



OPEN ACCESS

Serum cortisol concentration and COVID-19 severity: a systematic review and meta-analysis

Nasrin Amiri-Dashatan,¹ Mehdi Koushki ,² Negin Parsamanesh,¹ Hossein Chiti ²

► Additional supplemental material is published online only. To view, please visit the journal online (<http://dx.doi.org/10.1136/jim-2021-001989>).

¹Zanjan Metabolic Diseases Research Center, Zanjan University of Medical Sciences, Zanjan, Iran (the Islamic Republic of)

²Department of Clinical Biochemistry, School of Medicine, Zanjan University of Medical Sciences, Zanjan, Iran (the Islamic Republic of)

Correspondence to

Dr Hossein Chiti, Zanjan University of Medical Sciences, Zanjan, 77978-45157, Iran (the Islamic Republic of); h.chiti@yahoo.com

Accepted 13 December 2021

ABSTRACT

The novel COVID-19 outbreak is a major health threat to human beings with multiorgan injuries. However, its endocrine system manifestations are much less studied. In this study, we aimed to reassess the available findings on the association between cortisol level and severity of COVID-19 infection. We conducted a systematic search on Medline/PubMed, Scopus, Web of Science, and Cochrane Library databases. To pool data, a random-effects model was performed depending on the heterogeneity among studies. Sensitivity analysis was also carried out by removing each study systematically. In addition, subgroup and meta-regression analyses were performed depending on the presence of the variables of sex and age. Subsequently, 11 studies (5 observational studies and 6 case reports) were included in the meta-analysis. Pooled analysis on the observational studies showed significantly higher levels of cortisol in patients with severe COVID-19 in comparison with those with mild-to-moderate COVID-19 (standardized mean difference: 1.48 µg/dL; 95% CI (0.51 to 2.46); $p=0.003$). Assessment of the results of case reports revealed that the patients with severe COVID-19 demonstrated higher cortisol levels than the patients with mild-to-moderate COVID-19. No publication bias was observed using the Begg's ($p=0.08$) and Egger's tests ($p=0.09$). Meta-regression illustrated a significant correlation between cortisol levels with sex. The serum cortisol level seems to be higher in patients with severe COVID-19 infection. This finding could be helpful to detect patients with poor prognosis at early stages of the disease, although age and sex may modify this level.

INTRODUCTION

A novel coronavirus (COVID-19), caused by SARS-CoV-2, has infected about 152,000,000 persons and caused more than 3 million deaths (May 01, 2021) worldwide since its sudden epidemic in Wuhan, China in December 2019.^{1 2} Physiological stress from serious disease and elective surgery elevates cortisol concentrations and bioavailability in serum through the activation of the hypothalamic-pituitary-adrenal (HPA) axis, reduced cortisol synthesis, and the binding protein level like cortisol-binding globulin.^{3 4} Cortisol elevation

Significance of this study

What is already known about this subject?

- Due to COVID-19 pandemic, compounds are needed to separate severe status of COVID-19 from the mild-to-moderate ones.
- Several studies have reported serum cortisol level in severe COVID-19 in comparison with mild-to-moderate COVID-19.
- The results concerning the association between serum cortisol level and severity of COVID-19 are conflicting and inclusive.

What are the new findings?

- Serum cortisol level significantly increased in patients with severe COVID-19 compared with those with mild-to-moderate COVID-19.
- The results of the subgroup analysis showed higher levels of cortisol in men than in women in the severe form of COVID-19.

How might these results change the focus of research or clinical practice?

- Significant increase in serum cortisol level in patients with severe COVID-19 could be an effective biomarker for detection of serious complications in those hospitalized in the intensive care unit. Therefore, these data may be useful for clinicians.

is a necessary component of the body's stress response, causing adaptive improvements in metabolism, immune regulation, and cardiovascular function.³ Adrenal insufficiency is a problem in which the adrenal glands do not release enough cortisol, and it is usually known by a cortisol reaction to corticotrophin of lower than 21 µg/dL.⁵ Cortisol levels rise in direct proportion to the severity of sepsis. Certainly, glucocorticoids elevate the recruitment of the inflammatory agent and determine the systemic inflammatory response.⁶ However, in about 30%–70% of sepsis cases, the adrenal reaction is insufficient or there is glucocorticoid periphery resistance, all of which are linked to a weak prognosis and necessary supplementation.⁷



© American Federation for Medical Research 2022. No commercial re-use. See rights and permissions. Published by BMJ.

To cite: Amiri-Dashatan N, Koushki M, Parsamanesh N, et al. *J Investig Med* Epub ahead of print: [please include Day Month Year]. doi:10.1136/jim-2021-001989

Meanwhile, immunomodulatory effects are found in endocrine hormones. The path and effects of HPA axis activation are influenced by endocrine dysfunction. Cortisol and dehydroepiandrosterone (DHEA), two adrenal gland hormones, have opposite impacts on immune activity.^{8,9} DHEA, a precursor to estrogens and androgens, and sulfated form of DHEA are the most abundant adrenal steroids controlling the synthesis and activity of cortisol, the stress hormone. Adrenal hormones formed in response to infection will control immune function on their own.¹⁰ Glucocorticoids have a significant anti-inflammatory activity by interacting with glucocorticoid receptors in the cytoplasm of immune cells. Infection causes cytokine-producing immune cells to become more responsive to glucocorticoids.⁸

The effects of COVID-19 on cortisol are still uncertain. It has been recommended that SARS-CoV, the precursor of SARS-CoV-2, could activate an immunogenic reaction to adrenocorticotrophic hormones.¹¹ SARS-CoV-2 could employ similar pathways to increase morbidity and mortality by causing a cortisol synthesis insufficiency linked to a serious disease.^{11,12} The key glucocorticoid cortisol can cross the blood-brain barrier and affect central nervous system activity by stimulating central corticosteroid receptors.^{13,14} Since stress is also linked to mood shifts, researchers have looked into the effects of cortisol on emotional processes in a variety of studies. Stress has been revealed to have a substantial impact on negative affect, while cortisol levels and negative affective state have been shown to be related.¹⁵

To date, several inflammatory prognostic markers for this disease have been introduced, such as interleukin-6 (IL-6), C reactive protein (CRP), and several others, but no specific marker has yet been identified in association with endocrine hormone levels, such as cortisol, for the prognosis of the disease outcome.¹⁶ However, there is an immediate need to identify better and specific markers in this regard. In addition, we are informed that no meta-analysis studies have been published in this area. The purpose of the current meta-analysis was to review the available studies on the role of cortisol in patients with COVID-19 entirely to improve survival rates and decrease infection and fatality in this pandemic.

MATERIALS AND METHODS

Study protocol

The current study has been conducted according to the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines.¹⁷

Eligibility criteria

In order to investigate the association between cortisol level and COVID-19 infection severity in patients with confirmed SARS-CoV-2 infection, we included all published articles assessing the serum level of cortisol and severe outcome of COVID-19 infection without any language limitations. In addition, study articles were classified into two groups based on study design, including observational and case report studies. We further excluded review articles, letters, books and also studies with incomplete data from our meta-analysis. We also noted that none of the included studies in this meta-analysis reported a known underlying adrenal disease and corticosteroid use before admission

to the hospital due to previous underlying disease, so we performed this meta-analysis by assuming that none of the patients had such diseases.

Search strategies

We performed a literature search using the online databases of Medline/PubMed, Web of Science, Scopus and Cochrane Library for relevant publications up to April 2021. However, we used the following medical subject headings term in our search strategy: ("COVID-19" OR "severe acute respiratory syndrome coronavirus 2" OR "SARS-CoV-2" OR "new coronavirus" OR "2019-nCoV") AND ("Cortisol" OR "Cortisol Level" OR "Serum Cortisol Level" OR "Cortisol Concentration" OR "Adrenal"). In addition, we searched all reference lists of retrieved articles to get missed studies. The duplicated articles were removed from the analysis. The systematic search and reviewing of the full-text articles was performed by two independent reviewers (NA-D and MK).

Data extraction process and assessment for study quality

Data that include authors' names, date of study, country, study design, sample size, serum level of cortisol and outcome of the studies were extracted by two independent investigators, as appropriate. The Newcastle–Ottawa Scale (NOS) was used for quality assessment of the observational studies.¹⁸ Based on the NOS system, a maximum of 9 points can be awarded to each article. The selection, comparability, and exposure of every included study were evaluated and assigned a score from 0 to 9. In this study, the NOS scores <4, 4–6, and ≥7 were considered as low-quality, moderate-quality and high-quality studies, respectively. Furthermore, 7 case report studies were systematically assessed for risk of bias using instructions presented in the Joanna Briggs Institute (JBI) critical appraisal checklist.¹⁹ The following questions were used for the evaluation of every case report study: (1) Were the patient's demographic characteristics clearly described?; (2) Was the patient's history clearly described and presented as a timeline?; (3) Was the current clinical condition of the patient on presentation clearly described?; (4) Were diagnostic tests or assessment methods and the results clearly described?; (5) Was the intervention(s) or treatment procedure(s) clearly described?; (6) Was the post-intervention clinical condition clearly described?; (7) Were adverse events (harms) or unanticipated events identified and described?; (8) Does the case report provide takeaway lessons? According to the JBI checklist, a judgment of 'yes' showed high quality, whereas 'no' indicated low quality, labeling a question as 'unclear' or 'not applicable' indicated an unclear or unknown risk of bias.

Statistical analysis

A random-effects model was used to calculate the pooled effect size. The standardized mean difference (SMD) with 95% CI was used for data analysis in observational studies. Moreover, we also analyzed significance and calculated CI for SMD effect size using the Hartung-Knapp-Sidik-Jonkman (HKSJ) method regarding the small number of studies and between-study heterogeneity. Evaluating the results of case report studies was performed using reported characteristics of patients with severe COVID-19 and high cortisol level in comparison with patients with mild-to-moderate

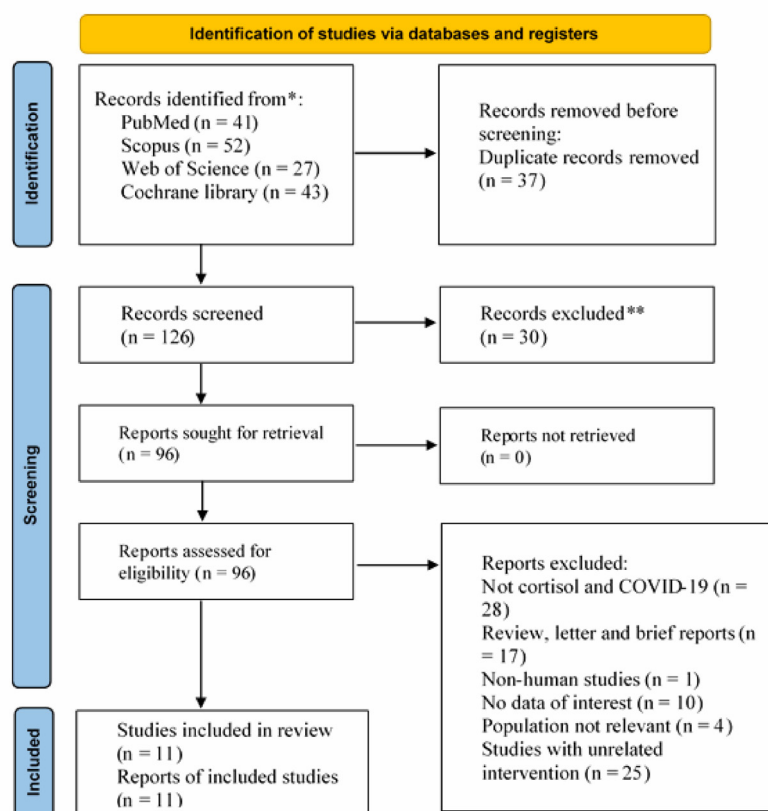


Figure 1 Process of study selection based on the Preferred Reporting Items for Systematic Reviews and Meta-Analyses.

COVID-19. In cases where the circulating levels of cortisol were reported using median and IQR values, mean value was estimated using a method previously defined.²⁰ To find the heterogeneity among included studies, the heterogeneity was measured using the Higgins I^2 ($p < 0.1$, $I^2 > 50\%$ was considered representative of significant statistical heterogeneity).²¹ To explore the source of significant heterogeneity between the studies, subgroup analysis was performed according to a subgroup of sex (male and female). The potential publication bias in observational studies was evaluated through a visual inspection of funnel plot and the Begg's and Egger's tests. The trim-and-fill analysis was used to adjust any significant publication bias detected. In addition, a sensitivity analysis was performed to assess the effect of each study on the overall effect size by using the 'leave-one-out' method by removing the step-by-step study in the analysis. Subsequently, a random-effects meta-regression analysis was performed on the observational studies, using an unrestricted maximum likelihood method, to determine the association between the circulating levels of cortisol with age and sex (male and female). A $p < 0.05$ was considered statistically significant. Comprehensive Meta-Analysis V.2 software was used for the data analysis (Biostat, New Jersey, USA).

RESULTS

Study selection and characteristics

A total of 163 records was identified from four main databases: PubMed, Scopus, Web of Science and Cochrane

Library up to April 2021. After the exclusion of duplicates and irrelevant studies, 11 articles were included in this systematic review and meta-analysis. A PRISMA flow chart detailing the process of study selection is shown in [figure 1](#).

The primary information of included studies

The summary characteristics of all included studies are presented in [table 1](#). Of these 11 studies, 4 and 3 studies were performed in the UK and Iran, respectively. The other studies were from Brazil, Cameroon, UAE and Israel. All studies were published during 2020 and 2021. Seven studies were designed as case reports and 4 as observational studies (cohort and cross-sectional). The 476 patients with COVID-19 infection participated in this meta-analysis. Of the participants, 374 (78%) were male and 102 (22%) were female. The NOS scores ranged from 4 to 9. Quality assessment of case report studies indicated that most of the case report studies did not provide sufficient data about question 8, while other questions from the JBI checklist were sufficiently addressed by most of the case report studies. Details of quality assessment of case report studies are summarized in [table 2](#).

The relationship of high cortisol levels with severity of COVID-19 based on observational studies

The meta-analysis of observational studies demonstrated significantly higher levels of cortisol in patients with severe COVID-19 in comparison with mild-to-moderate COVID-19 controls (SMD: 1.48 $\mu\text{g/dL}$; 95% CI (0.51 to 2.46); $p = 0.003$) ([figure 2](#)). Calculation of HKSJ adjustment

Table 1 The study characteristics included in this meta-analysis

Author	Country	Ratio of sex (M/F)	Study design	Sample size		Cortisol ($\mu\text{g/dL}$)		Outcome	NOS score
				Non-severe	Severe	Non-severe	Severe		
Frankel <i>et al</i> ²⁶	Israel	F	Case report	1	–	<1	–	COVID-19 infection is associated with BAH. Adrenal insufficiency is life-threatening, therefore we suggest considering performing early adrenal axis testing for patients with COVID-19 with clinical suspicion of adrenal insufficiency.	–
Elkhouly <i>et al</i> ²⁷	UK	M	Case report	–	1	–	26.6	This study reported that adrenal hemorrhage should be considered as a rare complication of COVID-19 and potentially lethal.	–
Etoja <i>et al</i> ⁷	Cameroon	45/35	Cross-sectional	70	10	4.5 \pm 0.5	11.45 \pm 1.8	This study recorded higher levels of cortisol among COVID-19 cases that need further oxygen therapy than those with mild condition.	8
Hashim <i>et al</i> ²⁸	UAE	M	Case report	1	–	4.6	–	SARS-CoV-2 can knock down the host's cortisol stress response and clinicians must be vigilant about the possibility of an underlying relative cortisol deficiency in patients with COVID-19.	–
Heidarpour <i>et al</i> ²⁹	Iran	M	Case report	1	–	12	–	This study suggested that early detection of adrenal insufficiency among critically ill patients infected with SARS-CoV-2 could be lifesaving.	–
Vaez Mahdavi <i>et al</i> ¹⁰	Iran	56/5	Cohort	46	15	21.4 \pm 11.2	26.2 \pm 13.7	The current study results support that COVID-19 affects the patients' body via mechanisms related to the effects of DHEA-S and cortisol.	9
Ramezani <i>et al</i> ³⁴	Iran	17/13	Cross-sectional	26	4	26.2 \pm 6.5	36.1 \pm 3.2	This study significantly correlated higher levels of cortisol in non-survived patients of COVID-19 in comparison with surviving patients.	8
Freire Santana <i>et al</i> ⁶	Brazil	M	Case series	16	12	22.4	48.01 \pm 21.2	In this study, adrenal lesions are frequent in patients with severe COVID-19. No cortisol level less than 10 $\mu\text{g/dL}$, which is a reliable and widely available laboratory marker of adrenal insufficiency in critically ill patients, could contribute to the lethal outcome.	–
Sharrack <i>et al</i> ³⁰	UK	M	Case report	1	–	31.3 \pm 2.7	–	AH and high serum cortisol are rare complications of COVID-19 infection.	–
Tan <i>et al</i> ¹¹	UK	240/51	Cohort	132	159	22.4 \pm 10	18.8 \pm 8.1	This study revealed the association between high serum total cortisol concentrations and mortality from COVID-19.	9
Kumar <i>et al</i> ³¹	UK	F	Case report	1	–	21.7	–	COVID-19 creates a hypercoagulable state, with acute adrenal infarction as a possible prothrombotic complication.	–

AH, adrenal hemorrhage; BAH, bilateral adrenal hemorrhage; DHEA-S, dehydroepiandrosterone-sulfated form; F, female; M, male; NOS, Newcastle–Ottawa Scale.

Table 2 Quality assessment of case report studies involved in the meta-analysis

Study	Q1	Q2	Q3	Q4	Q5	Q6	Q7	Q8
Frankel <i>et al</i> ²⁶	Y	N	Y	Y	N	Y	U	Y
Elkhouly <i>et al</i> ²⁷	Y	N	N	Y	N	Y	U	Y
Hashim <i>et al</i> ²⁸	Y	Y	Y	Y	Y	Y	U	Y
Heidarpour <i>et al</i> ²⁹	Y	Y	Y	Y	U	Y	U	Y
Freire Santana <i>et al</i> ⁶	Y	Y	N	N	U	U	N	Y
Sharrack <i>et al</i> ³⁰	Y	N	Y	Y	Y	Y	Y	Y
Kumar <i>et al</i> ³¹	Y	N	Y	Y	Y	Y	Y	Y

Q1: Were the patient's demographic characteristics clearly described?

Q2: Was the patient's history clearly described and presented as a timeline?

Q3: Was the current clinical condition of the patient on presentation clearly described?

Q4: Were diagnostic tests or assessment methods and the results clearly described?

Q5: Was the intervention(s) or treatment procedure(s) clearly described?

Q6: Was the post-intervention clinical condition clearly described?

Q7: Were adverse events (harms) or unanticipated events identified and described?

Q8: Does the case report provide takeaway lessons?

N, no; Q, question; U, unclear; Y, yes.

was also significant (SMD: 1.49 $\mu\text{g/dL}$; 95% CI (0.48 to 2.55); $p=0.007$) regarding the small number of included studies. There was a significant heterogeneity among included studies ($I^2=90.4\%$, $p<0.001$). To find sources of significant heterogeneity, subgroup and meta-regression analyses were performed.

The relationship of high cortisol levels with severity of COVID-19 based on case reports

We evaluated the relationship between higher cortisol levels and the severity of COVID-19 among case report studies that were reported in the mentioned electronic databases. Evaluation of the circulating cortisol level among case report studies showed that patients with severe COVID-19 have higher levels of cortisol than those with non-severe COVID-19.

Publication bias

To assess publication bias of observational studies, the Begg's rank correlation (Kendall's tau with continuity correction=0.7, $Z=1.71$, two-tailed $p=0.08$) and Egger's linear regression tests (intercept=3.9, $\text{SE}=1.6$; 95% CI=–1.1 to 9.1, $t=2.4$, $\text{df}=3$, two-tailed $p=0.09$) were indicated absence of publication bias. The funnel plot of the study precision (inverse SE) by effect size (SMD) was symmetric and suggested no potential publication bias in reporting the circulating levels of cortisol in patients with COVID-19 (figure 3). The observed publication bias was imputed using trim-and-fill correction. There were two imputed studies.

Sensitivity analysis

Sensitivity analysis was performed on the observational studies using the 'leave-one-out' method. Sensitivity analysis showed that the pooled effect size was not altered when every single study was in turn removed (effect size ranged between 0.74 and 1.87 $\mu\text{g/dL}$). Circulating cortisol level remained significantly higher (SMD: 1.91 $\mu\text{g/dL}$; 95% CI

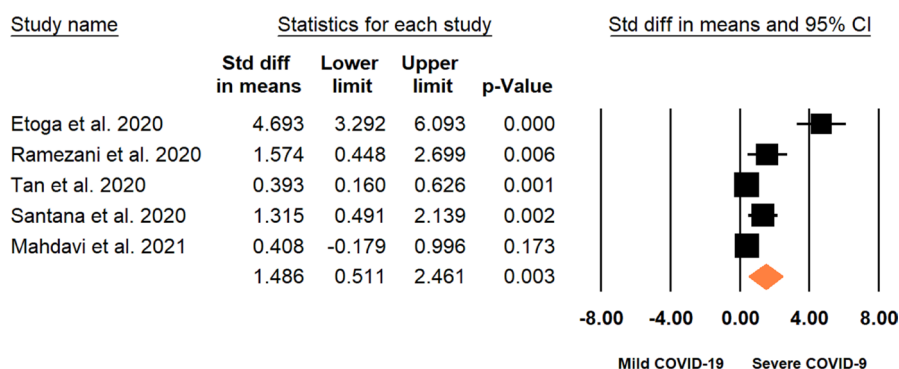


Figure 2 Forest plot evaluating standardized mean differences and 95% CIs for the relationship between the circulating cortisol level and COVID-19 severity. Data were analyzed using a random-effects model.

(0.77 to 1.61); $p < 0.001$) in patients with severe COVID-19 after excluding the study with larger sample size (figure 4).

Subgroup analysis and meta-regression analysis

To explore significant heterogeneity among studies, subgroup analysis was performed. Analysis of the subgroup of sex (male, female) showed that the circulating cortisol levels were not significant in male patients with severe COVID-19 (SMD: 0.5 $\mu\text{g/dL}$; 95% CI (-0.21 to 1.23); $p = 0.17$) compared with female patients with severe COVID-19 (figure 5). Besides, to get more source of heterogeneity, random-effects meta-regression was performed on the observational studies. Meta-regression indicated no significant association between circulating cortisol level and age (slope: -0.14; 95% CI (-0.20 to -0.08); $p < 0.001$). However, there was a significant positive association with male sex (slope: -0.016; 95% CI (-0.026 to -0.006); $p < 0.001$) and female sex (slope: -0.012; 95% CI (-0.020

to -0.004); $p = 0.001$) (online supplemental figure 1). Therefore, the age and sex variables show partly significant heterogeneity among included studies.

DISCUSSION

The novel emerging coronavirus (SARS-CoV-2) has threatened people all over world. The disease has a broad range of clinical manifestations, from asymptomatic to fatal infection. Additionally, there is no definitive cure for the disease and only supportive therapies are available.²² Recent studies have reported that the cytokine storm (hyperinflammation) is one of the main mechanisms of acute respiratory distress syndrome and multiple organ dysfunction syndromes in patients with COVID-19.²³ However, there is limited information on the relationship between COVID-19 and endocrine status. It can be said that stress during the disease leads to the HPA axis activation and as a result elevates the level of serum cortisol in patients.²⁴ Hence, to deal with the

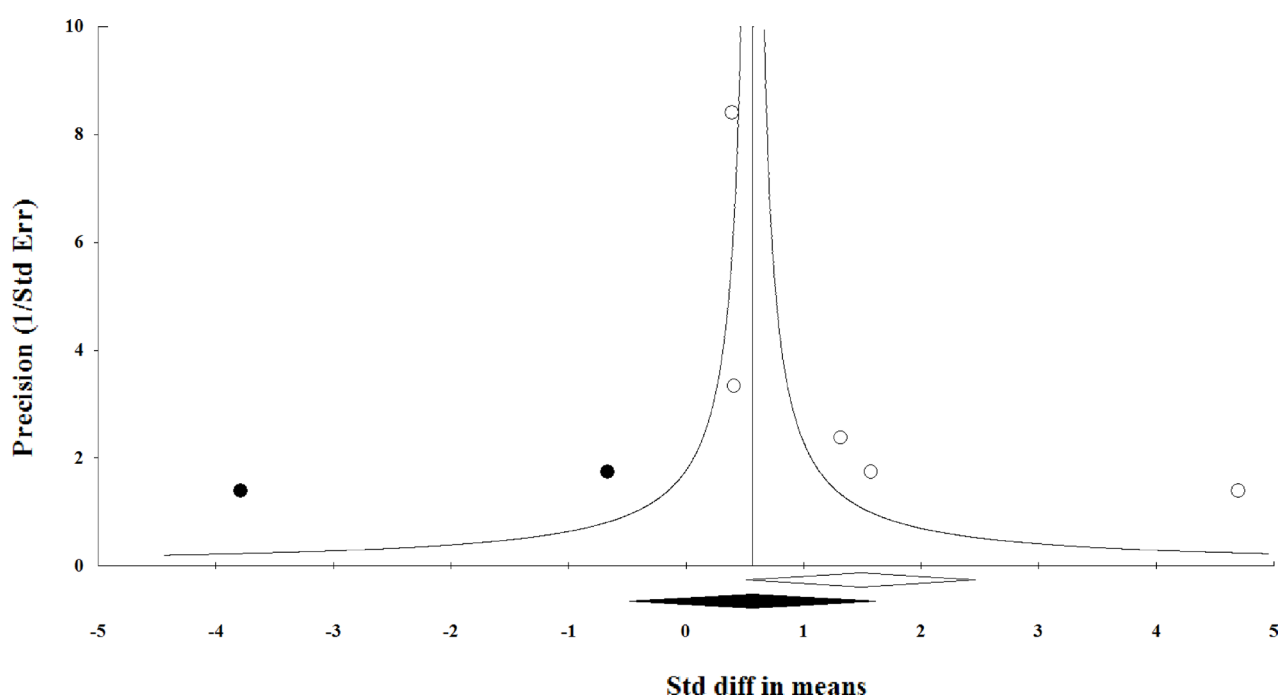


Figure 3 Funnel plot of publication bias detailing the study precision (inverse SE) by effect size (standard difference in means) for the relationship between the circulating cortisol level and COVID-19 severity. Data were analyzed using a random-effects model.

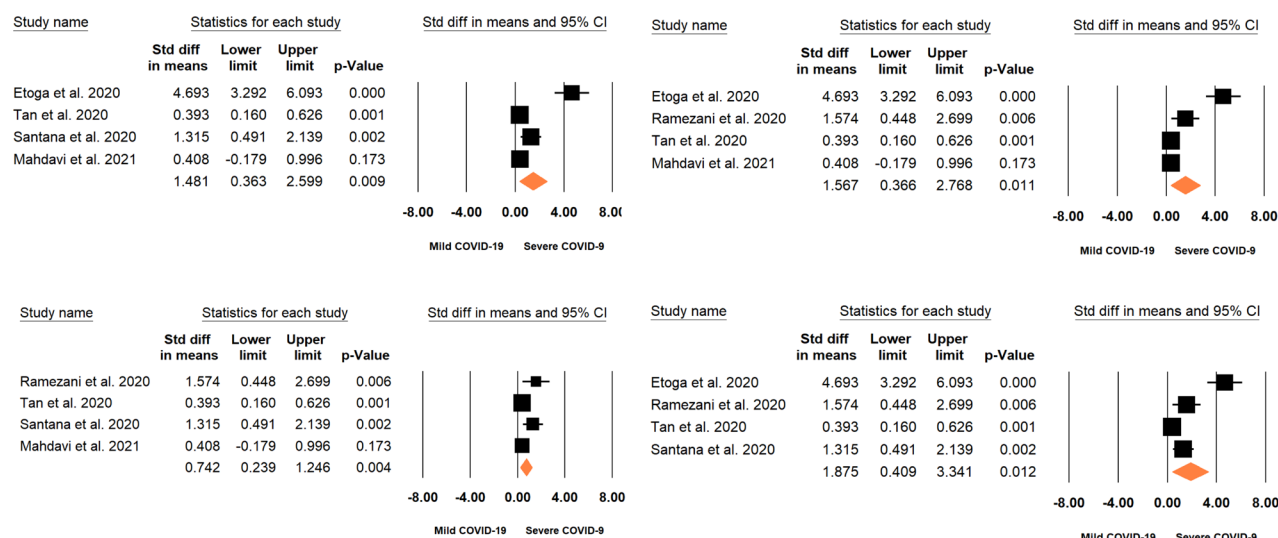


Figure 4 Sensitivity analyses were performed using 'leave-one-out' method. The pooled effect size was estimated when every single study was in turn removed. Data were analyzed using a random-effects model.

new emerging COVID-19 infection with such a wide range of complications, there is an urgent need to identify and introduce factors associated with the prediction of disease outcome.

In this meta-analysis, we aimed to analyze all the available data regarding serum cortisol level and disease severity in patients with COVID-19 for the first time. This work was based on 496 patients from 11 studies assessing the cortisol level in patients with severe versus non-severe evidence of COVID-19. The findings of this paper reinforced the hypothesis that the serum level of cortisol is associated with severe outcomes in patients with COVID-19 infection.

We found out that an increased cortisol level is prevalent among patients with the severe form of COVID-19 infection. Furthermore, the patients with high serum cortisol levels are most likely at higher risk of developing severe form of COVID-19 and even dying from the disease. Our results demonstrated that the serum cortisol levels were higher among patients with the severe form. Our findings are in an agreement with previous studies. Previously, elevated cortisol levels have been suggested as a potential risk factor for severe outcome and death in COVID-19.¹¹ Tan *et al* suggested cortisol as a predictor biomarker rather than other markers related to COVID-19, such as IL-6, CRP and D-dimer.¹¹ In addition, cortisol, in combination with other markers, can be applied as a prognostic marker of the disease outcome. In line with our study, Ramezani *et al* also

found that patients with more severe form of the disease were more likely to have elevated serum cortisol levels.²⁴

To enhance the validity of the results, the studies were classified into two groups, including observational and case report studies. The obtained results for the two types of studies proved that the circulating cortisol levels significantly increase in patients with severe COVID-19 in comparison with those with mild-to-moderate COVID-19. It should be noticed that in case report studies, all of the examined clinical symptoms were reported in one sample; thus, the obtained results of the combined data of case report studies should be interpreted with caution.

Currently, investigations on the mechanisms of COVID-19 being related to elevated cortisol are limited. The elevation in cortisol levels is an important component of the body's response to stress, triggering adaptive alterations in regulation of the immune system. It has been reported that SARS-CoV might activate an immunogenic response to adrenocorticotrophic hormone.²⁵ On account of the genomic similarity between SARS-CoV-2 and SARS-CoV, a similar mechanism is probably applied, leading to morbidity and mortality through induction of cortisol insufficiency related to the severe form.

The current study has some limitations, including the restricted interpretation of our meta-analysis with the small sample size and lack of reports on adrenal damage during COVID-19 infection in people tested positive for

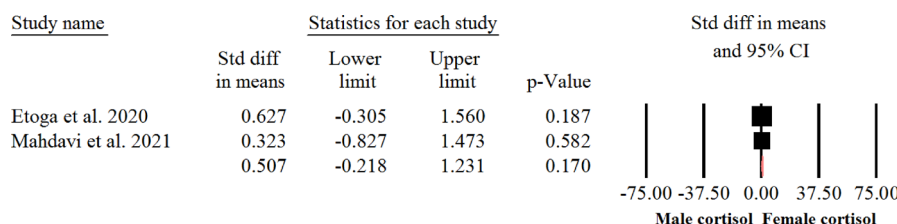


Figure 5 Forest plot detailing subgroup of standardized mean difference and 95% CIs for the relationship between the circulating cortisol level and COVID-19 severity. Studies were classified on the basis of sex (male and female).

SARS-CoV-2. Moreover, another limitation of the present study was significant heterogeneity among the included studies. To this end, we performed subgroup and meta-regression analyses to explore the source of heterogeneity. Additionally, the relatively small sample size in subgroup analysis could be another limitation of the current research.

In summary, given that the patients' conditions for cortisol response are different, it is too early to mention it as a distinctive biomarker. Regarding this, cortisol, in combination with other markers, may be helpful as a prognostic marker of the disease outcome. Measurements of serum cortisol levels in patients with COVID-19 can provide a new perspective on the proper management of the disease and in the future, can be effective alone or in combination with the other reported prognostic markers associated with the prediction of disease outcome. However, further validation studies are required in this regard. On the other hand, since cortisol has been implicated as the cause of a broad range of mental disorders, the psychological interventions during the illness might be important in reducing and improving the complications and outcome of the disease.

Acknowledgements The authors would like to thank the Zanjan Metabolic Diseases Research Center, Zanjan University of Medical Sciences, Zanjan, Iran for the support.

Contributors All the authors drafted the manuscript. NA-D, MK and NP contributed to the improvement of the selection criteria, the risk of bias assessment strategy and data extraction criteria. NA-D and MK started selecting publications and assessing their eligibility and quality. All the authors promoted the search strategy. MK and HC provided statistical expertise. All authors read, provided feedback and approved the final manuscript.

Funding The authors have not declared a specific grant for this research from any funding agency in the public, commercial or not-for-profit sectors.

Competing interests None declared.

Patient consent for publication Not required.

Ethics approval This study does not involve human participants.

Provenance and peer review Not commissioned; externally peer reviewed.

Supplemental material This content has been supplied by the author(s). It has not been vetted by BMJ Publishing Group Limited (BMJ) and may not have been peer-reviewed. Any opinions or recommendations discussed are solely those of the author(s) and are not endorsed by BMJ. BMJ disclaims all liability and responsibility arising from any reliance placed on the content. Where the content includes any translated material, BMJ does not warrant the accuracy and reliability of the translations (including but not limited to local regulations, clinical guidelines, terminology, drug names and drug dosages), and is not responsible for any error and/or omissions arising from translation and adaptation or otherwise.

Open access This article is made freely available for use in accordance with BMJ's website terms and conditions for the duration of the covid-19 pandemic or until otherwise determined by BMJ. You may use, download and print the article for any lawful, non-commercial purpose (including text and data mining) provided that all copyright notices and trade marks are retained.

ORCID iDs

Mehdi Koushki <http://orcid.org/0000-0003-0071-3505>

Hossein Chiti <http://orcid.org/0000-0001-9777-1570>

REFERENCES

- Parsamanesh N, Pezeshgi A, Hemmati M. Neurological manifestations of coronavirus infections: role of angiotensin-converting enzyme 2 in COVID-19. *Int J Neurosci* 2020;1–11.
- Asghari A, Naseri M, Safari H, et al. The novel insight of SARS-CoV-2 molecular biology and pathogenesis and therapeutic options. *DNA Cell Biol* 2020;39:1741–53.
- Téblick A, Peeters B, Langouche L, et al. Adrenal function and dysfunction in critically ill patients. *Nat Rev Endocrinol* 2019;15:417–27.
- Khoo B, Boshier PR, Freethy A, et al. Redefining the stress cortisol response to surgery. *Clin Endocrinol* 2017;87:451–8.
- Tallis PH, Rushworth RL, Torpy DJ, et al. Adrenal insufficiency due to bilateral adrenal metastases - A systematic review and meta-analysis. *Heliyon* 2019;5:e01783.
- Freire Santana M, Borba MGS, Baia-da-Silva DC, et al. Case report: adrenal pathology findings in severe COVID-19: an autopsy study. *Am J Trop Med Hyg* 2020;103:1604–7.
- Etoga MCE, Inna AH, Guewo-Fokeng M. Baseline serum total cortisol during the primary corona virus infection in the beginning of the pandemic in Cameroon, 2020.
- Heffner KL. Neuroendocrine effects of stress on immunity in the elderly: implications for inflammatory disease. *Immunol Allergy Clin North Am* 2011;31:95–108.
- Wu T-T, Chen Y, Zhou Y, et al. Prognostic value of dehydroepiandrosterone sulfate for patients with cardiovascular disease: a systematic review and meta-analysis. *J Am Heart Assoc* 2017;6:e004896.
- Vaez Mahdavi MR, Kaboudanian Ardestani S, Rezaei A, et al. COVID-19 patients suffer from DHEA-S sufficiency. *Immunoregulation* 2020;3:135–44.
- Tan T, Khoo B, Mills EG, et al. Association between high serum total cortisol concentrations and mortality from COVID-19. *Lancet Diabetes Endocrinol* 2020;8:659–60.
- Khodeir MM, Shabana HA, Alkhamiss AS, et al. Early prediction keys for COVID-19 cases progression: a meta-analysis. *J Infect Public Health* 2021;14:561–9.
- Sapolsky RM, Romero LM, Munck AU. How do glucocorticoids influence stress responses? integrating permissive, suppressive, stimulatory, and preparative actions. *Endocr Rev* 2000;21:55–89.
- Joëls M. Modulatory actions of steroid hormones and neuropeptides on electrical activity in brain. *Eur J Pharmacol* 2000;405:207–16.
- Het S, Schoofs D, Rohleder N, et al. Stress-induced cortisol level elevations are associated with reduced negative affect after stress: indications for a mood-buffering cortisol effect. *Psychosom Med* 2012;74:23–32.
- Amiri-Dashatan N, Koushki M, Ghorbani F, et al. Increased inflammatory markers correlate with liver damage and predict severe COVID-19: a systematic review and meta-analysis. *Gastroenterol Hepatol Bed Bench* 2020;13:282.
- Moher D, Liberati A, Tetzlaff J, et al. Preferred reporting items for systematic reviews and meta-analyses: the PRISMA statement. *PLoS Med* 2009;6:e1000097.
- Luchini C, Stubbs B, Solmi M, et al. Assessing the quality of studies in meta-analyses: advantages and limitations of the Newcastle Ottawa scale. *World J Metaanal* 2017;5:80–4.
- Pierson DJ. How to read a case report (or teaching case of the month). *Respir Care* 2009;54:1372–8.
- Hozo SP, Djulbegovic B, Hozo I. Estimating the mean and variance from the median, range, and the size of a sample. *BMC Med Res Methodol* 2005;5:1–10.
- Pathak M, Dwivedi SN, Deo S. Which is the preferred measure of heterogeneity in meta-analysis and why? A revisit. *Biostat Biometrics Open Acc* 2017;1:1–7.
- Wu Z, McGoogan JM. Characteristics of and Important Lessons From the Coronavirus Disease 2019 (COVID-19) Outbreak in China: Summary of a Report of 72 314 Cases From the Chinese Center for Disease Control and Prevention. *JAMA* 2020;323:1239–42.
- Hojyo S, Uchida M, Tanaka K, et al. How COVID-19 induces cytokine storm with high mortality. *Inflamm Regen* 2020;40:1–7.
- Ramezani M, Simani L, Karimialavijeh E, et al. The role of anxiety and cortisol in outcomes of patients with Covid-19. *Basic Clin Neurosci* 2020;11:179–84.
- Pal R. COVID-19, hypothalamo-pituitary-adrenal axis and clinical implications. *Endocrine* 2020;68:251–2.
- Frankel M, Feldman I, Levine M, et al. Bilateral adrenal hemorrhage in coronavirus disease 2019 patient: a case report. *J Clin Endocrinol Metab* 2020;105:dga487:3745–9.
- Elkhouly MMN, Elazzab AA, Moghul SS. Bilateral adrenal hemorrhage in a man with severe COVID-19 pneumonia. *Radiol Case Rep* 2021;16:1438–42.
- Hashim M, Athar S, Gaba WH. New onset adrenal insufficiency in a patient with COVID-19. *BMJ Case Rep* 2021;14:e237690.
- Heidarpour M, Vakhsheeri M, Abbasi S, et al. Adrenal insufficiency in coronavirus disease 2019: a case report. *J Med Case Rep* 2020;14:1–4.
- Sharrack N, Baxter CT, Paddock M, et al. Adrenal haemorrhage as a complication of COVID-19 infection. *BMJ Case Rep* 2020;13:e239643.
- Kumar R, Guruparan T, Siddiqi S, et al. A case of adrenal infarction in a patient with COVID 19 infection. *BJR Case Rep* 2020;6:20200075.