International Urology and Nephrology (2021) 53:2567–2575
https://doi.org/10.1007/s11255-021-02819-5

NEPHROLOGY - ORIGINAL PAPER

Characteristics of COVID-19 patients with preexisting CKD history

Chuou Xu[1] · Tianjing Zhang[2] · Na Zhu[2] · Min Han[2]

Received: 10 October 2020 / Accepted: 13 February 2021 / Published online: 5 March 2021

Abstract

Purpose This paper was intended to describe the characteristics of coronavirus disease 2019 (COVID-19) patients with known chronic kidney disease (CKD) history.

Methods Clinical information of 20 COVID-19 pneumonia patients with CKD history diagnosed between January 20th and March 1st, 2020 were collected in Tongji Hospital, Wuhan. We listed the clinical baseline data, laboratory findings, chest computed tomography (CT) changes and processed a short period of follow-up of these 20 patients.

Results Based on the estimated glomerular filtration rate (eGFR) on admission, 6 patients were classified as stage 2 of CKD, 5 were as 3a, 2 were as 3b, 3 were as 4 and 4 were as 5, respectively. COVID-19 patients with CKD history were elder and hypertension was the most common comorbidity. Cough and fever accounted for more than 80% of the infectious cases. Lymphopenia, increased D-dimer and elevated infectious indications such as hypersensitive C response protein (hsCRP), interleukin-6 (IL-6) and tumor necrosis factor alpha (TNF-α) were also common among these patients. Ground-glass opacity (GGO) and consolidation were the major manifestations in CT scans. 4 patients died and 7 patients underwent acute kidney injury (AKI) during observation. Among 16 discharged patients, 12 were with stable renal function and 4 had deteriorating renal function compared with that of admission.

Conclusion Compared to general population infected with SARS-CoV-2, COVID-19 patients with CKD history had a preference to develop to severity with higher fatality rate.

Keywords COVID-19 · SARS-CoV-2 · CKD AKI

Introduction

Back to December 2019, several cases with acute respiratory symptoms were successively reported from different hospitals in Wuhan, China [1]. Subsequently, a novel coronavirus was extracted from respiratory tract secretions and named as severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2) [2] and the illness was officially termed as coronavirus disease 2019 [3]. Since then, it has been extensively spread to all over the world and led to more than 900 thousand death globally until September 21st, 2020 [4]. Although patients with COVID-19 seemed to show more pulmonary symptoms and signs than other systems, multiple organs (kidneys, hearts, gastrointestinal tracts, etc.) have been demonstrated involved as well [5–8]. Particularly, several researchers illustrated kidney involvement in COVID-19 patients. They noticed acute kidney injury (AKI) among COVID-19 patients was common, and AKI was proved to be an independent predictor for poor prognosis of COVID-19 patients [9, 10]. Histopathologically, researchers have verified the viral particles located in both renal glomerular and tubular by light microscopy and transmission electron microscopy [11]. Besides, Su et al. also provided a direct evidence of renal viral invasion from kidney samples of 26 deceased COVID-19 patients [12]. A review has recently summarized the potential mechanisms of kidney involvement and divided it into 3 aspects: cytokine production, organ–organ crosstalk and systemic influence [13].

Chuou Xu and Tianjing Zhang contributed equally to this work.

✉ Min Han
minhan@tjh.tjmu.edu.cn

[1] Department of Radiology, Tongji Hospital Affiliated To Tongji Medical College, Huazhong University of Science and Technology, Wuhan, China

[2] Department of Nephrology, Tongji Hospital Affiliated To Tongji Medical College, Huazhong University of Science and Technology, 1095 Jiefang Avenue, Wuhan 430030, China

So far, studies regarding kidney damage with novel coronavirus pneumonia have mainly focused on AKI abnormality due to the direct tubular infection and severity of the disease [9, 14–17]. However, the relationship between COVID-19 and CKD has not been paid much attention at the initial outbreak due to less urgent than AKI. Besides, for some patients, the situation of preexisting CKD history or COVID-19-associated kidney damage was unclear. In addition, investigations about the incidence of patients with known CKD history were extremely rare [18]. Hence, our study aimed to describe the features of COVID-19 patients with known CKD history and seek for prognosis-related factors if possible.

Methods

Diagnostic criteria of COVID-19

On the basis of the New Coronavirus Pneumonia Diagnosis and Treatment Program [19] (7th edition, in Chinese), issued by National Health Commission of People's Republic of China on March 3rd, 2020, the diagnosis criteria of COVID-19 pneumonia were: (1) epidemiological history: exposure to confirmed patients or travel or dwell in anywhere reported confirmed cases, especially in Wuhan; (2) clinical manifestation: fever and/or other respiratory symptoms, implied signs of viral pneumonia from chest CT scan, and/or normal or reduced white blood cells (WBC) and lymphocytes; and (3) pathogenic and/or serological detection: nucleic tests of samples collected from swabs of patients' nasopharynx are positive, and/or antibodies to SARS-CoV-2 (immunoglobulin M and immunoglobulin G) are positive.

Patients

The study consists of 20 cases with preexisting CKD prior to COVID-19 diagnosis between January 20th and March 1st, 2020 in Tongji Hospital in Wuhan. Patients with normal GFR ($\geq$90 mL/min/1.73 m^2) and kidney transplantation history were excluded. Diagnosis and classification of CKD and AKI was based on the 2012 clinical practice guideline formulated by the Kidney Disease: Improving Global Outcomes (KDIGO) organization [20]. According to the eGFR on admission, those patients were classified as G2, G3a, G3b, G4 and G5, respectively. All records were reviewed retrospectively, including clinical baseline data, laboratory findings and chest imaging changes for each case involved.

Chest CT evaluation

Non-enhanced chest CT scans were regularly operated using either one of the two CT scanners (uCT 780, United Imaging; Somatom Force, Siemens Healthcare), patients' CT images were gathered under a single breath-hold status in the supine position. All CT images were reconstructed to 1.25-mm-thin slices.

The scans were conducted for each patient at different intervals. For each patient, the chest scan was evaluated for characteristics as follows: (1) presence of GGO, consolidation or interstitial abnormalities (including reticular appearance, fibrous strips and interlobular septal thickening); (2) the laterality of lesions involved (unilateral or bilateral); (3) the number of lobes affected; and (4) degree of involvement was subjectively scored from 0 to 5 for each lung lobe as no involvement, <5%, 5–25%, 26–49%, 50–75% and >75% involvement, separately. Each lobe's score was added up to obtain the final total scores, ranging from 0 to 25. Imaging evaluation was performed on a PACS system (Synapses, Fujifilm) by two radiologists with over 8-year experience, the final scores were determined by consensus.

Results

Clinical characteristics

Ten patients were male (50%) and ten were female (also 50%), with a median age of 68 years (range, 46–88 years). The average time from the onset of initial symptom to hospitalization was 13.05 ± 10.23 days. Only 2 patients (10%) had a history of lung diseases, while hypertension occurred in 13 cases (80%) and was the most common comorbidity. Diabetes mellitus and coronary heart disease were also present in partial cases and 1 case was previously diagnosed with kidney cancer. 9 patients (45%) were current smokers. The foremost symptoms were cough, fever and dyspnea, accounting for 95% (19/20), 85% (17/20) and 40% (8/20), individually. On admission, 6 patients were classified as G2 of CKD, 5 were as G3a, 2 were as G3b, 3 were G4 and 4 were G5, respectively.

Concerning the laboratory findings, most patients showed normal white blood cell count. Lymphocytes count decreased in 80% (16/20) of the cases and 89% (17/19) displayed an elevated D-dimer on admission. 6 patients (30%) presented a slight decrease of platelets counts while only 1 case exceeded the upper limiting value. Indications such as alanine aminotransferase, aspartate aminotransferase and total bilirubin with respect to liver function were normal overall. Serum albumin, however, revealed decreased in 60% (12/20) cases. Infection-related indications hsCRP, IL-6 and TNF-α escalated in the proportion of 83% (15/18), 94% (15/16) and 94% (15/16), separately. The median of blood urea nitrogen (BUN) was 7.25 mmol/L (range, 4.0–29.6 mmol/L) and serum creatinine (Scr) was 141.5 μmol/L (range, 74–1011 μmol/L). On admission,

the majority of patients showed urine test abnormalities. Table 1 lists comprehensive information about clinical characteristics.

Image changes

Each of the 20 patients underwent chest CT examinations, ranging from 1 to 7 times. A total of 63 person-time examinations were performed. According to time (days) from the onset, the chest CT scans were classified into 4 stages: Stage 1 (5–8 days, $n=2$); Stage 2 (9–13 days, $n=3$); Stage 3 (14–28 days, $n=20$); and Stage 4 (≥ 29 days, $n=38$).

The chest CT imaging characteristics and total CT scores are shown in Table 2. All 20 patients showed bilateral involvement. GGO and consolidation were the most universal CT manifestations. GGO was observed in 1 patient (50.0%) of stage 1, 1 patient (33.3%) of stage 2, 3 patients (15.0%) of stage 3 and 11 patients (28.9%) of stage 4, while consolidation was exclusively seen in stage 3 and 4 with 6 patients (30.0%) and 3 patients (7.9%) involved respectively. GGO with consolidation was seen in 1 patient (50.0%), 2 patients (66.7%), 5 patients (25.0%) and 13 patients (34.2%) of stage 1, 2, 3 and 4 separately. The mean CT involvement score was 12.0 ± 4.3 (mean $\pm$ standard derivation) for stage 3, which was the highest among all four stages.

From the day of admission, follow-up CT scans were performed in 17 (85.0%) patients, ranging from 4 to 86 days. 15 (75.0%) patients showed improved, 1 (0.5%) deteriorated and 1 (0.5%) stayed unchanged. Among these 15 patients who exhibited improvement, 3 patients improved within 13–15 days after admission, 2 within 16–20 days, 8 within 21–30 days and 2 within 31–35 days, respectively. 3 cases (15%) did not perform follow-up CT due to critical illness or death. The typical manifestations in chest CT images of 1 patient discharged and 1 died during hospitalization are shown in Figs. 1 and 2, respectively.

Treatments and outcomes

Drugs usage before this-time hospitalization included angiotensin-converting enzyme inhibitors (ACEIs) or angiotensin receptor blockers (ARBs), immunosuppressive (IS) agents, antibiotics and antivirals. Among these patients, antibiotics (75%, 15/20) and antivirals (60%, 12/20) use were quite general.

During hospitalization, various therapy strategies were disposed individually. Concisely, none of these cases accepted extracorporeal membrane oxygenation (ECMO). Only 1 case performed invasive mechanical ventilation for 7 days, while non-invasive mechanical ventilation was conducted for 2 patients, one for 1 day and the other for 4 days. 4 patients received continuous renal replacement therapy (CRRT) including 2 have accepted continuous hemodialysis before. Medications of systematic steroids and intravenous immunoglobulin (IVIG) were given to 13 (65%) and 11 (55%) patients, separately. 80% of these patients were prescribed for at least one kind of antiviral agents. The details about treatments reviewed in Table 3.

The clinical outcomes are revealed in Table 4. Severity of COVID-19 was defined as the occurrence of life-threatening complications or entrance to intensive care unit (ICU). As the table showed, of the 20 patients, 16 were convalescent and discharged. 12 patients were discharged with stable renal function while the other 4 had a deteriorating renal function. 4 patients died during the study period and all of them were severe on admission or developed as severe cases during hospitalization. A total of 7 patients occurred AKI with 5 cases developing at stage 1, 1 at stage 2 and 1 at stage 3. Among those 7 cases, 2 passed away, 2 had declined renal function and 3 patients' renal function returned back to admission levels when discharged.

For these 4 departed patients, all of them were elderly and severe cases. 2 patients were at G4, 1 at G5 and 1 at G3a on admission. Half of them developed as AKI (one as stage 1 and the other as stage 2). 75% of them had the history of hypertension. Decreased lymphocytes and platelets occurred in 3 patients and all of them displayed increased D-dimer. The data about infection-associated indications (hsCRP, IL-6, TNF-α) of these 4 cases were incomplete. However, 2 patients with complete data presented a milder rise than those who were alive.

Discussion

This is a descriptive study about clinical and radiological manifestations of 20 COVID-19 patients with CKD history. The incidence of pre-existent CKD in COVID-19 patients was diverse among different studies and a systematic meta-analysis of 22 articles revealed it as 5.4% [21]. Similarly, AKI prevalence among COVID-19 patients ranged from approximately 5.0 to 50.0% [9, 22–25]. AKI occurred on CKD could largely delay the recovery of kidney function as well as augment the mortality risk, which was reviewed by He et al. [26]. It was obviously improper to assess the fatality rate in our study because of the limited samples. Officially, it presented a death rate of 5.4% in 85,297 cases in China up to September 21st, 2020 [27]. A series of researches reported gender disparity in the epidemiology of COVID-19—men were more likely to be infected than women [28–30]. Nevertheless, no distinct sex discrepancy was noticed in our study. The possible reason may be attributed to small samples and the higher incidence of CKD in women essentially [31]. A large scale of multicenter research revealed that the median age was 47 years among infected patients (range

Table 1 Clinical characteristics and laboratory findings of 20 COVID-19 patients with known CKD history

ID	Sex	Age (y)	Time from onset to hospitalization (d)	History of lung diseases	Other comorbidities	CKD stage on admission	AKI stage during hospitalization	CKD stage at discharge	Smoker	Main complaints
1	M	68	12	N	Kidney Ca	2	0	2	Y	Dyspnea
2	M	65	10	N	N	2	0	2	Y	Fever, cough
3	F	69	10	COPD, bronchiectasis	HT	2	0	2	Y	Fever, cough, diarrhea, dyspnea
4	F	61	9	Tuberculosis	HT	4	0	/	Y	Fever, cough
5	M	53	6	N	HT, CHD	2	0	2	Y	Fever, cough, dyspnea
6	M	88	25	N	N	3a	0	3b	Y	Fever, cough
7	M	68	14	N	N	3b	0	3b	Y	Fever, cough, vomiting
8	M	66	13	N	N	2	0	2	Y	Fever, cough, headache
9	M	79	2	N	HT, CHD	5	0	5	N	Fever, cough
10	F	58	15	N	DM, HT	3a	1	3b	Y	Fever, cough, dyspnea, chest pain
11	F	74	14	N	HT	5	3	5	N	Fever, cough, confusion, diarrhea
12	F	60	10	N	N	3a	1	3a	N	Cough, headache, myalgia, dyspnea
13	F	79	13	N	HT, CHD	5	0	–	N	Fever, cough, diarrhea, dyspnea
14	M	68	31	N	DM, HT, CHD	4	0	4	N	Fever, cough, headache, myalgia, dyspnea
15	F	54	11	N	HT	2	0	2	N	Fever, cough, dizziness, chest pain
16	F	46	2	N	HT	5	0	5	N	Fever, cough
17	M	72	45	N	DM, HT	3a	1	3b	N	Fever, cough
18	M	83	7	N	N	4	2	–	N	Fever, cough, headache, diarrhea
19	F	86	9	N	HT	3b	1	3b	N	Cough, myalgia, diarrhea, dyspnea
20	F	84	3	N	HT	3a	1	–	N	Fever, cough

WBC ($\times 10^9$/L)	LY ($\times 10^9$/L)	PLT ($\times 10^9$/L)	D-dimer (μg/mL)	ALT (U/L)	AST (U/L)	TB (μmol/L)	ALB (g/L)	BUN (mmol/L)	Scr (μmol/L)	hsCRP (mg/L)	IL-6 (pg/mL)	TNF-α (pg/mL)	U-PRO	U-BLD	U-WBC	Outcomes
5.34	1.49	327	0.29	44	31	4.9	35.3	7	108	0.8	N/A	N/A	–	–	–	Discharge
3.59	1.07	118	0.57	8	38	12.5	32.1	5.8	82	80	52.14	8.9	1+	–	–	Discharge
5.24	1	294	1.32	7	27	14.4	34.1	5.9	74	57	35.01	14	±	1+	–	Discharge
4.42	0.12	104	1.12	5	24	3.2	30.6	18.1	230	4.5	9.45	14	2+	1+	–	Death
3.25	0.68	83	0.33	27	36	9.3	32.7	6.4	101	37	1.95	11	1+	±	±	Discharge
9.86	0.38	91	1.52	42	33	16.2	21.7	8.5	122	118	150.6	32	±	–	–	Discharge
6.78	0.78	163	1.08	32	50	14.6	37.1	5.7	156	67	N/A	N/A	N/A	N/A	N/A	Discharge
3.8	0.76	409	2.03	33	40	11.9	29.4	5.5	104	112	79.41	10	1+	—	—	Discharge
6.39	0.92	173	2.03	8	24	4.3	32.6	26.93	776	120	88	28	2+	±	–	Discharge
5.97	0.53	288	4.77	9	21	6.4	29.1	4	127	67	49.51	13	1+	–	–	Discharge
6.26	0.59	274	4.23	6	7	<2.5	40	29.6	657	7.2	9.07	42	2+	2+	–	Discharge
4.1	0.77	323	4.3	19	26	7	28.4	9.4	195	41	9.18	13	–	–	–	Discharge

Table 1 (continued)

WBC ($\times 10^9$/L)	LY ($\times 10^9$/L)	PLT ($\times 10^9$/L)	D-dimer (μg/mL)	ALT (U/L)	AST (U/L)	TB (μmol/L)	ALB (g/L)	BUN (mmol/L)	Scr (μmol/L)	hsCRP (mg/L)	IL-6 (pg/mL)	TNF-α (pg/mL)	U-PRO	U-BLD	U-WBC	Outcomes
4.25	0.56	108	1.59	18	31	7.8	37.9	28.1	1011	47	65.17	29	N/A	N/A	N/A	Discharge
3.51	0.22	267	N/A	13	24	7.9	32	22	336	80	16.31	30	N/A	N/A	N/A	Discharge
4.55	1.17	316	0.95	40	44	5.4	33.1	5.5	74	58	27.44	15	–	–	3+	Discharge
5.5	0.24	199	3.51	9	14	3.9	31.6	27.2	726	44	8.5	31	2+	2+	–	Death
8.8	1.75	116	0.98	21	28	4.8	29.2	7.5	131	14	24.51	24	±	–	–	Discharge
3.82	1.39	100	1.33	17	40	3.2	36	27.49	426	N/A	N/A	N/A	2+	3+	3+	Death
4.23	0.63	194	2.31	20	28	13.2	30.9	6.3	106	N/A	27.85	6.2	–	–	2+	Discharge
5.31	0.4	133	2.43	7	23	5.8	38.8	6.1	152	21	N/A	N/A	±	–	–	Death

COPD chronic obstructive pulmonary disease; *Kidney Ca* kidney cancer; *HT* hypertension; *CHD* coronary heart disease; *DM* diabetes mellitus; *WBC* white blood cells; *LY* lymphocytes; *PLT* platelets; *ALT* alanine aminotransferase; *AST* aspartate aminotransferase; *TB* total bilirubin; *ALB* albumin; *BUN* blood urea nitrogen; *Scr* serum creatinine; *hsCRP* hypersensitive C response protein; *IL-6* interleukin-6; *TNF-α* tumor necrosis factor-α; *U-PRO* urine protein; *U-BLD* urine occult blood; *U-WBC* urine white blood cells; *F* female; *M* male; *Y* yes; *N* no

35–58 years) [25], which was much younger than ours. This could be attributed to the chronic-condition population that we concerned about.

Consistent with many other studies, we detected lymphopenia in most patients. This has already been one of the alternative diagnosis markers in the update edition of our national COVID-19 diagnosis and treatment program. We also observed elevated inflammatory factors such as IL-6 and TNF-α in the majority of infected patients. One study also demonstrated that the decrease of T cell count accompanied with a rapid rise of cytokines such as IL-2, IL-4, IL-10 and TNF-α [32]. In fact, CKD patients usually remained B and T cell phagocytic dysfunction and persistent inflammatory activation [33]. Hence, COVID-19 patients with CKD may had a superimposed negative effect on immune system.

The major chest CT manifestations of CKD patients attacked by COVID-19 were GGO and consolidation, the same as other studies among general population [34–36]. Pan and his colleagues classified the pulmonary CT changes of COVID-19 patients into 4 stages: 0–4 days as early stage, 5–8 days as progressive stage, 9–13 days as peak stage and absorption stage (≥14 days) [36]. However, our study showed that the lung involvement peaked at 14–28 days and started to absorb at 21–30 days. The possible reason may be the occurrence of inflammation storm of these CKD patients. Besides, lower metabolism rate may be another cause due to the decrease eGFRs and the old ages. Of course, the influence of small samples to the result could not be ignored as well.

In terms of treatments, no effective measures have been explored until now to cure this infection. In spite of ACE2 as the significant portal of the coronavirus entry to organs, whether ACEI/ARBs could be a promising application for COVID-19 management is still of controversy [37]. Kaletra (lopinavir/ritonavir) had been expected to work before, nevertheless, World Health Organization (WHO) put an end to the clinical trials of this drug according to earlier experiment results [38].

Prognostic analysis from other researches illustrated that CKD raised the severe or mortality risk of infected patients [39–41]. In our study, 20% (4/20) and near half (45%, 9/20) of the patients ended up with death or progressed to severe cases, respectively. A single-center study showed a 11.6% mortality and 58.1% severity rate of CKD patients with viral infection [40], while another meta-analysis of 5 involved researches demonstrated a higher fatality and severity rate as 53.33% and 83.93%, separately [42]. In spite of these statistical discrepancies, CKD patients infected with COVID-19 may acquire poorer outcomes. 4 deceased patients in our study were almost at advanced ages with underlying diseases (mainly hypertension). All of them had poor renal function on admission and one of them endured persistent hemodialysis before this infection. The influence of CKD stage

Table 2 Chest CT features of 20 patients with total 63 scans among 4 stages divided by the intervals from the onset of initial symptom

	Stage 1 (5–8 days, $n=2$)	Stage 2 (9–13 days, $n=3$)	Stage 3 (14–28 days, $n=20$)	Stage 4 (≥ 29 days, $n=38$)
Imaging characteristics				
GGO	1 (50.0%)	1 (33.3%)	3 (15.0%)	11 (28.9%)
Consolidation	0 (0.0%)	0 (0.0%)	6 (30.0%)	3 (7.9%)
GGO with consolidation	1 (50.0%)	2 (66.7%)	5 (25.0%)	13 (34.2%)
Fibrous strips	0 (0.0%)	0 (0.0%)	5 (25.0%)	9 (23.7%)
Reticular appearance	0 (0.0%)	0 (0.0%)	0 (0.0%)	2 (5.3%)
Interlobular sepal thickening	0 (0.0%)	0 (0.0%)	1 (5.0%)	0 (0.0%)
Total CT score of involvement	11.5 ± 0.7	10.3 ± 1.5	12.0 ± 4.3	10.4 ± 3.8

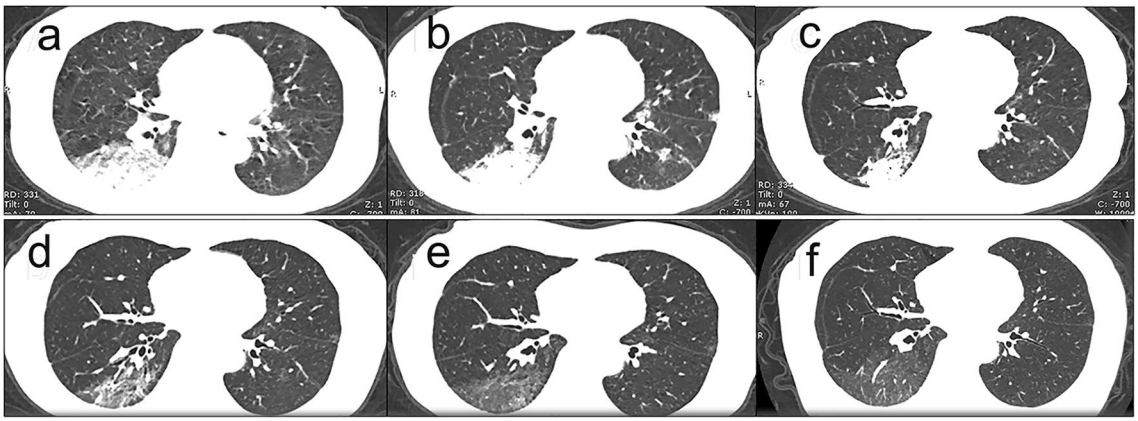

Fig. 1 Chest CT images of a 60-year-old woman, who has been diagnosed with chronic glomerulonephritis for 1 year. **a** 6 days after onset: consolidation was seen in the lower lobe of the right lung, the edge of the lesion was blurred with "halo sign". **b** 15 days after onset, also 5 days after admission: the consolidation in **a** became stiffer and denser, with sharper edge. **c** 29 days after onset, also 19 days after admission: consolidation was still observable, but the lesion area was reduced. **d** 37 days after onset, also 27 days after admission: the density of the lesion decreased, and appeared as GGO accompanied with consolidation. **e** 42 days after onset, also 32 days after admission: the area of the lesion was increased, but the density was lower, like sugar melted. **f** 48 days after onset, also 38 days after admission: the area of lesion was further increased, but the density was even lower

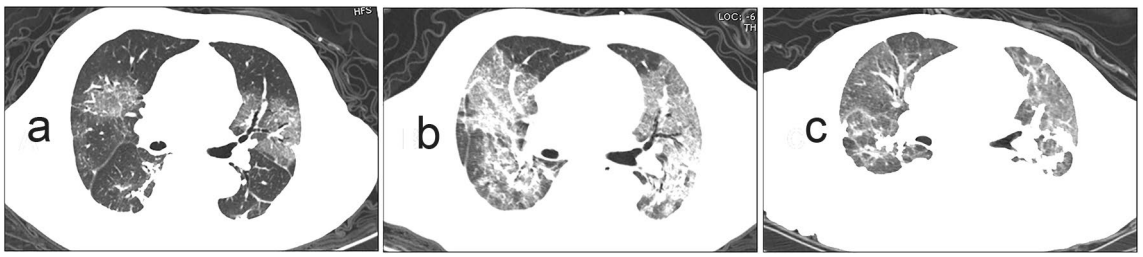

Fig. 2 Chest CT images of an 83-year-old man, who has been diagnosed with chronic renal failure for 40 years. **a** 11 days after onset, also 4 days after admission: diffused GGO with thickened interlobular septa. **b** 16 days after onset, also 9 days after admission: GGO increased significantly with patchy consolidation and interlobular septal thickening. **c** 77 days after onset, also 70 days after admission: the area of GGO was further increased with patchy consolidation, bilateral pleural effusion was observed. The patient died 79 days after hospitalization

on COVID-19 prognosis has recently articled by Alireza and Silvia. They both pointed out higher CKD stage was not associated with the worse outcomes [40, 43]. On the contrary, a study demonstrated the level of eGFR on admission was in negative correlation with the fatality [10]. Further investigations are required to be carried out.

Table 3 Treatment of cases classified by the CKD stage on admission before and after hospitalization

CKD stage on admission	Drugs use before hospitalization				Treatment during hospitalization						
	ACEI/ARB	IS agents	Antibiotics	Antivirals	CRRT	ECMO	Non-invasive ventilation	Invasive ventilation	Steroid	IVIG	Antivirals
G2 ($n=6$)	2	0	2	1	0	0	0	0	3	2	5
G3a ($n=5$)	3	0	5	4	0	0	0	1	3	2	4
G3b ($n=2$)	0	0	2	2	0	0	0	0	1	1	2
G4 ($n=3$)	0	1	2	2	0	0	1	0	3	3	3
G5 ($n=4$)	1	0	4	3	3	0	1	0	3	3	2

ACEI/ARBs angiotensin converting enzyme inhibitors/angiotensin receptor blockers, *IS* agents, immunosuppressive agents, *CRRT* continuous renal replacement treatment, *ECMO* extracorporeal membrane oxygenation, *IVIG*, intravenous immunoglobulin

Table 4 Clinical outcomes among patients of various CKD stages on admission

Clinical outcomes	The stage of CKD on admission					Total ($n=20$)
	G2 ($n=6$)	G3a ($n=5$)	G3b ($n=2$)	G4 ($n=3$)	G5 ($n=4$)	
Severity of COVID-19	2	1	1	2	3	9
AKI on CKD	0	4	1	1	1	7
Stable renal function at discharge	6	1	2	1	2	12
Hospital mortality	0	1	0	2	1	4

Several limitations were supposed to be mentioned in our study. First of all, the samples in our study came from single-center with relatively less cases, which may exert bias on the calculation of prevalence of some events (e.g., mortality rate, AKI incidence, severity proportion). Second, we classified CKD stages based on the eGFR on admission. Owing to the different durations between initial symptoms and admission among infected patients, whether COVID-19 infection affected the serum creatinine was unclear actually. Hence, the CKD stage of patients involved may be of inaccuracy. In addition, we only collected the laboratory findings on admission and some were incomplete, thus, it would be difficult to evaluate the dynamic changes of these indications for each case.

Conclusions

In conclusion, our study revealed that COVID-19 patients with pre-existent CKD inclined to progressed to critically ill cases and the mortality was higher than the general population.

Author contributions M.H. and C.X. designed the study and took responsibility for the integrity and accuracy of all clinical and radiological data. T.Z collected and managed the information as well as drafted the manuscript. N.Z. was responsible for data collection. M.H. discreetly reviewed the manuscript. C.X. and T.Z contributed equal to this work.

Funding The work was financially supported by National Natural Science Foundation of China (Grants No. 81770686, 81970591).

Data availability The data and material can be available in this article.

Code availability Not applicable.

Compliance with ethical standards

Conflict of interest The authors have no conflicts of interest to declare.

Ethics approval This study was approved of Medical Ethics Committee of Tongji Hospital Affiliated to Tongji Medical College, Huazhong University of Science and Technology (No. TJ-IRB20200216) and informed consent was waived.

Consent to participate Not applicable.

Consent for publication All the authors agreed to publish this article.

References

1. Huang C, Wang Y, Li X, Ren L, Zhao J, Hu Y, Zhang L, Fan G, Xu J, Gu X, Cheng Z, Yu T, Xia J, Wei Y, Wu W, Xie X, Yin W, Li H, Liu M, Xiao Y, Gao H, Guo L, Xie J, Wang G, Jiang R, Gao Z, Jin Q, Wang J, Cao B (2020) Clinical features of patients infected with 2019 novel coronavirus in Wuhan, China. Lancet. https://doi.org/10.1016/s0140-6736(20)30183-5
2. Lu R, Zhao X, Li J, Niu P, Yang B, Wu H, Wang W, Song H, Huang B, Zhu N, Bi Y, Ma X, Zhan F, Wang L, Hu T, Zhou H, Hu Z, Zhou W, Zhao L, Chen J, Meng Y, Wang J, Lin Y, Yuan J, Xie Z, Ma J, Liu WJ, Wang D, Xu W, Holmes EC, Gao GF, Wu

G, Chen W, Shi W, Tan W (2020) Genomic characterisation and epidemiology of 2019 novel coronavirus: implications for virus origins and receptor binding. Lancet 395(10224):565–574. https://doi.org/10.1016/s0140-6736(20)30251-8
3. WHO (2020) Naming the coronavirus disease (COVID-19) and the virus that causes it. https://www.who.int/emergencies/diseases/novel-coronavirus-2019/technical-guidance/. Accessed 11 February 2020
4. WHO (2020) Weekly operational update on COVID-19. https://www.who.int/docs/default-source/coronaviruse/situation-reports/20200921-weekly-epi-update-6.pdf. Accessed 21 September 2020
5. Ronco C, Reis T, Husain-Syed F (2020) Management of acute kidney injury in patients with COVID-19. Lancet Respir Med 8(7):738–742. https://doi.org/10.1016/s2213-2600(20)30229-0
6. Hendren NS, Drazner MH, Bozkurt B, Cooper LT Jr (2020) Description and proposed management of the acute COVID-19 cardiovascular syndrome. Circulation 141(23):1903–1914. https://doi.org/10.1161/CIRCULATIONAHA.120.047349
7. Wan Y, Li J, Shen L, Zou Y, Hou L, Zhu L, Faden HS, Tang Z, Shi M, Jiao N, Li Y, Cheng S, Huang Y, Wu D, Xu Z, Pan L, Zhu J, Yan G, Zhu R, Lan P (2020) Enteric involvement in hospitalised patients with COVID-19 outside Wuhan. Lancet Gastroenterol Hepatol 5(6):534–535. https://doi.org/10.1016/s2468-1253(20)30118-7
8. Gupta A, Madhavan MV, Sehgal K, Nair N, Mahajan S, Sehrawat TS, Bikdeli B, Ahluwalia N, Ausiello JC, Wan EY, Freedberg DE, Kirtane AJ, Parikh SA, Maurer MS, Nordvig AS, Accili D, Bathon JM, Mohan S, Bauer KA, Leon MB, Krumholz HM, Uriel N, Mehra MR, Elkind MSV, Stone GW, Schwartz A, Ho DD, Bilezikian JP, Landry DW (2020) Extrapulmonary manifestations of COVID-19. Nat Med. https://doi.org/10.1038/s41591-020-0968-3
9. Cheng Y, Luo R, Wang K, Zhang M, Wang Z, Dong L, Li J, Yao Y, Ge S, Xu G (2020) Kidney disease is associated with in-hospital death of patients with COVID-19. Kidney Int 97(5):829–838. https://doi.org/10.1016/j.kint.2020.03.005
10. Uribarri A, Nunez-Gil IJ, Aparisi A, Becerra-Munoz VM, Feltes G, Trabattoni D, Fernandez-Rozas I, Viana-Llamas MC, Pepe M, Cerrato E, Capel-Astrua T, Romero R, Castro-Mejia AF, El-Battrawy I, Lopez-Pais J, D'Ascenzo F, Fabregat-Andres O, Bardaji A, Raposeiras-Roubin S, Marin F, Fernandez-Ortiz A, Macaya C, Estrada V, Investigators HC (2020) Impact of renal function on admission in COVID-19 patients: an analysis of the international HOPE COVID-19 (Health Outcome Predictive Evaluation for COVID 19) Registry. J Nephrol. https://doi.org/10.1007/s40620-020-00790-5
11. Diao B, Wang C, Wang R, Feng Z, Tan Y, Wang H, Wang C, Liu L, Liu Y, Liu Y, Wang G, Yuan Z, Ren L, Wu Y, Chen Y (2020) Human kidney is a target for novel severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2) infection. MedRxiv 2. https://doi.org/10.1101/2020.03.04.20031120
12. Su H, Yang M, Wan C, Yi LX, Tang F, Zhu HY, Yi F, Yang HC, Fogo AB, Nie X, Zhang C (2020) Renal histopathological analysis of 26 postmortem findings of patients with COVID-19 in China. Kidney Int 98(1):219–227. https://doi.org/10.1016/j.kint.2020.04.003
13. Ronco C, Reis T (2020) Kidney involvement in COVID-19 and rationale for extracorporeal therapies. Nat Rev Nephrol 16(6):308–310. https://doi.org/10.1038/s41581-020-0284-7
14. Pei G, Zhang Z, Peng J, Liu L, Zhang C, Yu C, Ma Z, Huang Y, Liu W, Yao Y, Zeng R, Xu G (2020) Renal involvement and early prognosis in patients with COVID-19 pneumonia. J Am Soc Nephrol 31(6):1157–1165. https://doi.org/10.1681/ASN.2020030276
15. Chan L, Chaudhary K, Saha A, Chauhan K, Vaid A, Zhao S, Paranjpe I, Somani S, Richter F, Miotto R, Lala A, Kia A, Timsina P, Li L, Freeman R, Chen R, Narula J, Just AC, Horowitz C, Fayad Z, Cordon-Cardo C, Schadt E, Levin MA, Reich DL, Fuster V, Murphy B, He JC, Charney AW, Bottinger EP, Glicksberg BS, Coca SG, Nadkarni GN, Mount Sinai CIC, Li L (2020) AKI in Hospitalized patients with COVID-19. J Am Soc Nephrol. https://doi.org/10.1681/ASN.2020050615
16. Fisher M, Neugarten J, Bellin E, Yunes M, Stahl L, Johns TS, Abramowitz MK, Levy R, Kumar N, Mokrzycki MH, Coco M, Dominguez M, Prudhvi K, Golestaneh L (2020) AKI in hospitalized patients with and without COVID-19: a comparison study. J Am Soc Nephrol 31(9):2145–2157. https://doi.org/10.1681/ASN.2020040509
17. Hirsch JS, Ng JH, Ross DW, Sharma P, Shah HH, Barnett RL, Hazzan AD, Fishbane S, Jhaveri KD, Northwell C-RC, Northwell Nephrology C-RC (2020) Acute kidney injury in patients hospitalized with COVID-19. Kidney Int 98(1):209–218. https://doi.org/10.1016/j.kint.2020.05.006
18. Adapa S, Chenna A, Balla M, Merugu GP, Koduri NM, Daggubati SR, Gayam V, Naramala S, Konala VM (2020) COVID-19 pandemic causing acute kidney injury and impact on patients with chronic kidney disease and renal transplantation. J Clin Med Res 12(6):352–361. https://doi.org/10.14740/jocmr4200
19. NHCo C (2020) The new coronavirus pneumonia diagnosis and treatment program. http://www.nhc.gov.cn/xcs/zhengcwj/202003/46c9294a7dfe4cef80dc7f5912eb1989/files/ce3e6945832a438eaae415350a8ce964.pdf. Accessed 4 March 2020
20. Stevens PE, The KDIGO CKD Guideline Work Group (2013) Evaluation and management of chronic kidney disease synopsis of the kidney disease improving global outcomes 2012 clinical practice guideline. Ann Intern Med 158:825–830
21. Kunutsor SK, Laukkanen JA (2020) Renal complications in COVID-19: a systematic review and meta-analysis. Ann Med 52(7):343–353. https://doi.org/10.1080/07853890.2020.1790643
22. Arentz M, Yim E, Klaff L, Lokhandwala S, Riedo FX, Chong M, Lee M (2020) Characteristics and outcomes of 21 critically Ill patients with COVID-19 in Washington State. JAMA 19(16):323
23. Pelayo J, Lo KB, Bhargav R, Gul F, Peterson E, DeJoy IR, Salacup GF, Albano J, Gopalakrishnan A, Azmaiparashvili Z, Patarroyo-Aponte G, Rangaswami J (2020) Clinical characteristics and outcomes of community- and hospital-acquired acute kidney injury with COVID-19 in a US Inner City Hospital System. Cardiorenal Med 10(4):223–231. https://doi.org/10.1159/000509182
24. Fominskiy EV, Scandroglio AM, Monti G, Calabrò MG, Landoni G, Dell'Acqua A, Beretta L, Moizo E, Ravizza A, Monaco F, Campochiaro C, Pieri M, Azzolini ML, Borghi G, Crivellari M, Conte C, Mattioli C, Silvani P, Mucci M, Turi S, Tentori S, Baiardo Redaelli M, Sartorelli M, Angelillo P, Belletti A, Nardelli P, Nisi FG, Valsecchi G, Barberio C, Ciceri F, Serpa Neto A, Dagna L, Bellomo R, Zangrillo A (2020) Prevalence, characteristics, risk factors, and outcomes of invasively ventilated COVID-19 patients with acute kidney injury and renal replacement therapy. Blood Purif 50:102–109. https://doi.org/10.1159/000508657
25. Guan WJ, Ni ZY, Hu Y, Liang WH, Ou CQ, He JX, Liu L, Shan H, Lei CL, Hui DSC, Du B, Li LJ, Zeng G, Yuen KY, Chen RC, Tang CL, Wang T, Chen PY, Xiang J, Li SY, Wang JL, Liang ZJ, Peng YX, Wei L, Liu Y, Hu YH, Peng P, Wang JM, Liu JY, Chen Z, Li G, Zheng ZJ, Qiu SQ, Luo J, Ye CJ, Zhu SY, Zhong NS, China Medical Treatment Expert Group for C (2020) Clinical characteristics of coronavirus disease 2019 in China. N Engl J Med 382(18):1708–1720. https://doi.org/10.1056/NEJMoa2002032
26. He L, Wei Q, Liu J, Yi M, Liu Y, Liu H, Sun L, Peng Y, Liu F, Venkatachalam MA, Dong Z (2017) AKI on CKD: heightened

injury, suppressed repair, and the underlying mechanisms. Kidney Int 92(5):1071–1083. https://doi.org/10.1016/j.kint.2017.06.030
27. NHCo C (2020) The latest situation of new coronavirus pneumonia. http://www.nhc.gov.cn/xcs/yqfkdt/202009/2de52736b3c6447d89b07890c2b78fc3.shtml. Accessed 21 September 2020
28. Richardson S, Hirsch JS, Narasimhan M, Crawford JM, McGinn T, Davidson KW, Northwell C-RC, Barnaby DP, Becker LB, Chelico JD, Cohen SL, Cookingham J, Coppa K, Diefenbach MA, Dominello AJ, Duer-Hefele J, Falzon L, Gitlin J, Hajizadeh N, Harvin TG, Hirschwerk DA, Kim EJ, Kozel ZM, Marrast LM, Mogavero JN, Osorio GA, Qiu M, Zanos TP (2020) Presenting characteristics, comorbidities, and outcomes among 5700 patients hospitalized with COVID-19 in the New York City area. JAMA https://doi.org/10.1001/jama.2020.6775
29. Zhou F, Yu T, Du R, Fan G, Liu Y, Liu Z, Xiang J, Wang Y, Song B, Gu X, Guan L, Wei Y, Li H, Wu X, Xu J, Tu S, Zhang Y, Chen H, Cao B (2020) Clinical course and risk factors for mortality of adult inpatients with COVID-19 in Wuhan, China: a retrospective cohort study. Lancet 395(10229):1054–1062. https://doi.org/10.1016/s0140-6736(20)30566-3
30. Chen N, Zhou M, Dong X, Qu J, Gong F, Han Y, Qiu Y, Wang J, Liu Y, Wei Y, Xia Ja YuT, Zhang X, Zhang L (2020) Epidemiological and clinical characteristics of 99 cases of 2019 novel coronavirus pneumonia in Wuhan, China: a descriptive study. Lancet 395(10223):507–513. https://doi.org/10.1016/s0140-6736(20)30211-7
31. Carrero JJ, Hecking M, Chesnaye NC, Jager KJ (2018) Sex and gender disparities in the epidemiology and outcomes of chronic kidney disease. Nat Rev Nephrol 14(3):151–164. https://doi.org/10.1038/nrneph.2017.181
32. Liu J, Li S, Liu J, Liang B, Wang X, Wang H, Li W, Tong Q, Yi J, Zhao L, Xiong L, Guo C, Tian J, Luo J, Yao J, Pang R, Shen H, Peng C, Liu T, Zhang Q, Wu J, Xu L, Lu S, Wang B, Weng Z, Han C, Zhu H, Zhou R, Zhou H, Chen X, Ye P, Zhu B, Wang L, Zhou W, He S, He Y, Jie S, Wei P, Zhang J, Lu Y, Wang W, Zhang L, Li L, Zhou F, Wang J, Dittmer U, Lu M, Hu Y, Yang D, Zheng X (2020) Longitudinal characteristics of lymphocyte responses and cytokine profiles in the peripheral blood of SARS-CoV-2 infected patients. EBioMedicine 55:102763. https://doi.org/10.1016/j.ebiom.2020.102763
33. Heine GH, Ortiz A, Massy ZA, Lindholm B, Wiecek A, Martinez-Castelao A, Covic A, Goldsmith D, Suleymanlar G, London GM, Parati G, Sicari R, Zoccali C, Fliser D, European R, Cardiovascular Medicine working group of the European Renal Association-European D, Transplant A (2012) Monocyte subpopulations and cardiovascular risk in chronic kidney disease. Nat Rev Nephrol 8(6):362–369. https://doi.org/10.1038/nrneph.2012.41
34. Xu X, Yu C, Qu J, Zhang L, Jiang S, Huang D, Chen B, Zhang Z, Guan W, Ling Z, Jiang R, Hu T, Ding Y, Lin L, Gan Q, Luo L, Tang X, Liu J (2020) Imaging and clinical features of patients with 2019 novel coronavirus SARS-CoV-2. Eur J Nucl Med Mol Imaging 47(5):1275–1280. https://doi.org/10.1007/s00259-020-04735-9
35. Ye Z, Zhang Y, Wang Y, Huang Z, Song B (2020) Chest CT manifestations of new coronavirus disease 2019 (COVID-19): a pictorial review. Eur Radiol 30(8):4381–4389. https://doi.org/10.1007/s00330-020-06801-0
36. Pan F, Ye T, Sun P, Gui S, Liang Bo, Li L, Zheng D, Wang J, Hesketh RL, Yang L, Zheng C (2020) Time course of lung changes at chest CT during recovery from coronavirus disease 2019 (COVID-19). Radiology 295(3):715–721
37. Sommerstein R, Kochen MM, Messerli FH, Grani C (2020) Coronavirus disease 2019 (COVID-19): do angiotensin-converting enzyme inhibitors/angiotensin receptor blockers have a biphasic effect? J Am Heart Assoc 9(7):e016509. https://doi.org/10.1161/JAHA.120.016509
38. WHO (2020) WHO discontinues hydroxychloroquine and lopinavir/ritonavir treatment arms for COVID-19. https://www.who.int/news-room/detail/04-07-2020-who-discontinues-hydroxychloroquine-and-lopinavir-ritonavir-treatment-arms-for-covid-19. Accessed 4 July 2020
39. D'Marco L, Puchades MJ, Romero-Parra M, Gimenez-Civera E, Soler MJ, Ortiz A, Gorriz JL (2020) Coronavirus disease 2019 in chronic kidney disease. Clin Kidney J 13(3):297–306. https://doi.org/10.1093/ckj/sfaa104
40. Abrishami A, Khalili N, Dalili N, Tabari RK, Farjad R, Samavat S, Naghadehi AN, Haghighatkhah H, Nafar M, Sanei-Taheri M (2020) Clinical and radiologic characteristics of COVID-19 in patients with CKD. Iran J Kideny Dis 14(4):267–277
41. Henry BM, Lippi G (2020) Chronic kidney disease is associated with severe coronavirus disease 2019 (COVID-19) infection. Int Urol Nephrol 52(6):1193–1194. https://doi.org/10.1007/s11255-020-02451-9
42. Oyelade T, Alqahtani J, Canciani G (2020) Prognosis of COVID-19 in patients with liver and kidney diseases: an early systematic review and meta-analysis. Trop Med Infect Dis 5(2). https://doi.org/10.3390/tropicalmed5020080
43. Collado S, Arenas MD, Barbosa F, Cao H, Montero MM, Villar-Garcia J, Barrios C, Rodriguez E, Sans L, Sierra A, Perez-Saez MJ, Redondo-Pachon D, Coca A, Maiques JM, Guerri-Fernandez R, Horcajada JP, Crespo M, Pascual J (2020) COVID-19 in grade 4–5 chronic kidney disease patients. Kidney Blood Press Res 1–7. doi:https://doi.org/10.1159/000511082