Clinical impact of COVID-19 on patients with cancer (CCC19): a cohort study

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Data on patients with COVID-19 who have cancer are lacking. Here we characterise the outcomes of a cohort of patients with cancer and COVID-19 and identify potential prognostic factors for mortality and severe illness.

Methods In this cohort study, we collected de-identified data on patients with active or previous malignancy, aged 18 years and older, with confirmed severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2) infection from the USA, Canada, and Spain from the COVID-19 and Cancer Consortium (CCC19) database for whom baseline data were added between March 17 and April 16, 2020. We collected data on baseline clinical conditions, medications, cancer diagnosis and treatment, and COVID-19 disease course. The primary endpoint was all-cause mortality within 30 days of diagnosis of COVID-19. We assessed the association between the outcome and potential prognostic variables using logistic regression analyses, partially adjusted for age, sex, smoking status, and obesity. This study is registered with ClinicalTrials.gov, NCT04354701, and is ongoing.

Findings Of 1035 records entered into the CCC19 database during the study period, 928 patients met inclusion criteria for our analysis. Median age was 66 years (IQR 57–76), 279 (30%) were aged 75 years or older, and 468 (50%) patients were male. The most prevalent malignancies were breast (191 [21%]) and prostate (152 [16%]). 366 (39%) patients were on active anticancer treatment, and 396 (43%) had active (measurable) cancer. At analysis (May 7, 2020), 121 (13%) patients had died. In logistic regression analysis, independent factors associated with increased 30-day mortality, after partial adjustment, were: increased age (per 10 years; partially adjusted odds ratio 1.84, 95% CI 1.53–2.21), male sex (1.63, 1.07–2.48), smoking status (former smoker vs never smoked: 1.60, 1.03–2.47), number of comorbidities (two vs none: 4.50, 1.33–15.28), Eastern Cooperative Oncology Group performance status of 2 or higher (status of 2 vs 0 or 1: 3.89, 2.11–7.18), active cancer (progressing vs remission: 5.20, 2.77–9.77), and receipt of azithromycin plus hydroxychloroquine (vs treatment with neither: 2.93, 1.79–4.79; confounding by indication cannot be excluded). Compared with the US-Northeast, residence in Canada (0.24, 0.07–0.84) or the US-Midwest (0.50, 0.28–0.90) were associated with decreased 30-day all-cause mortality. Race and ethnicity, obesity status, cancer type, type of anticancer therapy, and recent surgery were not associated with mortality.

Interpretation Among patients with cancer and COVID-19, 30-day all-cause mortality was high and associated with general risk factors and risk factors unique to patients with cancer. Longer follow-up is needed to better understand the effect of COVID-19 on outcomes in patients with cancer, including the ability to continue specific cancer treatments.

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Introduction Severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2) and the resulting illness, COVID-19, have emerged as a global pandemic. Initial reports suggested that patients with a history of or active malignancy might be at increased risk of contracting the virus and developing COVID-19-related complications. Yet, initial reports are restricted by sample size, geographical region, and a lack of generalisability of findings to the overall population of patients with cancer. Patients with cancer might be immunocompromised by the effects of antineoplastic therapy, supportive...
Evidence before this study

Very little evidence exists describing the natural history of patients with cancer who have COVID-19, the disease associated with severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2). As of May 7, 2020, the peer-reviewed literature was limited to small or single-institution case series; the largest series that we are aware of had 334 cases at a single institution. These case series are of insufficient size or breadth to draw statistical and generalisable conclusions about the factors that might be associated with better or worse outcomes for patients with cancer.

Added value of this study

To our knowledge, we report the largest series of patients with cancer and COVID-19 to date, including over 900 patients with a broad geographical distribution. The population is diverse in terms of age distribution, race and ethnicity, cancer status, and whether they are on active anticancer treatment. We found significant associations with increased 30-day all-cause mortality and the general factors of increasing age, male sex, and past history of haematological malignancy or invasive solid tumour who have either a laboratory-confirmed SARS-CoV-2 infection or a presumptive diagnosis of COVID-19. Contributing institutions in the consortium (appendix pp 2–5) independently identify consecutive patients and report data through the online REDCap data collection survey instruments developed by CCC19 (appendix pp 14–18). Participating institutions were restricted to the USA and Canada. Participation by anonymous individual health-care practitioners located in Argentina, Canada, the EU, the UK, and the USA is also allowed. The mechanism of data collection can be retrospective (after the course of COVID-19) or concurrent, at the discretion of the respondent. Collection of follow-up data is strongly encouraged.

Methods

Study design and participants

In this cohort study, we report data from the COVID-19 and Cancer Consortium (CCC19) registry database. The CCC19 was formed on March 15, 2020, to study the clinical characteristics and course of illness among patients with COVID-19 who have a current or past diagnosis of cancer; accrual to the registry started on March 17, 2020. The registry is built and maintained as an electronic REDCap database housed at Vanderbilt University Medical Center (VUMC). The CCC19 registry is accruing de-identified data on adult patients (aged 18 years or older) with a current or past history of haematological malignancy or invasive solid tumour who have either a laboratory-confirmed SARS-CoV-2 infection or a presumptive diagnosis of COVID-19. Contributing institutions in the consortium (appendix pp 2–5) independently identify consecutive patients and report data through the online REDCap data collection survey instruments developed by CCC19 (appendix pp 14–18). Participating institutions were restricted to the USA and Canada. Participation by anonymous individual health-care practitioners located in Argentina, Canada, the EU, the UK, and the USA is also allowed. The mechanism of data collection can be retrospective (after the course of COVID-19) or concurrent, at the discretion of the respondent. Collection of follow-up data is strongly encouraged.

For this initial analysis, we collected data for patients who had baseline data entered onto the database between March 17 and April 16, 2020, and had follow-up data entered up until May 7, 2020. Patients eligible for inclusion were adults (aged 18 years or older), with a diagnosed invasive or haematological malignancy at any time, and a resident of the USA, Canada, or Spain. Due to possible confounding by other infections, patients with presumptive COVID-19 who did not have a laboratory-confirmed SARS-CoV-2 infection were excluded. Patients with non-invasive cancers including non-melanomatous skin cancer, in-situ carcinoma, or precursor haematological neoplasms were excluded from this analysis.

This study was considered exempt from institutional review board (IRB) review (VUMC IRB 200467) and was approved by local IRBs at participating sites per institutional policy, according to the principles of the Declaration of Helsinki. This study is registered on ClinicalTrials.gov, NCT04354701, and is ongoing.

Research in context
Procedures
The CCC19 survey collects de-identified data across approximately 300 structured and free-text variables in five forms: patient demographics, COVID-19 initial course of illness, cancer details, respondent details (ie, healthcare provider details), and follow-up. Potential prognostic variables were included: age, sex, race and ethnicity, geographical location of patient residence, smoking status, obesity, number of comorbidities requiring active treatment, recent surgery (including, but not limited to cancer surgeries), within 4 weeks of COVID-19 diagnosis), type of malignancy, cancer status (remission vs active [measurable] disease, with active further defined as stable or responding to treatment vs progressing), Eastern Cooperative Oncology Group (ECOG) performance status, anticancer therapy, and COVID-19 treatment with azithromycin, hydroxychloroquine, or both in combination. Active anticancer therapy was defined as either cytotoxic chemotherapy or all other therapies except surgery (targeted drugs, endocrine therapy, immunotherapy, radiotherapy) given within 4 weeks of COVID-19 diagnosis (appendix pp 14–18).

Outcomes
The primary endpoint was all-cause mortality within 30 days of diagnosis of COVID-19. Secondary outcomes were: a composite of severe illness (death, severe illness requiring admission to hospital, admission to an intensive care unit [ICU], mechanical ventilation, or a combination of these); admission to hospital; admission to an ICU; mechanical ventilation; and need for supplemental oxygen during the course of COVID-19.

Statistical analysis
A predefined statistical analysis plan was finalised before accrual lock (April 16, 2020) and was revised once before data analysis (April 18, 2020; appendix pp 6–8). Because of the possibility of a small number of events (deaths), we prespecified the potential prognostic variables for the primary outcome using clinical knowledge and allowable complexity of the model (ie, the number of covariates and degrees of freedom) on the basis of an effective sample size. We provided an unknown category for every variable in the survey. Because some of the survey questions were optional, we anticipated a non-zero level of missingness for some variables (ie, the answer box for the question could be left blank). We used multiple imputation using additive regression, bootstrapping, and predictive mean matching with ten iterations for variables with a 10% or lower missingness rate; variables with a missingness rate of more than 10% were not included in our analyses.

We used descriptive statistics to show the baseline demographic information of the participants included in our analyses. Due to privacy restrictions, we collected dates of COVID-19 diagnosis as intervals (eg, diagnosed 2–4 weeks ago). As a result, we planned an interval-censored Cox proportional hazards analysis; however, wide diagnosis intervals and insufficient primary outcome events restricted our ability to do this analysis. Therefore, we examined the correlations between the study variables and primary endpoint using a logistic regression model for bivariable and predetermined multivariable data analysis. In the multivariable model we partially adjusted the odds ratios: age was adjusted for sex, smoking status, and obesity; sex was adjusted for age, smoking status, and obesity; smoking status was adjusted for age, sex, and obesity; obesity was adjusted for age, sex, and smoking status; and other covariates were adjusted for age, sex, smoking status, and obesity. Age was treated as a continuous variable with age 90 years and older transformed into 90 years for modelling. We did not adjust our results for multiple comparisons. We assessed goodness of fit using Harrell’s C statistic with 95% CIs determined using DeLong and colleagues’ method.9 10 We calculated variance inflation factors for every potential prognostic variable in each adjusted model.

In an exploratory subanalysis, we also applied an elastic net regularised logistic regression analysis to examine the shrinkage of the coefficients in the predetermined set of covariates.11 Given the high rate of clinically important secondary outcomes, we did a post hoc, fully adjusted, logistic regression analysis of the secondary composite endpoint of severe illness. We also did post-hoc power analyses for the recent surgery and anticancer treatment variables to examine the study effect sizes.

We did all data analyses using base R (version 3.6.3) and the R packages rms 5.1-4 and Hmisc 4.4-0.

Role of the funding source
The funders of the study had no role in study design, data collection, data analysis, data interpretation, or writing of the report. The corresponding author had full access to all the data in the study and had final responsibility for the decision to submit for publication.

Results
Of the 1035 records with completed baseline forms added to the database during our study period, 928 patients met criteria for inclusion in the analyses (appendix p 10). Of these records, 73 (8%) reports originated from community practices and 851 (92%) from academic medical centres. 826 (89%) reports were from participating institutions and the remaining 102 (11%) were anonymous. Median follow-up for the cohort was 21 days (IQR 11–41 days). 570 (61%) records were initialised during the course of COVID-19; of these, 255 (45%) had at least one follow-up report.

Demographic, clinical, and tumour characteristics for the analysable population are in table 1 (data for 84 non-laboratory-confirmed cases are in the appendix [pp 22–23]). Median patient age was 66 years (IQR 57–76), 279 (30%) were aged 75 years or older, and 468 (50%) patients were...
male. 460 (50%) patients were non-Hispanic white, 148 (16%) were non-Hispanic black, and 150 (16%) were Hispanic. The most common geographical region of residence was the US-Northeast (375 [40%]). The most prevalent malignancies were breast (191 [21%]) and prostate (152 [16%]). 422 (45%) patients were reported to be in remission and 396 (43%) to have active cancer. Of those

| Age, years* | Median | Range | <65 | 65–74 | ≥75 |
|-------------|--------|-------|-----|-------|-----|
| Median      | 66     | (57–76)| 412 (44%) | 237 (26%) | 279 (30%) |
| Sex         | Female | 459 (49%) | 468 (50%) | 1 (<1%) |
| Race and ethnicity† | Non-Hispanic white | 460 (50%) | Non-Hispanic black | 148 (16%) | Hispanic | 150 (16%) | Other or unknown | 128 (14%) | Data missing | 42 (5%) |
| Region of patient residence‡ | US-Northeast | 375 (40%) | US-Midwest | 203 (22%) | US-South | 117 (13%) | US-West | 116 (13%) | Canada | 49 (5%) | Spain | 68 (7%) |
| Smoking status† | Never smoked | 469 (51%) | Former smoker | 326 (35%) | Current smoker | 43 (5%) | Unknown | 57 (6%) | Data missing | 33 (4%) |
| Obesity status† | Not specified | 720 (78%) | Obese | 172 (19%) | Data missing | 36 (4%) |
| Number of comorbidities† | 0 | 132 (14%) | 1 | 202 (22%) | 2 | 231 (25%) | 3 | 117 (13%) | ≥4 | 192 (21%) | Unknown | 23 (2%) | Data missing | 31 (3%) |
| Type of malignancy§ | Solid tumours | 758 (82%) | Breast | 191 (21%) | Prostate | 152 (16%) | Gastrointestinal | 108 (12%) | Thoracic | 91 (10%) | Gynaecological | 49 (5%) | Renal cell carcinoma | 45 (5%) | Endocrine | 39 (4%) | Melanoma | 38 (4%) |

(Continued from previous column)

| Cancer status† | Remission or no evidence of disease | 422 (45%) | Present, stable, or responding to treatment | 294 (32%) | Present, progressive disease | 102 (11%) | Unknown | 59 (6%) | Data missing | 51 (5%) |
| ECOG performance status† | 0 or 1 | 614 (66%) | 2 | 72 (8%) | 3 or 4 | 46 (5%) | Unknown | 167 (18%) | Data missing | 23 (3%) |
| Type of anticancer therapy§ | None in the 4 weeks before COVID-19 diagnosis | 553 (60%) | Non-cytotoxic therapy | 206 (22%) | Targeted therapy | 75 (8%) | Endocrine | 85 (9%) | Immunotherapy¶ | 38 (4%) | Radiotherapy | 12 (1%) | Surgery|| | 2 (1%) | Cytotoxic systemic therapy | 160 (17%) | Unknown | 9 (1%) |
| Recent surgery† | None in the 4 weeks before COVID-19 diagnosis | 811 (87%) | Yes|| | 32 (3%) | Unknown | 42 (5%) | Data missing | 43 (5%) |
with active cancer, 294 (74%) had stable or responding disease, and 102 (26%) had progressive disease at the time of COVID-19 diagnosis. 366 (39%) patients had received anticancer therapy within 4 weeks of COVID-19 diagnosis, of whom, 160 (44%) were receiving cytotoxic therapy and 206 (56%) were receiving other anticancer therapies. The four most common presenting symptoms of COVID-19 were fever (590 [64%]), cough (563 [61%]), fatigue or malaise (396 [43%]), and dyspnoea (382 [41%]; appendix p 11). 40 (4%) patients were reported as asymptomatic. 89 (10%) patients were given hydroxychloroquine alone, and 181 (20%) were given a combination of these drugs. Notably, only two (<1%) patients were reported to have been given these drugs within the context of a clinical trial.

As of May 7, 2020, 121 (13%) patients had died, all within 30 days of COVID-19 diagnosis (table 2). None of the potential prognostic variables had a missingness rate of more than 10% and all were therefore included in the multivariable models. Associations between prognostic variables and 30-day all-cause mortality are shown in table 3. Goodness of fit was similar across the fitted variables and 30-day all-cause mortality are shown in multivariable models. Associations between prognostic variables and 30-day all-cause mortality are shown in table 3. Goodness of fit was similar across the fitted models, with an average C-statistic value of 0·75 (95% CI 0·69–0·80; appendix p 25). None of the variance inflation factors except for comorbidity was greater than five (appendix p 25), indicating that significant multicollinearity was not present in the models, with this exception. Multiple clinically relevant prognostic variables associated with increased 30-day all-cause mortality were identified, after partial adjustment in our multivariable model: increasing age, male sex, smoking status (former smoker vs never smoked), cancer status (present, stable, or responding, and present, progressive disease vs remission or no evidence of disease), ECOG performance status (2 vs 0 or 1; 3 or 4 vs 0 or 1); and treatment with hydroxychloroquine plus azithromycin versus treatment with neither (table 3). Two, three, and four or more comorbidities requiring treatment were also associated with increased mortality, although the 95% CIs were

### Table 1: Patient demographic, clinical, and tumour characteristics

| Variable                        | Died | Met composite endpoint | Admitted to an ICU | Required mechanical ventilation |
|---------------------------------|------|------------------------|--------------------|---------------------------------|
| **Region of patient residence** |      |                        |                    |                                 |
| US-Northeast (n=375)            | 55 (15%) | 107 (29%) | 56 (15%) | 54 (14%) |
| US-Midwest (n=203)              | 19 (9%) | 55 (27%) | 38 (19%) | 32 (16%) |
| US-South (n=117)                | 15 (13%) | 30 (26%) | 19 (16%) | 17 (15%) |
| US-West (n=116)                 | 19 (16%) | 27 (23%) | 14 (12%) | 9 (8%) |
| Canada (n=49)                   | 3 (6%) | 11 (22%) | 5 (10%) | 4 (8%) |
| Spain (n=68)                    | 10 (15%) | 12 (18%) | 0 | 0 |
| **Smoking status**              |      |                        |                    |                                 |
| Never smoked (n=469)            | 44 (9%) | 99 (21%) | 54 (12%) | 48 (10%) |
| Former smoker (n=126)           | 64 (20%) | 116 (36%) | 64 (20%) | 55 (17%) |
| Current smoker (n=43)           | 5 (12%) | 8 (19%) | 4 (9%) | 4 (9%) |
| Unknown (n=57)                  | 6 (13%) | 15 (26%) | 9 (16%) | 8 (14%) |
| Data missing (n=33)             | 2 (6%) | 4 (12%) | 1 (3%) | 1 (3%) |
| **Obesity status**              |      |                        |                    |                                 |
| Not specified (n=720)           | 98 (14%) | 190 (26%) | 95 (12%) | 83 (12%) |
| Obese (n=172)                   | 20 (12%) | 49 (28%) | 36 (21%) | 32 (19%) |
| Data missing (n=36)             | 3 (8%) | 3 (8%) | 1 (3%) | 1 (3%) |
| **Number of comorbidities**     |      |                        |                    |                                 |
| 0 (n=132)                       | 3 (2%) | 12 (9%) | 6 (5%) | 4 (3%) |
| 1 (n=202)                       | 13 (6%) | 31 (15%) | 18 (9%) | 13 (6%) |
| 2 (n=231)                       | 41 (18%) | 79 (34%) | 42 (18%) | 39 (17%) |
| 3 (n=117)                       | 24 (21%) | 37 (32%) | 20 (17%) | 18 (15%) |
| ≥4 (n=132)                      | 31 (16%) | 71 (37%) | 41 (21%) | 35 (18%) |
| Unknown (n=23)                  | 5 (22%) | 8 (35%) | 4 (17%) | 5 (22%) |
| Data missing (n=31)             | 4 (13%) | 4 (13%) | 1 (3%) | 2 (6%) |
| **Type of malignancy**          |      |                        |                    |                                 |
| Solid tumour (n=654)            | 76 (12%) | 151 (23%) | 78 (12%) | 70 (11%) |
| Haematological malignancy (n=167) | 24 (14%) | 58 (35%) | 37 (22%) | 28 (17%) |

### Table 2: Analysable population (n=928)

| Variable                        | Died | Met composite endpoint | Admitted to an ICU | Required mechanical ventilation |
|---------------------------------|------|------------------------|--------------------|---------------------------------|
| **Treatment of COVID-19**†**     |      |                        |                    |                                 |
| Hydroxychloroquine alone        | 89 (10%) |                    |                   |                                 |
| Azithromycin alone              | 93 (10%) |                    |                   |                                 |
| Azithromycin plus hydroxychloroquine | 181 (20%) |                    |                   |                                 |
| Neither                         | 486 (52%) |                    |                   |                                 |
| Unknown                         | 22 (2%) |                        |                    |                                 |
| Data missing                    | 57 (6%) |                        |                    |                                 |

Data are n (%), median (IQR), or range. Due to rounding, not all variables might add up to 100%. ECOG=Eastern Cooperative Oncology Group. *Age ≥90 years transformed into exact age of 90 years for reporting purposes. †These questions were optional in the survey, such that a proportion of results are missing. EUS regions are census tract defined. ‡Includes checkpoint inhibitors, allelogeneic haemopoietic stem-cell transplant, and adaptive cellular therapy. ***Cancer surgeries are separated in the table for descriptive purposes but are combined with any recent surgery in the prognostic modelling. **Some patients were already taking these medications at the time of presentation: hydroxychloroquine (n=12 [1%]), azithromycin (n=26 [3%]), or both (n=23 [2%]).
Table 2: Primary and secondary outcomes by potential prognostic variables

| Died | Met composite endpoint | Admitted to an ICU | Required mechanical ventilation |
|------|------------------------|--------------------|-------------------------------|
| **Cancer status** | | | |
| Remission or no evidence of disease (n=422) | 39 (9%) | 95 (23%) | 63 (15%) | 55 (13%) |
| Present, stable, or responding to treatment (n=294) | 41 (14%) | 80 (27%) | 40 (14%) | 38 (13%) |
| Present, progressive disease (n=102) | 25 (25%) | 36 (35%) | 12 (12%) | 11 (11%) |
| Unknown (n=59) | 11 (19%) | 23 (39%) | 14 (24%) | 11 (19%) |
| Data missing (n=51) | 5 (10%) | 8 (16%) | 3 (6%) | 1 (2%) |
| **ECOG performance status** | | | |
| 0 or 1 (n=614) | 54 (9%) | 135 (22%) | 81 (13%) | 81 (13%) |
| 2 (n=72) | 23 (32%) | 31 (43%) | 16 (22%) | 8 (11%) |
| 3 or 4 (n=46) | 19 (41%) | 22 (48%) | 6 (13%) | 5 (11%) |
| Unknown (n=167) | 22 (13%) | 51 (31%) | 28 (17%) | 21 (13%) |
| Data missing (n=29) | 3 (10%) | 3 (10%) | 1 (3%) | 1 (3%) |
| **Type of anticancer therapy** | | | |
| None in the 4 weeks before COVID-19 diagnosis (n=553) | 75 (14%) | 156 (28%) | 91 (16%) | 79 (14%) |
| Non-cytotoxic therapy (n=206) | 23 (11%) | 50 (24%) | 24 (12%) | 24 (12%) |
| Cytotoxic systemic therapy (n=160) | 22 (14%) | 35 (22%) | 17 (11%) | 12 (8%) |
| Unknown (n=9) | 1 (11%) | 1 (11%) | 0 | 1 (11%) |
| **Recent surgery** | | | |
| None in the 4 weeks before COVID-19 diagnosis (n=811) | 108 (13%) | 212 (26%) | 118 (15%) | 104 (13%) |
| Yes (n=12) | 6 (19%) | 12 (38%) | 6 (19%) | 7 (22%) |
| Unknown (n=42) | 4 (10%) | 14 (33%) | 6 (14%) | 3 (7%) |
| Data missing (n=43) | 3 (7%) | 4 (9%) | 2 (5%) | 2 (5%) |
| **Treatment of COVID-19** | | | |
| Hydroxychloroquine alone (n=59) | 11 (12%) | 32 (36%) | 18 (20%) | 14 (16%) |
| Azithromycin alone (n=93) | 12 (13%) | 26 (28%) | 15 (16%) | 14 (15%) |
| Azithromycin plus hydroxychloroquine (n=181) | 45 (25%) | 86 (48%) | 53 (29%) | 51 (28%) |
| Neither (n=486) | 41 (8%) | 80 (16%) | 39 (8%) | 29 (6%) |
| Unknown (n=22) | 7 (32%) | 8 (36%) | 2 (9%) | 4 (18%) |
| Data missing (n=57) | 5 (9%) | 10 (18%) | 5 (9%) | 4 (7%) |

Data are in %. Due to rounding, not all variables might add up to 100%. The composite endpoint was a combination of death, severe illness requiring admission to hospital, admission to an ICU, or mechanical ventilation. ECOG=Eastern Cooperative Oncology Group. ICU=intensive care unit. *Data not shown for one patient, with sex not specified. †US regions are census-tract defined. ‡Any patient with two or more cancers reported, which could be solid, haematological, or both.

very wide due to a small number of events in the reference group (no comorbidities). Residence in Canada or the US-Midwest was associated with decreased mortality compared with residence in the US-Northeast. Race and ethnicity, obesity, type of malignancy, type and recency of anticancer therapy, and recent surgery were not associated with 30-day all-cause mortality in the partially adjusted analysis. A forest plot of the potential prognostic variables is shown in figure 1. Results of the elastic net regularised logistic regression analysis are similar to those of the primary analysis; however, the association between present and stable or responding disease and mortality was no longer significant (appendix p 26).

242 (26%) patients met the composite severe illness endpoint; 132 (14%) patients were admitted to the ICU; and 116 (12%) required mechanical ventilation (table 2). 52 (39%) of 132 patients who were in the ICU at baseline had 30-day follow-up data available. During follow-up, 16 (31%) of 52 died, 13 (25%) were still in the ICU, and 19 (37%) had recovered. Notably, 71 (59%) of 121 patients who died were never admitted to the ICU; a comparison between patients who died with and without ICU admission is in the appendix (p 27). A numerically higher rate of death outside the ICU was seen in patients with present cancer, with the reverse pattern seen for those in remission. Furthermore, we saw a numerically higher rate of death outside the ICU for patients receiving palliative care, and the reverse pattern for those receiving care with a curative intent. 43 (61%) of 70 patients who died aged 75 and older died without ICU admission, compared with 27 (39%) who died with ICU admission. 466 (50%) required admission to hospital, of whom 175 (38%) were actively receiving anticancer therapy. Admissions to hospital differed by geographical region, from 37 (32%) of 116 patients in the US-West region to 34 (69%) of 49 patients in Canada. 405 (44%) patients required supplemental oxygen (appendix pp 28–29).

The crude mortality for patients who met the secondary outcomes was 106 (23%) of 466 for any admission to hospital, 110 (27%) of 405 for any supplemental oxygen needed, 50 (38%) of 132 for admission to ICU, 50 (43%) of 116 for requiring mechanical ventilation, and 121 (50%) of 242 for the composite secondary endpoint. Incidence of secondary outcomes by cancer type, cancer status, and anticancer therapy type-defined subgroups are shown in figure 2 and in the appendix (p 12). ICU admission rates were highest in former smokers and in those with obesity, four or more comorbidities, haematological malignancies, unknown cancer status, and an ECOG performance status of 2. Rates of mechanical ventilation were highest in those with unknown comorbidity status and in those with recent surgery.

From our post-hoc analysis of the severe illness composite outcome we found that increasing age, other or unknown race or ethnicity, number of comorbidities (two and four or more), haematological malignancy, progressing cancer or unknown cancer status, ECOG performance status of 2 or higher, or treatment with azithromycin, hydroxychloroquine, and both in combination were associated with an increased rate of the composite outcome (appendix pp 13, 30–31). Based on the post-hoc power analysis of the recent surgery and anticancer treatment variables, the effect sizes are reasonable and clinically meaningful (appendix p 9).
Discussion

The CCC19 began as a grassroots effort to fill an unmet need generated by the SARS-CoV-2 pandemic. Through social media and other communication networks, over 100 institutions have been mobilised to capture widely available data regarding outcomes of COVID-19 in patients with cancer. The initial mission of the consortium was data capture to better understand strategies to mitigate risk for patients with cancer. This first analysis of the CCC19 database focuses on important and previously recognised prognostic factors and potential anticancer treatments. Several important hypotheses have emerged from this initial analysis. First, patients with cancer appear to be at increased risk of mortality and severe illness due to SARS-CoV-2 infection, regardless of whether they have active cancer, are on anticancer treatment, or both. Most members of our cohort had symptoms compatible with a diagnosis of COVID-19.

### Table 3: Bivariable and multivariable regression models of potential prognostic variables associated with 30-day all-cause mortality

| Variable                                      | Bivariable odds ratio | Multivariable odds ratio* |
|-----------------------------------------------|-----------------------|--------------------------|
| Age, per 10 years†                           | 1·88 (1·58–2·24)     | 1·84 (1·53–2·21)         |
| Sex                                           |                       |                          |
| Female                                        | 1 (ref)               | 1 (ref)                  |
| Male                                          | 1·94 (1·30–2·88)     | 1·63 (1·07–2·48)         |
| Race and ethnicity                            |                       |                          |
| Non-Hispanic white                            | 1 (ref)               | 1 (ref)                  |
| Non-Hispanic black                            | 0·85 (0·50–1·45)     | 1·11 (0·63–1·97)         |
| Hispanic                                      | 0·65 (0·36–1·17)     | 1·00 (0·54–1·86)         |
| Other or unknown                              | 0·57 (0·30–1·09)     | 0·55 (0·28–1·08)         |
| Smoking status                                |                       |                          |
| Never smoked                                  | 1 (ref)               | 1 (ref)                  |
| Former smoker                                 | 2·35 (1·55–3·55)     | 1·60 (1·03–2·47)         |
| Current smoker                                | 1·27 (0·47–3·39)     | 1·34 (0·49–3·67)         |
| Unknown                                       | 1·14 (0·46–2·79)     | 0·89 (0·34–2·27)         |
| Obesity status                                |                       |                          |
| Not specified                                 | 1 (ref)               | 1 (ref)                  |
| Obese                                         | 0·84 (0·50–1·41)     | 0·99 (0·58–1·71)         |
| Number of comorbidities                       |                       |                          |
| 0                                             | 1 (ref)5              | 1 (ref)§                 |
| 1                                             | 3·12 (0·87–11·19)    | 1·87 (0·51–6·85)         |
| 2                                             | 9·52 (2·89–31·40)    | 4·50 (1·33–15·28)        |
| 3                                             | 11·54 (3·17–39·53)   | 5·04 (1·42–17·93)        |
| ≥4                                            | 8·77 (2·62–29·29)    | 3·55 (1·03–12·30)        |
| Unknown                                       | 12·33 (2·71–56·01)   | 6·77 (1·42–21·32)        |
| Type of malignancy                            |                       |                          |
| Solid tumour                                  | 1 (ref)               | 1 (ref)                  |
| Haematological malignancy                     | 1·28 (0·78–2·09)     | 1·40 (0·83–2·37)         |
| Multiple cancers                              | 1·86 (1·09–3·17)     | 1·34 (0·77–2·34)         |
| Cancer status                                 |                       |                          |
| Remission or no evidence of disease           | 1 (ref)               | 1 (ref)                  |
| Present, stable, or responding to treatment  | 1·57 (0·98–2·49)     | 1·79 (1·09–2·95)         |
| Present, progressive disease                  | 3·07 (1·77–5·33)     | 5·20 (2·77–9·77)         |
| Other or unknown                              | 2·24 (1·06–4·71)     | 2·71 (1·21–6·09)         |

(Continued from previous column)

| Variable                                      | Bivariable odds ratio | Multivariable odds ratio* |
|-----------------------------------------------|-----------------------|--------------------------|
| Recent surgery¶                                |                       |                          |
| None in the 4 weeks before COVID-19 diagnosis | 1 (ref)               | 1 (ref)                  |
| Yes                                           | 1·50 (0·60–3·74)     | 1·52 (0·58–3·96)         |
| Unknown                                       | 0·66 (0·23–1·89)     | 0·78 (0·26–2·33)         |
| Treatment of COVID-19                         |                       |                          |
| Hydroxychloroquine alone                      | 1·43 (0·71–2·90)     | 1·06 (0·51–2·20)         |
| Azithromycin alone                            | 1·56 (0·79–3·06)     | 1·30 (0·65–2·64)         |
| Azithromycin plus hydroxychloroquine          | 3·42 (2·14–5·45)     | 2·93 (1·79–4·79)         |
| Neither                                       | 1 (ref)               | 1 (ref)                  |
| Unknown                                       | 4·82 (1·84–12·60)    | 3·97 (1·41–11·19)        |

Data are odds ratio with 95% CI in parentheses. ECOG = Eastern Cooperative Oncology Group. *Age is adjusted for sex, smoking status, and obesity, sex is adjusted for age, smoking status, and obesity; smoking status is adjusted for age, sex, and obesity; obesity is adjusted for age, sex, and smoking status; and all other variables are adjusted for age, sex, smoking status, and obesity. †Age ≥90 years transformed into exact age of 90 years for modelling purposes; odds ratios are per 10-year age increment. US regions are census-tract defined. ¶Precision of estimation for this category is poor due to small number of events in the reference group. §§Includes any surgery, including cancer-specific surgeries, done within 4 weeks of COVID-19 diagnosis.
New York City region (NY, USA) have reported specifically on outcomes in patients with cancer. An aggregate-level analysis of 334 patients with cancer from the Mount Sinai Health System reported an 11% rate of death and 11% rate of intubation. A series of 218 patients with cancer from the Montefiore Health system reported a case fatality rate of 28%, although the authors acknowledged a bias towards more severe cases. Taken together with our cohort from multiple institutions, these findings have important policy implications including, but not limited to, the need for increased surveillance and testing for SARS-CoV-2, minimising health-care system exposure, and reconsideration of procedures and treatments in patients with cancer. Notably, health-care systems are screening asymptomatic individuals before many cancer treatments, and we anticipate that as the CCC19 cohort grows, separate analysis of asymptomatic individuals who have been screened will be necessary.

Important subgroups of patients with cancer appear to be at increased risk for adverse outcomes. In addition to the previously reported risk factors of age and sex in the general COVID-19 population, ECOG performance status of 2 or higher and active cancer seem to be associated with an increased risk of worse outcomes from COVID-19 in patients with cancer. Although moderate or poor ECOG performance status is well known to have a deleterious effect on overall outcomes, an ECOG performance status of 2 is not always considered a contraindication to aggressive therapy for active cancer. Our study highlights the potentially additive negative effect of COVID-19 in this susceptible population. Some potential implications of this finding include acceleration of advanced care planning and patient and family discussions on restricting aggressive interventions, such as mechanical ventilation.

The American Society of Clinical Oncology has issued guidance on ethical considerations pertaining to resource-limited situations during the SARS-CoV-2 pandemic. Although an ECOG performance status of 2 was relatively uncommon in this cohort, the presence of active (measurable) cancer was common. From our analysis, active cancer might be a risk factor associated with worse COVID-19 outcomes, especially in patients who have progressive disease. In our cohort, patients with progressive cancer died at a numerically higher rate without ICU admission than among those who were admitted to an ICU, and the reverse pattern was seen for patients in remission. This finding, and the numerically higher rate of deaths without ICU admission in patients aged 75 years and older and those receiving treatment with palliative intent, suggests that aggressive interventions might have already been reduced in these subpopulations. And similarly to patients with moderate or poor ECOG performance status, careful conversations about the risks and benefits of continuing anticancer therapy will urgently be required in these subpopulations. Conversely, the absence of an association between 30-day all-cause mortality and recent surgery, recent non-cytotoxic therapy,

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**Figure 1:** Forest plot of factors associated with 30-day all-cause mortality
Data are partially adjusted odds ratios, with 95% CIs. ECOG=Eastern Cooperative Oncology Group. *Adjusted for sex, smoking status, and obesity. †Adjusted for age, sex, smoking status, and obesity. ‡Adjusted for age, sex, and smoking status.
or recent cytotoxic systemic therapy suggests that curative surgical resections, adjuvant chemotherapy, and maintenance chemotherapy could continue during the SARS-CoV-2 pandemic with extreme caution, although this finding should not be interpreted as a recommendation. Some of the observations reported here potentially have a biological basis—eg, smoking in particular has previously been implicated in inflammatory lung disease and SARS-CoV-2 biology.20–23 Former smoking was associated with increased mortality in the baseline analysis and in the elastic net regression; no conclusions can be drawn about current smoking due to the small number of events. Human and animal models suggest that the alveolar epithelial cells in the lungs of smokers might have increased angiotensin-converting enzyme 2 (ACE2) expression, which might increase mucus-secreting goblet cells.24 Although the potential systemic dysregulation of ACE2 is not yet fully understood, downregulation caused by SARS-CoV-2 viral binding to this receptor could lead to increased angiotensin II, which can cause acute lung injury and other systemic effects.25 SARS-CoV-2 is similar to other coronaviruses, including the severe acute respiratory syndrome (SARS) CoV that led to the SARS outbreak in 2003.26 Cell entry of both of these viruses appears to rely on protein binding to ACE receptors on host cells, with an additional required proteolytic step to allow fusion of the viral and cellular membranes. This proteolytic step is dependent on transmembrane serine protease 2 (TMPRSS2).27 TMPRSS2 expression is regulated by the androgen receptor in the prostate.28,29 Androgens have been hypothesised to also regulate TMPRSS2 expression in lung tissue, potentially explaining the increased mortality in male patients from COVID-19 seen consistently across national health departments to varying degrees.30 Further analysis is needed of the observed association between male sex and 30-day all-cause mortality, which might be driven by biological differences between the sexes versus differences in high risk jobs, professional exposure, or other factors.31 Notably, we did not find any association between recent surgery and 30-day all-cause mortality, as previously described in a smaller case series.2 Given that delays in elective cancer surgeries might lead to deleterious outcomes, this finding should be taken into consideration if policies to delay treatments are being implemented, while acknowledging that many other factors exist that should be considered, such as surge capacity and provider availability.32,33 As the CCC19 cohort increases and matures,
additional factors can be examined in greater detail, such as myelosuppression associated with cytotoxic chemotherapy, immune activation associated with immunotherapy, and risks specific to some cancer diagnoses and regimens.

Our study has some limitations, such that some observations should be interpreted with caution. Some notable regional variations in the primary and secondary outcomes exist. The Spanish subgroup had no ICU admissions and no patients put on mechanical ventilation, but had ten deaths. The Canadian subgroup had the highest proportion of patients admitted to hospital, yet had the numerically lowest rate of deaths of any of the regional subgroups. These findings, including the reduced risk of 30-day all-cause mortality associated with residence in Canada and the US-Midwest probably reflect regional differences in the response to COVID-19, and different timelines of the local pandemic, and deserve further study. Higher numbers of comorbidities were significantly associated with increased mortality; however, the number of events in the reference group was very low (three deaths). This variable also had a high inflation factor, indicating significant collinearity with other variables in the model. A cancer status of unknown was also associated with increased mortality, intermediate between the groups of present, stable, or responding, and present, progressive disease. These patients are likely to be a distinct subgroup—eg, having scans with mixed or equivocal findings or having recently started a new anticancer therapy without re-assessment.

A strong association with 30-day all-cause mortality was observed in the subgroup treated with the combination of azithromycin plus hydroxychloroquine; this same effect was not seen in the subgroups treated with either drug alone. This combination was commonly used in patients who met the composite endpoint, possibly on the basis of these medications in a prospective randomised study. The importance of establishing the aggregated risks and benefits of these medications in a prospective randomised study before widespread application.36 The Lancet Oncology, New England Journal of Medicine, The Lancet Oncology, and Heron Therapeutics; consulting or advisory roles for AstraZeneca, Alexion, Sanofi/Aventis, Bayer, Bristol-Myers Squibb/ER Squibb and sons, Cerulean, Eisai, Foundation Medicine, Exelixis, Ipsen, Merck, Novartis, Peloton, Pfizer, Prometheus Labs, Corvus, Calithera, Analysis Group, Sanofi/Aventis, and Takeda outside of the submitted work; honoraria from AstraZeneca, Alimta, Sanofi/Aventis, Bayer, Bristol-Myers Squibb/ER Squibb and sons, Cerulean, Eyel, Foundation Medicine, Exelixis, Ipsen, Merck, Novartis, Peloton, Pfizer, EMD Serono, Prometheus Labs, Corvus, Ipsen, Up-to-Date, National Comprehensive Cancer Network (NCCN), Analysis Group, MH Life Sciences (a healthcare communications company with several brands such as OncLive, PeerView and Physicians’ Education Resource), Research to Practice, L-path, Kidney Cancer Journal, Clinical Care Options, Platform Q, Navinata Healthcare, Harborside Press, American Society of Medical Oncology, New England Journal of Medicine, The Lancet Oncology, and Heron Therapeutics; consulting or advisory roles for AstraZeneca, Alexion, Sanofi/Aventis, Bayer, Bristol-Myers Squibb/ER Squibb and sons, Cerulean, Eisai, Foundation Medicine, Exelixis, Genentech, Heron Therapeutics, Eli Lilly, Roche, GlaxoSmithKline, Merck, Novartis, Peloton, Pfizer, EMD Serono, Prometheus Labs, Corvus, Ipsen, Up-to-Date, NCCN, Analysis Group, Pionyr, Tempest, and Lilly Ventures; owns stocks in Pionyr and Tempest; has leadership roles as Director of GU Oncology Division at Dana-Farber, was past President of medical staff at Dana-Farber Cancer Institute, is a member of NCCN Kidney panel and the GU Steering Committee, past chairman of the Kidney Cancer Association Medical and Scientific Steering Committee and KidneyCan Advisory board, and is Kidney cancer Research Summit co-chair (2019–present); and has patents, royalties, and other intellectual properties...
in International Patent Application number PCT/US2018/12209, entitled “PBRM1 Biomarkers Predictive of Anti-Immune Checkpoint Response,” filed Jan 3, 2018 (claiming priority to US Provisional Patent Application No 62/445,094, filed Jan 11, 2017) and International Patent Application Number PCT/US2018/058410, entitled “Biomarkers of Clinical Response and Benefit to Immune Checkpoint Inhibitor Therapy,” filed Oct 31, 2018 (claiming priority to US Provisional Patent Application No 62/145,175, filed Nov 1, 2017). TCK (Director of Clinical Oncology [Dual fees from Bristol-Myers Squibb] might have received additional independent funding of drug companies or royalties potentially involved in research around the subject matter of this Article. TCK has mentored several non-US citizens on research projects with potential funding (in part) from non-US sources or foreign components. 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Data sharing
Aggregate de-identified patient data with site identifiers removed and geographical region of patient residence masked to a level no smaller than US Census Divisions will be made publicly available for any purpose beginning 6 months and ending a minimum of 36 months after publication of this Article through the CCC19 website. Individual de-identified patient data with site identifiers removed and geographical region of patient residence masked to a level no smaller than US Census Divisions will be made available to researchers who provide a methodologically sound proposal, whose proposed use of the data has
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been approved by an independent review committee identified for this purpose. Proposals can be submitted beginning 6 months and up to 36 months after publication of this Article. Proposals should be directed to sanjay.mishra.1@vumc.org; to gain access, data requestors will need to sign a data access agreement.

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References

1. WHO. WHO Director-General's opening remarks at the media briefing on COVID-19 - 11 March 2020. Geneva: World Health Organization, March 11, 2020. https://www.who.int/dg/speeches/detail/who-director-general-s-opening-remarks-at-the-media-briefing-on-covid-19--11-march-2020 (accessed April 20, 2020).
2. Liang W, Guan W, Chen R, et al. Coronavirus disease 2019 in China: the epidemiology of an emerging infection. Lancet 2020; 8: 36–41.
3. Dai M, Liu D, Liu M, et al. Patients with cancer appear more vulnerable to SARS-CoV-2: a multicenter study during the COVID-19 outbreak. Cancer Discov 2020; published online April 28. DOI:10.1158/2159–8290.CD-20–0451.
4. Miyashita H, Mikami T, Chopra N, et al. Do patients with cancer have a poorer prognosis of COVID-19? An experience in New York City. Ann Oncol 2020; published online April 21. DOI:10.1016/j.annonc.2020.04.006.
5. Blimark C, Holmberg E, Mellqvist U-H, et al. Multiple myeloma and infections: a population-based study on 9253 multiple myeloma patients. Haematologica 2015; 100: 107–13.
6. CDC. COVID-19 Response Team. Severe outcomes among patients with coronavirus disease 2019 (COVID-19) - United States, February 12-March 16, 2020. MMWR Morb Mortal Wkly Rep 2020; 69: 343–46.
7. Desai A, Warner J, Kuderer N, et al. Crowdsourcing a crisis response for COVID-19 in oncology. Nat Cancer 2020; published online April 21. DOI:10.1038/s41388–020–0605-z.
8. Harris PA, Taylor R, Thielke R, Payne J, Gonzalez N, Conde JG. Research electronic data capture (REDCap)—a metadata-driven methodology and workflow process for providing translational research informatics support. J Biomed Inform 2009; 42: 377–81.
9. DeLong ER, DeLong DM, Clarke-Pearson DL. Comparing the areas under two or more correlated receiver operating characteristic curves: a nonparametric approach. Biometrics 1988; 44: 837–45.
10. Harrell FE Jr, Lee KL, Mark DB. Multivariable prognostic models: issues in developing models, evaluating assumptions and adequacy, and measuring and reducing errors. Stat Med 1996; 15: 361–87.
11. Zou H, Hastie T. Regularization and variable selection via the elastic net. J R Statistic Soc B 2005; 67: 301–20.
12. Guan WJ, Ni ZY, Hu Y, et al. Clinical characteristics of coronavirus disease 2019 in China. N Engl J Med 2020; 382: 1708–20.
13. Mehta V, Goel S, Kaharzii R, et al. Case fatality rate of cancer patients with COVID-19 in a New York hospital system. Cancer Discov 2020; published online May 1. DOI:10.1158/2159–8290.CD–02–0516.
14. Wang D, Hu B, Hu C, et al. Clinical characteristics of 138 hospitalized patients with 2019 novel coronavirus–infected pneumonia in Wuhan, China. JAMA 2020; 323: 1061–69.
15. Richardson S, Hirsch JS, Narasimhan M, et al. Presenting characteristics, comorbidities, and outcomes among 5700 patients hospitalized with COVID-19 in the New York City area. JAMA 2020; published online April 22. DOI:10.1001/jama.2020.6775.