Prognostic value of elevated lactate dehydrogenase in patients with COVID-19: a systematic review and meta-analysis

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ABSTRACT

Purpose This meta-analysis aimed to evaluate the prognostic performance of elevated lactate dehydrogenase (LDH) in patients with COVID-19.

Methods A systematic literature search was performed using PubMed, Embase and EuropePMC on 19 November 2020. The outcome of interest was composite poor outcome, defined as a combined endpoint of mortality, severity, need for invasive mechanical ventilation and need for intensive care unit care. Severity followed the included studies' criteria.

Results There are 10 399 patients from 21 studies. Elevated LDH was present in 44% (34%–53%) of the patients. Meta-regression analysis showed that diabetes was correlated with elevated LDH (OR 1.01 (95% CI 1.00 to 1.02), p=0.038), but not age (p=0.710), male (p=0.068) and hypertension (p=0.969). Meta-analysis showed that elevated LDH was associated with composite poor outcome (OR 5.33 (95% CI 3.90 to 7.31), p<0.001; I²: 77.5%). Subgroup analysis showed that elevated LDH increased mortality (OR 4.22 (95% CI 2.49 to 7.14), p<0.001; I²: 89%). Elevated LDH has a sensitivity of 0.74 (95% CI 0.60 to 0.85), specificity of 0.69 (95% CI 0.58 to 0.78), positive likelihood ratio of 2.4 (95% CI 1.9 to 2.9), negative likelihood ratio of 0.38 (95% CI 0.26 to 0.55), diagnostic OR of 6 (95% CI 4 to 9) and area under curve of 0.77 (95% CI 0.73 to 0.80). Elevated LDH would indicate a 44% posterior probability and non-elevated LDH would indicate 11% posterior probability for poor prognosis. Meta-regression analysis showed that age, male, hypertension and diabetes did not contribute to the heterogeneity of the analyses.

Conclusion LDH was associated with poor prognosis in patients with COVID-19.

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INTRODUCTION

COVID-19 is one of the most common diseases, and the trend is rapidly increasing. It has infected 63.8 million people globally, resulting in over 1.5 million deaths. Even though most of the patients with COVID-19 is only mildly symptomatic, a notable proportion of patients deteriorate remarkably, causing multiple organ failure that resulted in death. Cost-effective biomarkers, especially those that are routinely tested, enable risk stratification to allow prudent resource allocation.

Lactate dehydrogenase (LDH) catalyses the last step of aerobic glycolysis, the pyruvate to lactate conversion. LDH has been shown to be a potential prognostic biomarker in patients with COVID-19.

Elevated LDH signifies tissue hypoperfusion indicates the extent of the disease, hence, may affect prognosis. However, there are studies showing that LDH is not associated with poor prognosis. This meta-analysis aimed to evaluate the prognostic performance of elevated LDH in patients with COVID-19.

MATERIAL AND METHODS

This meta-analysis is reported according to the Preferred Reporting Items for Systematic Reviews and Meta-Analyses guidelines.

ELIGIBILITY CRITERIA

The inclusion criteria were letters and research articles reporting COVID-19 patients with information on LDH (dichotomous) along with mortality/severity/invasive mechanical ventilation (IMV)/critical care/intensive care unit (ICU) care. The exclusion criteria were preprint studies, conferences abstract, commentaries, letters containing no primary data, case reports and articles in a language other than English.

Search strategy and study selection

A systematic literature search was performed using PubMed, Embase and EuropePMC with keywords "2019-nCoV" OR “SARS-CoV-2” OR “COVID-19” AND “lactate dehydrogenase” OR “LDH” AND “Mortality” OR “non-survivor” OR “severity” OR “intensive care unit” OR “intubation” OR “invasive mechanical ventilation” on 19 November 2020. The PubMed (MEDLINE) search keywords was ((2019-nCoV) OR (SARS-CoV-2) OR (COVID-19) AND ((lactate dehydrogenase) OR (LDH)) AND (Mortality) OR (non-survivor) OR (severity) OR (intensive care unit) OR (intubation) OR (invasive mechanical ventilation)). Duplicates were removed from the initial record, and two individuals independently screened the title/abstract of the relevant studies.

DATA EXTRACTION

Extraction of data from the included studies was performed by two individuals independently using extraction forms that consisted of author, year, study design, age, gender, diabetes, hypertension, cardiovascular diseases, LDH cut-off points and outcome of interests.

The key exposure was elevated LDH, defined as level of LDH above specific cut-off points defined by each individual study. The outcome of interest
was composite poor outcome, defined as a combined endpoint of mortality, severity, need for IMV, and need for ICU care. Severity followed the included studies’ criteria. The effect estimate was reported as OR. Sensitivity and specificity, positive and negative likelihood ratio (PLR and NLR), diagnostic OR (DOR) were calculated. Sensitivity analysis was performed, with age, gender, diabetes mellitus and hypertension as covariates, for the prevalence of elevated LDH and the association between elevated LDH and composite poor outcome. Funnel plot and Egger’s test were performed to assess publication bias. Trim-and-fill analysis was performed to account for the asymmetrical funnel plot. Pooled sensitivity and specificity, summary receiver operating characteristic curve, Fagan’s normogram and Deek’s asymmetry test were performed. Univariate meta-regression and subgroup analyses were performed for age, male, hypertension and diabetes.

RESULTS
Study selection and baseline characteristics
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LDH and Poor Prognosis
Elevated LDH was present in 44% (34%–53%) of the patients. Meta-regression analysis showed that diabetes was correlated with elevated LDH (OR 1.01 (95% CI 1.00 to 1.02), p=0.038), but not age (p=0.710), male (p=0.068) and hypertension (p=0.969). Meta-analysis showed that elevated LDH was

Table 1 Characteristics of the included studies

| Authors | Design | Samples | Cut-off (U/L) | Age (years) | Male (%) | Hypertension (%) | Diabetes (%) | CAD/CVD (%) | Outcome | NOS |
|---------|--------|---------|--------------|-------------|-----------|------------------|--------------|-------------|---------|-----|
| Chen et al 2020 | Retrospective Cohort | 21 | >300 | 56 | 81 | 23.8 | 14.3 | – | Severity 7 |
| Chen et al 2020 | Retrospective Cohort | 635 | >245 | 61 | 50 | 37.6 | 22.8 | 8.2 (CAD) | Severity 7 |
| Colaneri et al 2020 | Retrospective Cohort | 44 | >300 | – | 72.7 | 34.9 | 15.9 | 25 (CVD) | Severity 7 |
| Deng et al 2020 | Retrospective Cohort | 65 | >243 | 34 | 55.3 | 4.6 | 3 | 0 | Severity 7 |
| Guan et al 2020 | Retrospective Cohort | 675 | >250 | 47 | 58.1 | 15 | 7.4 | 2.5 (CAD) | ICU +IMV + Mortality 7 |
| Hong et al 2020 | Retrospective Cohort | 98 | – | 55.4 | 38.8 | 30.6 | 9.2 | 11.2 (CVD) | ICU 7 |
| Huang et al 2020 | Retrospective Cohort | 40 | >245 | 49 | 73 | 15 | 20 | 15 (CVD) | ICU Care 7 |
| Huang et al 2020 | Retrospective Cohort | 614 | >250 | 56 | 46.4 | 33.4 | 14.8 | 10.5 (CVD) | Mortality 9 |
| Jang et al 2020 | Retrospective Cohort | 110 | >550 | 56.9 | 60.9 | 33.6 | 26.4 | 4.3 (CVD) | Severity 7 |
| Khamis et al 2020 | Retrospective Cohort | 110 | >300 | 48 | 85 | 32 | 32 | 6.4 (CVD) | ICU 7 |
| Li et al 2018 | Retrospective Cohort | 113 | >300 | – | – | – | – | – | Mortality 6 |
| Li 2018 | Retrospective Cohort | 534 | >250 | 60 | 50.9 | 30.3 | 15.1 | 6.2 (CAD) | Severity 9 |
| Mikami et al 2020 | Retrospective Cohort | 2126 | >250 | 44 | 51.6 | 16 | 7.2 | 1.4 (CAD) | Severity 7 |
| Ramos-Rincon et al 2020 | Retrospective Cohort | 2772 | >500 | 86.3 | 49.4 | 75 | 25.6 | 30.8 (CVD) | Mortality 9 |
| Wang et al 2020 | Retrospective Cohort | 65 | – | 57.1 | 57 | – | – | – | Severity 5 |
| Wang et al 2020 | Retrospective Cohort | 252 | >250 | 49 | 46.5 | 19 | 6.2 | 1.8 (CAD) | Severity 7 |
| Wei et al 2020 | Retrospective Cohort | 102 | >250 | 51 | 56.2 | 17 | 5.1 | 4 (CAD) | Severity 7 |
| Zhang et al 2020 | Retrospective Cohort | 937 | – | 55.6 | 48.4 | – | – | 24.7 (CVD) | Mortality 7 |
| Zhang 5 2020 | Retrospective Cohort | 788 | >250 | 44 | 51.6 | 16 | 7.2 | 1.4 | Severity 7 |
| Zheng et al 2020 | Retrospective Cohort | 161 | >250 | 45 | 49.7 | 13.7 | 4.3 | 2.5 (CAD) | Severity 7 |
| Zhou et al 2020 | Retrospective Cohort | 184 | >245 | 56 | 62 | 30 | 19 | 8 (CAD) | Mortality 8 |

CAD, coronary artery disease; CVD, cardiovascular disease; ICU, intensive care unit; IMV, invasive mechanical ventilation; NOS, Newcastle-Ottawa Scale.

Figure 1 PRISMA flow chart. LDH, lactate dehydrogenase; PRISMA, Preferred Reporting Items for Systematic Reviews and Meta-Analyses.
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LDH and Poor Prognosis

| Study ID | OR (95% CI) | Weight |
|----------|-------------|--------|
| Chen G 2020 | 9.00 (4.48, 16.59) | 1.03 |
| Chen Z 2020 | 6.24 (2.47, 10.31) | 0.94 |
| Colaner M 2020 | 6.29 (4.60, 24.73) | 3.34 |
| Deng M 2020 | 12.25 (6.57, 22.71) | 2.91 |
| Guan W 2020 | 3.73 (1.82, 7.27) | 0.46 |
| Hong KS 2020 | 17.14 (2.13, 137.94) | 1.82 |
| Huang C 2020 | 7.08 (0.79, 62.72) | 1.89 |
| Huang Y 2020 | 11.22 (7.12, 17.87) | 7.54 |
| Jiang 2020 | 19.95 (4.38, 90.86) | 2.33 |
| Khansan F 2020 | 29.78 (3.65, 243.01) | 1.80 |
| Li L 2020 | 5.42 (2.00, 13.71) | 3.50 |
| Li X 2020 | 5.06 (1.24, 7.91) | 7.09 |
| Miwa T 2020 | 2.91 (2.39, 3.55) | 8.78 |
| Ramos-Peron 2020 | 2.84 (1.11, 3.29) | 8.70 |
| Wang F 2020 | 13.09 (6.62, 233.78) | 1.00 |
| Wang Y 2020 | 6.25 (2.06, 12.80) | 6.16 |
| Wei Y 2020 | 0.90 (0.26, 3.14) | 3.76 |
| Zhang J 2020 | 1.52 (0.73, 3.15) | 6.21 |
| Zhang S 2020 | 5.98 (3.62, 9.86) | 7.40 |
| Zheng 2020 | 4.70 (2.02, 10.94) | 5.48 |
| Zhou F 2020 | 48.43 (4.10, 338.44) | 1.94 |

Overall (equal weights = 0.0000)
5.33 (3.89, 7.30) 100.00

NOTE: Weights are rounded to the nearest 0.0001

LDH and Poor Prognosis

Figure 2 Forest-plot for lactate dehydrogenase and composite poor outcome. LDH, lactate dehydrogenase.

Diagnostic meta-analysis

Elevated LDH has a sensitivity of 0.74 (95% CI 0.60 to 0.85), specificity of 0.69 (95% CI 0.58 to 0.78) (figure 3), PLR of 2.4 (95% CI 1.9 to 2.9), NLR of 0.38 (95% CI 0.26 to 0.55), DOR of 6 (95% CI 4 to 9) and AUC of 0.77 (95% CI 0.73 to 0.80) (figure 4). Elevated LDH would indicate a 44% posterior probability and non-elevated LDH would indicate 11% posterior probability for poor prognosis (figure 5).

DISCUSSION

Elevated LDH was associated with poor prognosis in patients with COVID-19, indicating 37% posterior probability for 'composite poor outcome' with AUC of 0.77, sensitivity of 74%, and specificity of 69%.

The incidence of LDH was associated with presence of diabetes, this phenomenon might be due to reduced glycogen synthesis, change in glucose oxidative metabolism and elevated whole-body rate of non-oxidative glycolysis.28–31 These mechanisms cause elevated lactate in patients with insulin resistance compared with those without. LDH has been found to affect the prognosis of various diseases, including cancers.32 LDH elevation in patients with COVID-19 indicates lung and tissue injuries.19 COVID-19 may lead to inadequate tissue perfusion and multiple organ failure due to various mechanisms, including thrombosis, which lead to LDH elevation.22–33 Thus, high LDH serves as a biomarker of the disease extent. This study indicated that the association between LDH elevation and poor prognosis was not affected by age, gender, hypertension or diabetes; these factors were known to increase COVID-19 severity and its associated mortality, thus, may confound the association.33–37 Three studies reported that elevated LDH was independently...
associated with poor prognosis (HR 1.01, HR 2.00 and OR 1.63).\textsuperscript{15,19,21} One study reported that elevated LDH was lost its statistical significance after adjustment.\textsuperscript{20}

The heterogeneity might be due to different cut-off points, lab references and diagnostic tools. Another possible explanation was due to the very different methods by which patients with COVID-19 get the attention of medical services. Nevertheless, most of the studies demonstrate that elevation of LDH for at least >250 U/L was associated with poor prognosis. Funnel-plot analysis and Egger’s test indicate small study effect in the pooled estimate. Trim-and-fill analysis was performed to evaluate whether the adjustment to publication bias will cause the effects estimate to become non-significant. With the imputation of six hypothetical studies the OR was only reduced slightly (OR 4.31 vs 4.22), indicating the robustness of the effect estimate. Thus additional studies are unlikely to nullify the prognostic performance of this meta-analysis.

The pooled result is that LDH has poor predictive performance; and might be similar to other metabolic marker of physiological distress (Troponin, C reactive proteins, white cell count, d-dimer, brain natriuretic peptide (BNP) and others),\textsuperscript{38,39} thus, it should be studies further and integrated into a risk prediction model rather used alone. This result adds to the literature that elevated LDH is associated with poor outcome, whether they are discriminatory requires further investigation with large sample size.

This systematic review’s limitation was mainly due to retrospective studies, which have a higher potential for bias. Additionally, different cut-off points may cause high heterogeneity. Future studies are suggested to use single cut-off points for prognostic purposes. Drugs associated with comorbidities, such as metformin and renin–angiotensin–aldosterone system

\begin{figure}[h]
\centering
\includegraphics[width=\textwidth]{image1}
\caption{Summary receiver operating characteristics (SROC) curve. AUC, area under curve; SROC, summary receiver operating characteristic.}
\end{figure}

\begin{figure}[h]
\centering
\includegraphics[width=\textwidth]{image2}
\caption{Univariable meta-regression and subgroup analyses.}
\end{figure}

\begin{figure}[h]
\centering
\includegraphics[width=\textwidth]{image3}
\caption{Fagan’s normogram. LR, likelihood ratio.}
\end{figure}
inhibitor, may affect LDH\(^{40,41}\); the studies inadequately report these.

**CONCLUSION**

LDH was associated with poor prognosis in patients with COVID-19.

### Main messages

- Elevated lactate dehydrogenase (LDH) has a sensitivity of 74% and specificity of 69%.
- Elevated LDH would indicate a 44% posterior probability and non-elevated LDH would indicate 11% posterior probability for poor prognosis.
- Meta-regression analysis showed that age, male, hypertension and diabetes did not contribute to the heterogeneity.

### Current research question

- Future studies are suggested to use a single cut-off point for prognostic purposes.
- Integrating lactate dehydrogenase into a model may enhance prognostication.
- More prospective studies are required for a higher quality of evidence.

### What is already known on the subject

- Lactate dehydrogenase (LDH) catalyses the last step of aerobic glycolysis, the pyruvate to lactate conversion.
- Elevated LDH signifies tissue hypoperfusion indicates the extent of the disease, hence, may affect prognosis in COVID-19.
- There are studies showing that elevated LDH was associated with mortality, and some studies did not.

### Correction notice

This article has been corrected since it first published. The provenance and peer review statement has been included.

### Contributors

JWM and RP were involved in the conceptualisation and design of the manuscript. JWM, AW and RP participated in data curation and investigation, RP performed data analysis, formal analysis and statistical analysis. AW and RP drafted the manuscript. JWM reviewed and edited the manuscript.

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### Competing interests

None declared.

### Patient consent for publication

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### Data availability statement

Data are available on reasonable request.

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