Arterial oxygen saturation and hypoxemia in hemodialysis patients with COVID-19

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ABSTRACT

Background. Maintenance hemodialysis (MHD) patients are particularly vulnerable to COVID-19, a viral disease that may cause interstitial pneumonia, impaired alveolar gas exchange, and hypoxemia. We ascertained the time course of intradialytic arterial oxygen saturation (SaO₂) in MHD patients between 4 weeks pre- and the week post-diagnosis of COVID-19.

Methods. We conducted a quality improvement project in confirmed COVID-19 in-center MHD patients from 11 dialysis facilities. In patients with an arterio-venous access SaO₂ was measured 1x/minute during dialysis using the Crit-Line monitor (Fresenius Medical Care, Waltham, MA). We extracted demographic, clinical, treatment, and laboratory data and COVID-19 related symptoms from the patients’ electronic health records.

Results. Intradialytic SaO₂ was available in 52 patients (29 males; age 66.5±15.7 years) contributing 338 hemodialysis treatments. Mean time between onset of symptoms indicative of COVID-19 and diagnosis was 1.1 days (median 0; range 0 to 9). Prior to COVID-19 diagnosis the rate of hemodialysis treatments with hypoxemia, defined as treatment-level average SaO₂ < 90%, increased from 2.8% (2 to 4 weeks pre-diagnosis) to 12.2% (1 week) and 20.7% (3 days pre-diagnosis). Intradialytic oxygen supplementation increased sharply post-diagnosis. Eleven patients died from COVID-19 within 5 weeks. Compared to patients who recovered from COVID-19, demised patients showed a more pronounced decline in SaO₂ prior to COVID-19 diagnosis.

Conclusion. In hemodialysis patients, hypoxemia may precede the onset of clinical symptoms and the diagnosis of COVID-19. A steep decline of SaO₂ is associated with poor patient outcomes. Measurements of SaO₂ may aid the pre-symptomatic identification of patients with COVID-19.

Keywords: chronic kidney disease, COVID-19, hemodialysis, hypoxemia, oxygen saturation
INTRODUCTION
The clinical spectrum of COVID-19 varies from asymptomatic to life-threatening, with respiratory and multiorgan failure [1-6]. Older age and comorbidities, including chronic kidney disease and dialysis, are risk factors for adverse outcomes [4, 7].

COVID-19 may cause interstitial pneumonia and impaired gas exchange. Measurement of arterial oxygen saturation (\( \text{SaO}_2 \)) provides an easy-to-use, non-invasive means to assess blood oxygenation. Hypoxemia, conventionally defined as an \( \text{SaO}_2 \) below 90%, is a harbinger of clinical instability and progressive hypoxemia is associated with poor outcomes in patients with pulmonary diseases [8]. \( \text{SaO}_2 \) is used to evaluate the severity of the COVID-19, although not widely applied [5, 9]. In the general population, previous studies reported a \( \text{SaO}_2 <90\% \) in around 40% of the COVID-19 patients at the time of hospital admission [9, 10]. A retrospective study in 36 hospitalized MHD patients with COVID-19 reported a \( \text{SaO}_2 <95\% \) in 61% of the patients; a report of 23 hospitalized MHD patients with COVID-19 indicated a hypoxemia rate of 16% [11, 12]. However, these studies were focused on hospitalized MHD patients, data is limited on non-hospitalized in-center MHD patients.

In MHD patients with arterio-venous vascular access, the Crit-Line Monitor affords the opportunity to quasi-continuously measure \( \text{SaO}_2 \) during hemodialysis. The goal of our analysis was to interrogate routinely collected intradialytic \( \text{SaO}_2 \) data to ascertain the frequency and degree of hypoxemia in COVID-19 MHD patients before and after diagnosis.
MATERIALS AND METHODS

Population

In this quality improvement project, we focus on MHD patients with confirmed COVID-19 dialyzed in 11 U.S. facilities (seven from the Renal Research Institute, RRI; four from Fresenius Kidney Care, FKC). We report observations between February 1st and April 30th, 2020. In these clinics, the Crit-Line monitor (CLM; Fresenius Medical Care, Waltham, MA, USA) is used as standard of care. Only patients with arterio-venous access and eligible SaO\textsubscript{2} measurements (definition see below) were included in our analysis. We extracted demographic, clinical, treatment-related, and laboratory data and COVID-19 related signs and symptoms from the patients' electronic health records (EHR). The use of supplemental oxygen during diaysis was documented in the EHR. We defined “silent” hypoxemia as the presence of SaO\textsubscript{2} < 90% without administration of supplemental oxygen. This quiality improvement protocol was approved by corresponding committees and leagal and compliance officers. Informed consent was waived.

Screening for and diagnosis of COVID-19

Since March 12\textsuperscript{th}, 2020 all in-center MHD patients and clinic staff underwent a systematic screening process prior to admittance to their clinics. They were required to wear gloves and surgical masks while being in the dialysis facility. A trained healthcare worker asked standardized questions regarding recent travel, contact with COVID-19 patients, fever, and respiratory symptoms. Body temperature was measured (threshold for a positive test was 37.4 °C), the entrance screening results were documented. Patients screened negative were admitted to the dialysis facility, where they had again their body temperature measured. Nasopharyngeal or oropharyngeal swabs for RT-PCR testing were obtained in patients who presented with any signs and symptoms indicative of COVID-19 or reported a recent exposure to a person with COVID-19.
The clinics followed the U.S. Center of Disease Control and Prevention (CDC) recommendations for the diagnosis of SARS-CoV-2 (https://www.cdc.gov/coronavirus/2019-ncov/hcp/dialysis/screening.html).

**Measurement of arterial oxygen saturation**

The CLM is approved by the U.S. Food and Drug Administration for the measurement of hematocrit and oxygen saturation in the extracorporeal circuit. The CLM reports hematocrit and oxygen saturation 1x / minute (an example is shown in Supplemental Figure 1). Per manufacturer, the accuracy of SaO2 measurements is 2%. CLM telemetry readings of SaO2 were continuously, automatically and securely transferred to either the RRI or FKC data warehouse and were subsequently extracted for joint analysis.

**SaO2 data elegibility**

CLM data with the following characteristics were deemed implausible or unreliable and hence excluded: relative blood volume > 120% or <60%, SaO2 >100% or zero, hematocrit levels < 15% or > 60%, and data points collected before or after dialysis.

**Laboratory data**

Laboratory measurements (Spectra Laboratories, New Jersey, NJ, USA) were downloaded to the RRI and FKC data warehouses and extracted for subsequent joint analysis.

**Statistical Analyses**
Descriptive statistics comprise mean ± standard deviation (SD) for continuous variables and percentages for categorical variables. Average treatment-level SaO₂ was calculated utilizing all eligible measurements. The treatment-level average SaO₂ was then used for further analysis. HD treatments were also characterized by mean treatment-level SaO₂ (≥90% and <90%). We used SaO₂ available up to 4 weeks pre-diagnosis and the week post-diagnosis for this analysis. Additionally, we also examined HD treatments grouped by mean treatment-level SaO₂ (≥90%; and <90%) in non-COVID-19 MHD patients.

We report baseline descriptive statistics, group differences (95% confidence intervals) in all patients and stratified by survivor status. A baseline period was defined as the time between 4 and 6 weeks before the diagnosis of COVID-19. Next, we report the association between hypoxemia and/or oxygen supplementation with death and hospitalization.

To further assess SaO₂ patterns in relation to outcomes, we used estimates from adaptive spline mixed-effects models [13]. For this analysis, patients were stratified by clinical outcomes into two groups (hospitalization or death; neither of both).

Statistical analyses were performed using SAS version 9.4 (SAS Institute Inc., Cary, NC, USA) and R 3.4.4 (libraries ggplot2, dplyr, and mgcv. R Foundation for Statistical Computing, Vienna, Austria).

RESULTS

Patient characteristics

Between February and April 2020, 1,166 MHD patients were dialyzed in these 11 facilities. Eighty patients (6.7 % of the total population) were diagnosed with COVID-19. Twenty-five of these 80 COVID-19 patients (31.3 %) had no arterio-venous vascular access, making a measurement of
SaO$_2$ by CLM impossible; the baseline characteristics of these 25 patients are shown in Supplemental Table 1. Three COVID-19 patients (3.8%) lacked eligible CLM measurements. The remaining 52 MHD patients contributed in total 338 HD treatments with eligible SaO$_2$ recordings. Their age was 66.5±15.7 years, dialysis vintage was 6.9±5.0 years, 44.2% were white, 65.4% males, 81.2% had hypertension, 68.7% diabetes, 31.2% congestive heart failure, and 14.6% chronic obstructive pulmonary disease (Table 1).

Eleven patients expired from COVID-19 within 5 weeks after diagnosis; their baseline characteristics are compared to the ones of the 41 COVID-19 recovered patients in Table 1.

**COVID-19 related signs and symptoms**

Data regarding COVID-19 signs and symptoms were available for 46 of the 52 patients (88.5%). Among those, only one patient was asymptomatic; the remaining patients presented with a variety of symptoms. At presentation, malaise (63%), fever (54%), cough (35%), and shortness of breath (30%) were the most common. Gastrointestinal symptoms were present in 5 (11%) patients, specifically diarrhea, anosmia or dysgeusia were not reported. To note, none of these patients presented hypoxemia on the days prior to diagnosis. Most patients (76.1%) showed first symptoms within 48 hours before COVID-19 diagnosis. Naso-pharyngeal swabs for SARS-CoV-2 RT-PCR were collected on average 1.1 days after symptom onset (median 0, range 0 to 9).

**Treatment level average SaO$_2$**

The weekly distribution of HD treatments stratified by SaO$_2$ levels in the 4 weeks pre-diagnosis is shown in Figure 1; the day-by-day distribution in the final pre-diagnosis week is shown in Figure 2. Because of its effect on SaO$_2$, this analysis is limited to SaO$_2$ recordings from dialysis treatments without the use of supplementary oxygen. Prior to COVID-19 diagnosis the rate of hemodialysis treatments with hypoxemia, i.e. an average SaO$_2 < 90\%$ during dialysis, increased...
from 2.9% (2 to 4 weeks pre-diagnosis) to 12.2% (1 week) and 21.7% (3 days pre-diagnosis). Six days pre-diagnosis, SaO\textsubscript{2} \geq 90\% was observed in all HD treatments; three days later the rate dropped to 83%. In contrast, 4 to 6 days pre-diagnosis SaO\textsubscript{2} < 90\% was not observed with a significant increased noted three days later (Figure 2). In the week following the diagnosis of COVID-19, hypoxemia was present in 5% of the treatments (Figure 1).

*Intradialytic SaO\textsubscript{2} in non-COVID-19 patients*

In 1,567 MHD patients without COVID-19 MHD the rate of hemodialysis treatments with hypoxemia remained < 5.5% (Supplemental Figure 3).

*Oxygen supplementation and “silent” hypoxemia before COVID-19 diagnosis*

In the 4 weeks pre-diagnosis, oxygen supplementation was documented in 5% of HD treatments. In the post-diagnosis week this rate increased to 19% (Figure 3). In the weeks pre- and post-diagnosis, we observed 7 treatments (10% of all treatments with hypoxemia) with an average intradialytic SaO\textsubscript{2} < 90\% without a concurrent use of supplemental oxygen, indicative of “silent” hypoxemia. Indication for oxygen supplementation was based on clinical assessment by the clinic staff and was administered exclusively during the in-center dialysis sessions.

*Hospitalization and Mortality*

Patients were followed for up to 5 weeks post-diagnosis. During that period 11 (21.5\%) out of the 52 patients died (Table 1). The mean post-diagnosis survival time was 14 days (range 2 – 24). Twenty-nine patients were hospitalized, with an average length of hospitalization of 14 days (median 14, range 5 to 20). All patients who died were hospitalized during the course of the disease. Hospitalization was based on clinical assessment and criteria by the emergency room physician.
Hypoxemia and/or oxygen supplementation was documented in 4 (36%) of 11 patients who died, compared to 7 (17%) of the 41 patients who survived (Table 2). Five (18%) out of 28 patients who were hospitalized were either hypoxemic or required O₂ supplementation (Table 3).

We then stratified patients based on outcome into two groups, i.e. hospitalization and/or death versus non-hospitalized/survival. We analyzed these 2 groups using adaptative spline mixed effects models. We analyzed these 2 groups based on COVID-19 onset of symptoms and on COVID-19 diagnosis. Patients who were hospitalized or passed away showed both a pronounced pre-onset of symptoms and pre-diagnosis SaO₂ decline, this decline was not observed in the non-hospitalized/survival group (Figures 4-5).

**DISCUSSION**

In our analysis we interrogated routinely collected intradialytic SaO₂ data to ascertain the rate and dynamics of hypoxemia in MHD patients with confirmed COVID-19. This is the first report of SaO₂ levels during dialysis in a larger group of in-center MHD patients with COVID-19. The main finding is a rise in intradialytic hypoxemia rate in the days before onset of symptoms and diagnosis of COVID-19. We also corroborated the presence of “silent” hypoxemia, defined as SaO₂ < 90% without the use of supplemental oxygen.

Hypoxemia results from pathologies that impair pulmonary gas exchange (e.g., pneumonia), respiratory control (e.g., neurological diseases), or ventilation mechanics (e.g., pneumothorax); it may compound tissue hypoxia and organ dysfunction. Hypoxemia during hemodialysis has been well described in the pre-COVID-19 era [14, 15].

In the general population, hypoxemia, usually defined as SaO₂ <90%, has been described in 9 to 38% of COVID-19 patients [9, 10, 16]. It is attributed to interstitial pneumonia, reduced alveolar
oxygen diffusion, intrapulmonary shunts (V/Q mismatch), and microthrombi [17, 18]. Data on hypoxemia in MHD patients with COVID-19 are scarce. Two reports on MHD patients who had to be hospitalized due to a more severe clinical course of COVID-19 show decreased SaO$_2$ levels (below 95%) and hypoxemia at admission in 16% to 60% of patients [11, 12]. In our study, patients who were hospitalized and those who expired due to COVID-19 had a higher hypoxemia rate than those who were not hospitalized or expired. Patients who succumbed to COVID-19 infection were older, had more comorbidities and a longer dialysis vintage. These findings corroborate previously reported risk factors for mortality [11, 12, 19]. It is also noticeable that half of our patients with documented hypoxemia or requiring oxygen supplementation during dialysis were hospitalized; almost half of them died from COVID-19.

In our study, malaise and fever were the most common symptoms at presentation, corroborating previous publications [11, 12, 19-21]; on the other hand we found a lower frequency of cough and shortness of breath compared to other cohorts [12, 21, 22]. Patients showed symptoms on average around one day before being tested positive for COVID-19. This brief time period indicates that strict screening procedures implemented in dialysis facilities allow for timely identification and isolation of COVID-19 positive patients. Our results show a sharp decline on SaO$_2$ levels before any symptoms occurred in those patients who required hospitalization or died.

We observed patients who are hypoxemic with an apparent absence of symptoms, a clinical phenotype called “silent hypoxemia” [23-25]. The variability in breathing response to hypoxemia, as well as differences in intra-pulmonary shunts early in the course of the disease, have been proposed as explanations of silent hypoxemia [26]. However, its pathophysiology is still poorly understood. Carbon dioxide, the key stimulus of respiratory drive, diffuses roughly 20 times faster than oxygen in liquids. Therefore, in some disease circumstances oxygen exchange can be compromised before carbon dioxide removal, resulting in hypoxemia without pronounced
hypercapnia and hence less shortness of breath. It is also intriguing to speculate that an infection of the central nervous system by SARS-CoV-2 might play a role.

To the best of our knowledge, this is the first report of intradialytic SaO\textsubscript{2} levels in in-center MHD patients before and shortly after COVID-19 diagnosis and symptoms onset. The strength of this report is the routine, quasi-continuous and automatic documentation of SaO\textsubscript{2} during dialysis, allowing us to interrogate a large number of SaO\textsubscript{2} recordings. We acknowledge that our study has some limitations. We lack objective data such as imaging studies that might have been done outside the dialysis units and could provide useful information on the severity of the disease. Unfortunately, such studies are not available due to healthcare regulations. Lastly, the relatively brief follow-up after COVID-19 diagnosis. While after May 2020 no new COVID-19 cases were diagnosed in our 11 dialysis, continued vigilance is warranted.

In summary, hypoxemia may precede both the symptoms onset and diagnosis of COVID-19 in MHD patients. Patients with adverse outcomes such as hospitalization or death showed a steeper decline in SaO\textsubscript{2} compared to their fellow patients with an uncomplicated clinical course. Measurement of SaO\textsubscript{2} may afford nephrologists with an opportunity to identify pre-symptomatic COVID-19 patients and alert them to patients at increased risk of adverse outcomes. Informed by the current data we posit that routine measurement of SaO\textsubscript{2} in MHD patients is a valuable addition to our surveillance armamentarium.

CONFLICT OF INTEREST STATEMENT
P.P, L.M.T.S, X.Y., H.Z. and P.K. are employees of the Renal Research Institute, a wholly-owned subsidiary of Fresenius Medical Care North America. P.K. holds stock in Fresenius Medical Care North America. The other authors report no financial disclosures.
AUTHORS’ CONTRIBUTIONS

P.P., L.M.T.S., X.Y., H.Z., Y.W., and P.K contributed to the design and implementation of the research. X.Y, H.Z, Y.W. and P.W. analyzed the data. P.P., L.M.T.S and J.P.K wrote the manuscript with input from all authors. P.K directed the project. All authors provided critical feedback and helped shape the research, analysis and manuscript.

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DATA AVAILABILITY STATEMENT

The data underlying this article cannot be shared publicly due to privacy company policies. The data will be shared on reasonable request to the corresponding author.
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Table 1. Patient characteristics at baseline of all patients and stratified by survival status

| Variable                                      | Baseline*        | Recovered        | Died          | Difference between patients who recovered and passed away (mean; 95% CI) |
|-----------------------------------------------|------------------|------------------|---------------|--------------------------------------------------------------------------|
| **Number of patients**                        | 52               | 41               | 11            | n.a                                                                      |
| **Demographics**                              |                  |                  |               |                                                                          |
| Age [years]                                   | 66.5±15.7        | 63.3±15.4        | 78.5±10.5     | 15.2 (7.0 to 23.4)                                                       |
| Males [%]                                     | 65.4             | 68               | 55            | 13 (-13 to 43)                                                           |
| Hemodialysis vintage [years]                  | 6.9±5.0          | 6.7±4.9          | 7.7±5.6       | 1.0 (-2.4 to 4.5)                                                        |
| White                                         | 44               | 41               | 55            | -14 (-16.0 to 45.0)                                                     |
| Black or African American                     | 37               | 15               | 18            | 3 (-22 to 30.0)                                                          |
| Other                                         | 15               | 44               | 27            | -17 (-22 to 31)                                                          |
| **Comorbidities [%]**                         |                  |                  |               |                                                                          |
| Hypertension                                  | 81               | 60               | 86            | 26 (-49 to 11)                                                           |
| Diabetes mellitus                             | 69               | 71               | 90            | 19 (-5.0 to 50)                                                          |
| Congestive heart failure                      | 31               | 34               | 30            | -4 (-27 to 30)                                                           |
| COPD                                          | 15               | 14               | 10            | -4 (-58 to 12)                                                           |
| **Treatment-related variables**               |                  |                  |               |                                                                          |
| Treatment time [min]                          | 228.7±25.7       | 210.7±45.3       | 211.4±37.1    | 0.7 (-29.2 to 30.6)                                                     |
| IDWG [kg]                                     | 1.8±1.4          | 1.4±1.4          | 1.5±0.9       | 0.1 (-9.2 to 1.1)                                                        |
| Pre-dialysis weight [kg]                      | 84.9±24.3        | 85.4±25.2        | 78.5±21.7     | -6.9 (-23.6 to 10.0)                                                    |
| Pre-dialysis temperature [°C]                 | 36.4±0.3         | 36.7±0.8         | 37.2±0.8      | 0.6 (0.0 to 1.1)                                                        |
| Pre-dialysis heart rate [beats / min]         | 79.0±12          | 82.0±17.7        | 88.0±19.3     | 6.0 (-6.3 to 18.3)                                                      |
| Pre-dialysis SBP [mmHg]                       | 147.6±25.9       | 140.3±28.0       | 152.4±26.4    | 12.1 (-6.8 to 31.0)                                                     |
| UFV [L]                                       | 2.0±1.1          | 1.6±1.0          | 1.6±1.0       | 0.0 (-0.7 to 0.7)                                                       |
| UFR [mL/kg/hr]                                | 6.5±3.7          | 5.9±4.2          | 5.5±1.3       | 0.3 (-2.3 to 3.0)                                                       |
| Intradialytic oxygen saturation [%]           | 95.7±3.5         | 95.9±2.8         | 94.5±5.3      | -1.3 (-3.8 to 1.1)                                                      |
| **Biochemical variables**                     |                  |                  |               |                                                                          |
| Hemoglobin [g/dL]                             | 10.8±1.2         | 10.8±1.3         | 10.7±0.7      | -0.1 (-0.9 to 0.7)                                                      |
| Leukocytes [1000/µL]                          | 7.2±2.4          | 7.1±2.4          | 7.4±2.4       | 0.3 (2.4 to 0.8)                                                        |
| Lymphocytes [1000/µL]                         | 19.9±8.4         | 20.0±9.1         | 19.4±5.1      | -0.6 (-6.7 to 5.5)                                                      |
| Serum albumin [g/dL]                          | 3.9±0.4          | 3.9±0.4          | 3.9±0.4       | 0.0 (-0.2 to 0.3)                                                       |
| Serum sodium [mmol/L]                         | 138.5±2.7        | 138.1±2.6        | 140.1±2.4     | 2.0 (0.2 to 3.7)                                                        |
| Serum potassium [mmol/L]                      | 4.7±0.5          | 4.6±0.5          | 4.9±0.5       | 0.2 (-0.1 to 0.6)                                                       |
| NLR                                           | 4.3±2.8          | 4.5±3.1          | 3.7±1.5       | -0.8 (-2.8 to 1.2)                                                      |
| Serum Ferritin [ng/dL]                        | 1196±325         | 1137±487         | 1110±257      | -27 (-335 to 281)                                                       |

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*Baseline measurements for both groups were obtained between 30 and 45 days prior to COVID-19 diagnosis. The first available data point during this baseline period was used for analysis.

Data are expressed as mean ± SD, or percentage (%).

SD, standard deviation; COPD, chronic obstructive pulmonary disease; SBP, systolic blood pressure; IDWG, interdialytic weight gain; UFV, ultrafiltration volume; UFR, ultrafiltration rate; NLR, neutrophil-to-lymphocyte ratio.
Table 2. Frequency of hypoxemia and oxygen supplementation during dialysis. Patients were stratified by their survivor status. The % are expressed relative to the number of patients per row.

| Hypoxemia and Oxygen supplementation | COVID-19 Survival Status |
|-------------------------------------|--------------------------|
|                                     | Died                     | Recovered                |
|                                     | N = 11                   | N = 41                   |
| Either SaO$_2$ < 90% or O$_2$ given; N = 9 | 4 (44%)                 | 5 (56%)                 |
| SaO$_2$ ≥ 90% and no O$_2$ given; N = 43 | 7 (16%)                 | 36 (84%)                |
Table 3. Frequency of hypoxemia and oxygen supplementation during dialysis. Patients were stratified by hospitalization status. The % are expressed relative to the number of patients per row.

| Hypoxemia and Oxygen supplementation | COVID-19 Hospitalization |
|--------------------------------------|--------------------------|
|                                      | Yes  | No           |
|                                      | N = 28 | N = 24      |
| Either SaO$_2$ < 90% or O$_2$ given; N = 9 | 5 (56%) | 4 (44%)    |
| SaO$_2$ ≥ 90% and no O$_2$ given; N = 43 | 23 (53%) | 20 (47%)  |
Figure legends:

**FIGURE 1**: Distribution of intradialytic SaO₂ in the 4 weeks before and the week after the COVID-19 diagnosis.

**FIGURE 2**: Distribution intradialytic SaO₂ in the days prior to the COVID-19 diagnosis. During none of these treatments supplemental oxygen was given.

**FIGURE 3**: Rate of hemodialysis treatments with oxygen supplementation in the 4 weeks before and the week after COVID-19 diagnosis.

**FIGURE 4**: Arterial oxygen saturation prior to COVID-19 onset of symptoms. Patients are stratified by outcomes.

Estimates from adaptive spline mixed-effects models (blue line) with 95% confidence intervals (shaded areas) stratified based on the absence (left panel) or presence (right panel) of hospitalization and/or death. Grey lines are a spaghetti plot of individual trajectories. Time zero corresponds to the time of COVID-19 onset of symptoms.

**FIGURE 5**: Arterial oxygen saturation prior to COVID-19 diagnosis. Patients are stratified by outcomes.

Estimates from adaptive spline mixed-effects models (blue line) with 95% confidence intervals (shaded areas) stratified based on the absence (left panel) or presence (right panel) of hospitalization and/or death. Grey lines are a spaghetti plot of individual trajectories. Time zero corresponds to the time of COVID-19 diagnosis.
FIGURE 1: Distribution of intradialytic \( \text{SaO}_2 \) in the 4 weeks before and the week after the COVID-19 diagnosis. During none of these treatments supplemental oxygen was given.

The y-axis shows the indicated \( \text{SaO}_2 \) categories in \%. 
FIGURE 3: Rate of hemodialysis treatments with oxygen supplementation in the 4 weeks before and the week after COVID-19 diagnosis.

The y-axis shows the indicated categories in %.
FIGURE 4: Arterial oxygen saturation prior to COVID-19 onset of symptoms. Patients are stratified by outcomes.

Estimates from adaptive spline mixed-effects models (blue line) with 95% confidence intervals (shaded areas) stratified based on the absence (left panel) or presence (right panel) of hospitalization and/or death. Grey lines are a spaghetti plot of individual trajectories. Time zero corresponds to the time of COVID-19 onset of symptoms.
FIGURE 5: Arterial oxygen saturation prior to COVID-19 diagnosis. Patients are stratified by outcomes.

Estimates from adaptive spline mixed-effects models (blue line) with 95% confidence intervals (shaded areas) stratified based on the absence (left panel) or presence (right panel) of hospitalization and/or death. Grey lines are a spaghetti plot of individual trajectories. Time zero corresponds to the time of COVID-19 diagnosis.
Week –4 | Week –3 | Week –2 | Week –1 | Week 1
---|---|---|---|---
Weekly treatments without $O_2$:
- Week –4: 96
- Week –3: 95
- Week –2: 94
- Week –1: 94
- Week 1: 81

Weekly treatments with $O_2$:
- Week –4: 4
- Week –3: 5
- Week –2: 6
- Week –1: 6
- Week 1: 19
Non-hospitalized/survived (N=24)

Hospitalized/died (N=28)

Oxygen saturation (%)

Time (days)