the vessel’s diameter through CCT axial images with mediastinal windows. In addition, we focused on measurements of the main, right, and left pulmonary artery diameters, ascending and descending aorta, and PA/AA ratio. The PA/AA diameter ratio was measured at the main pulmonary trunk bifurcation level (Fig. 1A). Pulmonary trunk enlargement was defined as a PA/AA > 1 to identify patients at increased risk for exacerbations, with a higher ratio correlating with higher pulmonary artery pressure [28]. Then, heart width and thoracic interval diameters were measured to calculate the CTR. CTR was measured through axial images, typically at the diaphragmatic apex level and defined as the greatest transverse cardiac diameter from outer to outer myocardium divided by the greatest transverse thoracic diameter from inner to the inner chest wall (Fig. 1B) [29]. Normal CTR measurements are between 0.42 and 0.49. A CTR < 0.42 is usually considered pathologic, while a CTR ≥ 0.49 is
considered a sign of cardiomegaly [29]. Additionally, the long and short axes of the heart were measured at the heart apex level (Fig. 1C) [30], and the long/short axis ratio was calculated. In addition, the transverse and anterior-posterior diameter of the inferior vena cava (IVC) was measured below the diaphragm, and the transverse to anterior-posterior (Tran/AP) ratio was calculated (Fig. 1D) [31, 32]. Measuring transverse diameter helps in better for elucidating the anatomical structure of blood vessel diameter [9, 33, 34]. Determining the maximal diameter of vessels from edge to edge is straightforward [9, 34]. Using only one axis at the level of pulmonary bifurcation to serve as a constant landmark in all cases.

Statistical analysis
Data were analysed using the Statistical Package of Social Sciences (SPSS; v.25). After the homogenous normality test, the parametric variables with descriptive statistics were used as frequencies, percentages, and mean ± standard deviation (SD). Independent sample t, Chi-square, and Fisher’s Exact tests were used to compare groups. A Cox regression survival analysis was performed to investigate the potential predictors of mortality. A binary logistic regression analysis was performed to identify the mortality odds ratio. A p-value of less than 0.05 was considered statistically significant.

Results
Clinical and laboratory data characteristics
The 152 patients were divided into two groups: recovered (n=93) and deceased (n=59). The mean age in the recovered group (58.7 ± 15.38) was lower than in the deceased group (64.19 ± 12.17). Severe illnesses were significantly more frequent in the recovered group (n=83; 89.2%), while critical conditions were significantly more frequent in the deceased group (n=51; 86.4%).

The recovered group had more frequent ischemic heart disease and hypertension and lower interstitial lung disease and morbid obesity compared to the deceased group. Laboratory findings showed lower D-dimer,
ferritin, and urea levels in the recovered group than in the deceased group. The clinical characteristics and laboratory data are summarized in Table 1.

**Association between CCT findings and patient outcome**
The relationship between CCT radiological findings and the two outcome groups is reported in Table 2. The GGO and crazy paving opacity patterns were more frequent in the deceased group than in the recovered group ($p = 0.001$ and $p = 0.0001$, respectively). Consolidation, sup-plural line, reticular and nodular opacities patterns did not differ significantly between groups.

CCT-specific radiological COVID-19 signs of vascular dilatation around lesions, airway wall thickness, interstitial septa thickness, bronchiectasis, and honeycomb were more frequent in the deceased group compared to the recovered group ($p < 0.0001$, $p = 0.001$, $p = 0.046$, $p = 0.0001$, and $p = 0.0002$, respectively).

Both central perihilar and central and peripheral sites were significantly increased in the deceased group compared to the recovered group ($p = 0.005$ and $p = 3.00 \times 10^{-5}$, respectively). While unilateral lung involvement was significantly increased in the recovered group ($p = 0.043$), bilateral lung involvement was significantly increased in the deceased group ($p = 0.023$). The main pulmonary branch, ascending aorta, descending aorta, and coronary artery calcification did not differ significantly between groups.

**Association between cardiovascular CCT-parameters and patient outcome**
The right pulmonary diameter was significantly increased in the deceased group compared to the recovered group ($p = 0.001$). The PA/AA ratio showed a nonsignificant increase in the deceased group compared to the recovered group. In addition, heart width diameter ($p = 0.0001$) and CTR ($p = 0.001$) were significantly increased in the deceased group compared to the recovered group. In addition, heart width diameter ($p = 0.0001$) and CTR ($p = 0.001$) were significantly increased in the deceased group compared to the recovered group ($14.12 \pm 2.51$ cm and $0.60 \pm 0.1$, respectively) compared to the recovered group ($12.64 \pm 1.8$ cm and $0.54 \pm 0.11$, respectively; Table 3).

In contrast, the long and short axis heart measurements and their ratio did not differ significantly between groups. Similarly, the transverse IVC diameter, anteroposterior IVC diameter, and transverse/anteroposterior IVC ratio did not differ significantly between groups (Fig. 2).

**Odds and hazard ratios of death based on lungs involvement scores and cardiovascular CCT-parameters**
Our results show the effects of lung involvement scores and cardiovascular CCT parameters on COVID-19 mortality (Table 4). Lung involvement scores in the right upper, middle, and lower zones and total right scores were significantly increased in the deceased group compared to the recovered group ($p = 0.0001$ in all comparisons). Similarly, the left upper, middle, and lower zones and total left scores were significantly increased in the deceased group compared to the recovered group ($p = 0.0001$ in all comparisons).

In addition, lung involvement scores in the right upper, middle, and lower zones and total right scores were significantly associated with the hazard ratio (HRs) for death ($p = 0.002$, $p = 0.0001$, $p = 0.001$, and $p = 0.0001$, respectively). Moreover, the left upper, middle, and lower zones and total left scores were significantly associated with the HR for death ($p = 0.001$, $p = 0.0001$, $p = 0.0001$, and $p = 0.0001$, respectively). Overall, both lung scores had significantly increased odds ratio ($p = 0.0001$) and HR ($p = 0.0001$) for death.

In the recovered group, 83 patients (89.2%) had PA/A < 1 and 10 patients (10.8%) who PA/A > 1. In contrast, in the deceased group, 52 patients (88.1%) patients had PA/A < 1 and 7 patients (11.9%) had PA/A > 1. Logistic and Cox regression models did not show a PA/A ratio > 1 to be a predictor of death from COVID-19.

In the recovered group, 23 patients (24.7%) had a CTR < 0.49 and 70 patients (75.3%) had a CTR ≥ 0.49. In contrast, in the deceased group, 2 patients (3.4%) had a CTR < 0.49 and 57 patients (96.6%) had a CTR ≥ 0.49. The logistic and Cox regression models identified CTR ≥ 0.49 as a predictor of death from COVID-19 (Table 4).

Based on the CTR analysis, the odds ratio for death with a CTR ≥ 0.49 was 9.8-fold higher than with a CTR < 0.49. In addition, a CTR ≥ 0.49 was a significant predictor of the HR for death, which was 4.4-fold higher with a CTR ≥ 0.49 than a CTR < 0.49. The cumulative HR for the pulmonary-aorta and cardiothoracic ratios is illustrated in Fig. 3.

**Discussion**
This study adds to the body of knowledge about the prediction of the mortality of COVID-19 patients based on CCT and lung involvement. Our findings show that CCT provides prognostic information that can guide patient management and risk stratification. The CTR was significantly higher in severely hospitalized COVID-19 patients and an independent predictor of COVID-19 mortality. The PA/AA ratio and IVC dimensions were not found to be predictive of COVID-19 patient mortality.

Increased CTR has been associated with a higher risk of adverse cardiovascular events [35]. Our study found that increased cardiomegaly (CTR ≥ 0.49) is frequent in hospitalized COVID-19 patients and strongly predicts their mortality. This finding is similar to a previous study that reported increased CTRs in 76% of patients who eventually died [10]. Our results also...
### Table 1  Clinical and laboratory data characteristics for COVID19 patients

| Variables                              | Patient outcomes (n = 152) |  |
|----------------------------------------|----------------------------|---|
|                                        | Recovered (n = 93)         | Deceased (n = 59) |
| Age                                    |                            |  |
| Mean±(SD)                              | 58.7±(15.38)               | 64.19±(12.17)     | 0.022* |
| Age groups                             |                            |  |
| 40 y and Less                          | 16 (17.2%)                 | 2 (3.4%)          | 0.007* |
| 41–50 y                                | 9 (9.7%)                   | 5 (8.5%)          |      |
| 51–60 y                                | 25 (26.9%)                 | 13 (22%)          |      |
| 61–70 y                                | 24 (25.8%)                 | 22 (37.3%)        |      |
| 71–80 y                                | 13 (14%)                   | 13 (22%)          |      |
| 81–90 y                                | 6 (6.5%)                   | 4 (6.8%)          |      |
| Gender                                 |                            |  |
| Male                                   | 41 (44.1%)                 | 28 (47.5%)        | 0.405 |
| Female                                 | 52 (55.9%)                 | 31 (52.5%)        |      |
| Hospitalization period                 |                            |  |
| Mean±(SD)                              | 12.97±(8.45)               | 12.51±(6.84)      | 0.726 |
| COVID patient’s status                 |                            |  |
| Severe illness                         | 83 (89.2%)                 | 8 (13.6%)         | 0.0001* |
| Critical illness                       | 10 (10.8%)                 | 51 (86.4%)        |      |
| Morbidity factors                      |                            |  |
| Chronic heart disease                  | 29 (31.2%)                 | 24 (40.7%)        | 0.068 |
| Ischemic heart disease                 | 21 (22.6%)                 | 8 (13.6%)         | 0.019* |
| Congestive heart failure disease       | 2 (2.2%)                   | 5 (8.5%)          |      |
| Ischemic and congestive heart disease  | 7 (7.5%)                   | 11 (18.6%)        |      |
| Diabetes mellitus                      | 52 (55.9%)                 | 39 (66.1%)        | 0.063 |
| Hypertension                           | 57 (61.3%)                 | 47 (79.7%)        | 0.008* |
| Liver disease                          | 2 (2.2%)                   | 3 (5.1%)          | 0.22 |
| Interstitial lung disease              | 8 (8.6%)                   | 14 (23.7%)        | 0.008* |
| Chronic kidney disease                 | 8 (8.6%)                   | 9 (15.3%)         | 0.093 |
| Cancer                                 | 1 (1.1%)                   | 1 (1.7%)          | 0.478 |
| Morbid obesity                         | 21 (22.6%)                 | 4 (6.8%)          | 0.006* |
| COVID-19 symptoms                      |                            |  |
| Fever                                  | 67 (72%)                   | 53 (89.8%)        | 0.005* |
| Cough                                  | 88 (94.6%)                 | 53 (89.8%)        | 0.135 |
| Shortness of breathing                 | 84 (90.3%)                 | 59 (100%)         | 0.010* |
| Headache                               | 54 (58.1%)                 | 32 (54.2%)        | 0.12 |
| Loss of smell and taste                | 51 (54.8%)                 | 23 (39%)          | 0.022* |
| Diarrhea                               | 54 (58.1%)                 | 34 (57.6%)        | 0.134 |
| Nausea& vomiting                       | 31 (33.3%)                 | 22 (37.3%)        | 0.122 |
| Abdominal pain                         | 26 (28%)                   | 13 (22%)          | 0.11 |
| Chest pain                             | 47 (50.5%)                 | 41 (69.5%)        | 0.009* |
| Laboratory tests finding               |                            |  |
| WBC                                    | 11.79±(17.10)              | 13.11±(29.88)     | 0.729 |
| Platelets                              | 271.37±(110.68)            | 270.44±(137.91)   | 0.964 |
| CRP                                    | 8.23±(2.54)                | 5.89±(1.89)       | 0.0001* |
| D-dimer                                | 1.85±(1.24)                | 4.71±(1.73)       | 0.0001* |
| Ferritin                               | 431.37±(340.52)            | 795.14±(414.07)   | 0.0001* |
| Urea                                   | 66.66±(43.57)              | 83.51±(53.69)     | 0.045* |
| Creatinine                             | 1.09±(0.98)                | 1.37±(1.1)        | 0.11 |
| HB                                     | 12.11±(1.82)               | 11.34±(1.79)      | 0.012* |
| Glucose random                         | 195.33±(140.64)            | 232.19±(134.3)    | 0.108 |

*Statistically significant
indicated that enlarged main pulmonary trunk diameter has high specificity and positive predictive value for the diagnosis of pulmonary hypertension and increased mortality risk. An Italian study reported that an enlarged main pulmonary artery diameter (≥ 31 mm) on the admitting CCT is an independent predictor of mortality in COVID-19 patients [36]. However, another study reported no significant relationship between right and left pulmonary artery

Table 2  Radiological findings of lung CT of COVID-19 patients

| Variables                                      | Patient outcomes (n = 152) | P-value |
|------------------------------------------------|---------------------------|---------|
|                                                | Recovered (n = 93)      | Deceased (n = 59) |         |
| Predominant patterns involvement               |                           |         |
| Ground-glass opacity                           | 65 (69.9%)                | 55 (93.2%) | 0.001** |
| No                                             | 28 (30.1%)                | 4 (6.8%)  |         |
| Consolidation opacity                          | 48 (51.6%)                | 37 (62.7%) | 0.12    |
| No                                             | 45 (48.4%)                | 22 (37.3%) |         |
| Crazy paving opacity                           | 24 (25.8%)                | 42 (71.2%) | 0.0001**|
| No                                             | 69 (74.2%)                | 17 (28.8%) |         |
| Sup-plural line opacity                        | 57 (61.3%)                | 42 (71.2%) | 0.227   |
| No                                             | 36 (38.7%)                | 17 (28.8%) |         |
| Reticular opacity                              | 68 (73.1%)                | 44 (74.6%) | 0.853   |
| No                                             | 25 (26.9%)                | 15 (25.4%) |         |
| Nodular opacity                                | 41 (44.1%)                | 27 (45.8%) | 0.868   |
| No                                             | 52 (55.9%)                | 32 (54.2%) |         |
| COVID_19 radiological signs                    |                           |         |
| Halo sign                                      | 35 (37.6%)                | 24 (40.7%) | 0.735   |
| No                                             | 58 (62.4%)                | 33 (59.3%) |         |
| Revers Halo sign                               | 13 (14%)                  | 13 (22%)  | 0.269   |
| No                                             | 80 (86%)                  | 46 (78%)  |         |
| Vascular dilatation around lesions             | 34 (36.6%)                | 42 (71.2%) | 0.00001*|
| No                                             | 59 (63.4%)                | 17 (28.8%) |         |
| Airways wall thickness                         | 41 (44.1%)                | 42 (71.2%) | 0.001   |
| No                                             | 52 (55.9%)                | 17 (28.8%) |         |
| Interstitial Septa thickness                   | 67 (72%)                  | 51 (86.4%) | 0.046   |
| No                                             | 26 (28%)                  | 8 (13.6%)  |         |
| Bronchiectasis                                 | 20 (21.5%)                | 33 (55.9%) | 0.00001*|
| No                                             | 73 (78.5%)                | 26 (44.1%) |         |
| Honeycombing                                   | 2 (2.2%)                  | 12 (20.3%) | 0.0002* |
| No                                             | 91 (97.8%)                | 47 (79.7%) |         |
| Cavitation                                     | 2 (2.2%)                  | 3 (5.1%)   | 0.377   |
| No                                             | 91 (97.8%)                | 56 (94.9%) |         |
| Opacities distribution extension                |                           |         |
| Peripheral                                    | 88 (94.6%)                | 58 (98.3%) | 0.406   |
| No                                             | 5 (5.4%)                  | 1 (1.7%)   |         |

* Statistical significance in Chi-Square test
** Statistical significant in Fisher’s Exact test

Table 2 (continued)

| Variables                                      | Patient outcomes (n = 152) | P-value |
|------------------------------------------------|---------------------------|---------|
|                                                | Recovered (n = 93)      | Deceased (n = 59) |         |
| Central perihilar                              | 48 (51.6%)                | 47 (79.7%) | 0.0005* |
| No                                             | 45 (48.4%)                | 12 (20.3%) |         |
| Central and peripheral                         | 33 (35.5%)                | 44 (74.6%) | 0.00003*|
| No                                             | 60 (64.5%)                | 15 (25.4%) |         |
| Unilateral lung involvement                    | 7 (7.3%)                  | 0 (0%)    | 0.043*  |
| No                                             | 86 (92.5%)                | 59 (100%)  |         |
| Bilateral lung involvement                     | 85 (91.4%)                | 59 (100%)  | 0.023*  |
| No                                             | 8 (8.6%)                  | 0 (0%)    |         |
| Other radiological features                    |                           |         |
| Pleural effusion                               | 16 (17.2%)                | 17 (28.8%) | 0.108   |
| No                                             | 77 (82.8%)                | 42 (71.2%) |         |
| Pneumothorax                                   | 0 (0%)                    | 30 (5.1%)  | 0.57f   |
| No                                             | 93 (100%)                 | 56 (94.9%) |         |
| Pericardial effusion                           | 5 (5.4%)                  | 3 (5.1%)   | 0.624   |
| No                                             | 88 (94.6%)                | 56 (94.9%) |         |
| Cardiovascular calcification                    |                           |         |
| Pulmonary branch                               | 2 (2.2%)                  | 4 (6.8%)   | 0.208   |
| No                                             | 91 (97.8%)                | 55 (93.2%) |         |
| Ascending Aorta calcification                   | 30 (32.3%)                | 22 (37.3%) | 0.599   |
| No                                             | 63 (67.7%)                | 37 (62.7%) |         |
| Descending Aorta calcification                  | 30 (32.3%)                | 26 (44.1%) | 0.169   |
| No                                             | 63 (67.7%)                | 33 (55.9%) |         |
| Coronary calcification                         | 37 (39.8%)                | 26 (44.1%) | 0.616   |
| No                                             | 56 (60.2%)                | 33 (55.9%) |         |

* Statistical significance in Chi-Square test
** Statistical significant in Fisher’s Exact test
diameter and mortality among COVID-19 patients [37].

A PA/AA ratio > 1 has previously been proposed as a biomarker for pulmonary hypertension [38]. Some studies have shown pulmonary embolism, including microembolism, to be one of the causes of severe COVID-19 cases [39, 40]. There has been inconsistency among studies on the increase in PA/AA ratio as a predictor of mortality. In this study, we did not find a significant increase in the odds ratio of COVID-19

### Table 3 Cardiovascular CT-Parameters of COVID-19 patients

| Cardiovascular CT-parameters | Patient Outcomes (n = 152) | P-value |
|------------------------------|-----------------------------|---------|
|                              | Recover (n = 93) | Deceased (n = 59) | |
| Main pulmonary diameter      | 2.91 ± (0.41) | 3.1 ± (0.36) | 0.062 |
| Right pulmonary diameter     | 2.18 ± (0.41) | 2.40 ± (0.47) | 0.001* |
| Left pulmonary diameter      | 2.10 ± (0.47) | 2.19 ± (0.41) | 0.212 |
| Ascending aorta diameter     | 3.39 ± (0.46) | 3.47 ± (0.39) | 0.257 |
| Descending aorta diameter    | 2.70 ± (0.40) | 2.78 ± (0.39) | 0.221 |
| Pulmonary/Asc. Aorta ratio   | 0.86 ± (0.18) | 0.87 ± (0.10) | 0.421 |
| Heart width                  | 12.64 ± (1.8) | 14.12 ± (2.51) | 0.0001* |
| Thoracic intervals           | 23.5 ± (2.74) | 23.4 ± (2.71) | 0.875 |
| Cardiorespiratory ratio (CTR) | 0.54 ± (0.11) | 0.60 ± (0.1) | 0.0001* |
| Long_Axis_heart              | 12.37 ± (1.88) | 12.67 ± (1.89) | 0.329 |
| Short_Axis_heart             | 9.95 ± (1.63) | 9.95 ± (1.63) | 0.484 |
| Long/Short axis ratio        | 1.28 ± (0.17) | 1.26 ± (0.17) | 0.783 |
| Trans_IVC diameter           | 2.47 ± (0.59) | 2.42 ± (0.72) | 0.151 |
| AP_IVC-diameter              | 1.77 ± (0.64) | 1.59 ± (0.73) | 0.074 |
| Tran/AP-IVC ratio            | 1.46 ± (0.44) | 1.46 ± (0.46) | 0.592 |

* Statistical significant

### Table 4 Characteristics of mortality prediction and hazard ratio derived from the lung involvement scores and cardiovascular CT-Parameters measurements

| Lung involvement scores | Patent outcome | Logistic model | Cox model |
|-------------------------|---------------|----------------|-----------|
|                         | Recover (n = 93) | Deceased (n = 59) | P-value | Odd ratio OR (95% CI) | P-value | Hazard ratio HR (95% CI) |
| Right lung              |               |                 |          |                       |         |                         |
| Upper zone score        | 1 ± (1.5) | 3 ± (2) | 0.0001* | 2.584 (1.83–3.63) | 0.002* | 1.43 (1.14–1.80) |
| Middle zone score       | 2 ± (2) | 3.5 ± (1) | 0.0001* | 4.607 (2.75–7.71) | 0.0001* | 2.06 (1.48–2.86) |
| Lower zone score        | 2.5 ± (2) | 4 ± (1) | 0.0001* | 3.316 (2.12–5.17) | 0.001* | 1.75 (1.25–2.43) |
| Total score             | 6 ± (4) | 10 ± (4) | 0.0001* | 1.761 (1.46–2.11) | 0.0001* | 1.27 (1.14–1.42) |
| Left lung               |               |                 |          |                       |         |                         |
| Upper zone score        | 1 ± (1) | 2 ± (2) | 0.0001* | 2.82 (1.93–4.13) | 0.001* | 1.46 (1.17–1.83) |
| Middle zone score       | 2 ± (1.5) | 3.5 ± (1) | 0.0001* | 7.65 (4.09–14.33) | 0.001* | 2.391 (1.69–3.37) |
| Lower zone score        | 2 ± (2) | 4 ± (1) | 0.0001* | 4.50 (2.72–7.44) | 0.001* | 2.029 (1.45–2.82) |
| Total score             | 5.5 ± (3.5) | 9 ± (3.5) | 0.0001* | 2.16 (1.70–2.74) | 0.001* | 1.32 (1.18–1.47) |
| Overall lungs score     | 12 ± (7) | 20 ± (7) | 0.0001* | 1.46(1.30–1.65) | 0.001* | 1.15 (1.09–1.22) |
| PA/aorta ratio ≤ 1.0 (Ref) | 83 (89.2%) | 52 (88.1%) | 0.484 | 1.493 (0.48–4.58) | 0.863 | 1.073 (0.48–2.37) |
| > 1.0                   | 10 (10.8%) | 7 (11.9%) | 0.003* | 9.877 (2.20–44.24) | 0.039* | 4.444 (1078–18.32) |
| CTR ≤ 0.49 (Ref)        | 23 (24.7%) | 2 (3.4%) | 0.039* | 9.877 (2.20–44.24) | 0.039* | 4.444 (1078–18.32) |
| ≥ 0.49                  | 70 (75.3%) | 57 (96.6%) | 0.003* | 9.877 (2.20–44.24) | 0.039* | 4.444 (1078–18.32) |
mortality in patients with a PA/AA ratio $> 1$. This finding is similar to another study [9] that found a PA/AA ratio $> 1$ associated with substantial lung involvement but a nonsignificant increase in the risk of death. In addition, a recent study found that increased pulmonary artery diameter in admitted COVID-19 patients was associated with death [41].

IVC dimensions have been previously suggested as helpful predictive markers of cardiac events and survival [42-45]. However, we could not find an increased risk of death in patients with dilated IVC.
or an increased long/short heart axis ratio. This finding is supported by another study [9] that reported no increased death among patients with dilated IVC. Moreover, the increase in lung involvement scores on CCT has been associated with the clinical severity and prognosis of COVID-19 patients [46, 47]. Our findings support this since greater lung involvement leads to a significant increase in the odds and risk of death from COVID-19. In addition, deceased patients had much greater involvement in all three zones (upper, middle, and lower), with the middle zone being the most involved with the highest odds ratio for death. We attributed this to its closeness to the main bronchus branches, which have the largest infection burden.

Our use of a cross-sectional design is one limitation of this study, making it difficult to confirm the accuracy of our results. Further comparative research, such as matched control studies, is needed to confirm and extend our findings.

**Conclusions**

Our findings indicate that the CTR is significantly higher in hospitalized patients with severe COVID-19 and is an independent predictor of COVID-19 mortality. Moreover, they suggest that assessing cardiac indices on CCT could provide prognostic information that can guide physicians in patient management and risk stratification.

Fig. 3 Cumulative HR function for death in COVID-19 patients according to the pulmonary aorta and cardiothoracic ratios. The outcome was defined as death or recovery, and length of hospitalization was considered the time to outcome in the Cox regression analysis.
Abbreviations
CT: Computed tomography; CCT: Chest CT; COVID-19: 2019 Coronavirus disease; CTR: Cardiothoracic ratio; PA/AA: Pulmonary artery diameter; pulmonary artery-to-ascending aorta; IVC: Inferior vena cava; RT-PCR: Reverse transcriptase-polymerase chain reaction; GGO: Ground-glass opacification.

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Author contributions
MM, MM, and SJ planned the study. MM M analysed the data, and HA-B, YA, MA, and AF together interpreted the findings. MM wrote the first draft of the manuscript, and AO and HA‑B made the final revision. All of the authors approved the final manuscript.

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Availability of data and materials
The datasets used and/or analysed during the current study are available from the first and corresponding authors on reasonable request.

Declarations
Ethics approval and consent to participate
This study was approved by the institution’s ethical committee (Helsinki Committee of The Palestinian Health Research Council-Institutional Research Board) (ethical reference number: PHRC/HC/767/20) and by the Directorate General of Human Resources Development-Ministry of Health (reference number: 571112). It was also received administrative approval from the Palestinian-Turkish Friendship Hospital. Written informed consent was obtained from participants during the admission to hospital after informed them that their information and CT findings will be used for future studies considering their anonymous of personal information.

Consent for publication
All patients included in this research gave written informed consent to publish the data contained within this study.

Competing interests
The authors declare that they have no competing interests.

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