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Early View

RESEARCH LETTER

A serum calprotectin lateral flow test as an inflammatory and prognostic marker in acute lung infection: a prospective observational study

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A serum calprotectin lateral flow test as an inflammatory and prognostic marker in acute lung infection: a prospective observational study

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Excess neutrophilic inflammation is associated with poor prognosis in a number of acute and chronic respiratory infections (1). Increased numbers of circulating neutrophils are observed during acute respiratory tract infections including COVID-19, where increased numbers of immature neutrophils are associated with more severe disease (2). S100A8/A9 (calprotectin) is an antimicrobial complex which is found in the cytoplasm and granule membranes of neutrophils and is released by activated neutrophils during NETosis (3). Serum S100A8/A9 levels are increased in sepsis (4) and COVID-19 (5-7), as well as other acute(8) and chronic lung diseases(9, 10), and correlate with disease severity(11). COVID-19 presentation ranges from asymptomatic infection to severe disease requiring invasive mechanical ventilation and previous research suggests that the extent of neutrophil activation can predict poor clinical outcomes (12). A rapid biomarker test for neutrophil activation which is convenient to perform and able to predict outcomes in multiple diseases including COVID-19 would be useful for clinical decision making. Such a test may be utilised to direct the use of neutrophil-targeting treatments in the future. In this study we investigated the clinical utility of a lateral flow test (LFT) for S100A8/A9 in people with COVID-19, non-COVID-19 lower respiratory tract infection (LRTI), and matched controls.

We conducted a prospective observational study of adults admitted to hospital with acute respiratory infection. All patients were recruited within 96 hours of hospital admission from two centres, Ninewells Hospital (Dundee, UK) and Sheffield teaching hospitals (Sheffield, UK). All patients underwent combined nasal and pharyngeal swab for COVID-19 PCR testing. "Healthy" controls were recruited from hospital inpatients without infection predominantly awaiting elective procedures such as cardiac or orthopaedic surgery. Clinical status and severity were based on the WHO 7-point ordinal scale (not hospitalised and no limitations on activities [1]; not hospitalised and limitations on activities [2]; hospitalised and not requiring supplemental oxygen [3]; hospitalised and requiring supplemental oxygen [4]; hospitalised and on non-invasive ventilation or high-flow oxygen devices [5]; hospitalised and on invasive mechanical ventilation or extracorporeal membrane oxygenation [6]; and death [7]). Patients were eligible for enrolment if they had a clinical severity of 3-5 on the WHO scale at baseline. Outcomes were evaluated at day 29 after enrolment. Serum samples at baseline were used to measure S100A8/A9 levels quantitatively using the quantum blue® sCAL kit (BÜHLMANN) lateral flow test and Human S100A8/S100A9 Heterodimer DuoSet ELISA (R&D systems). 45 serum cytokines were measured using the Olink Target 48 cytokine panel. Additional neutrophil markers including DNA-myeloperoxidase (MPO) complexes (13), heparin-binding protein (HBP/AZU1; Axis-Shield), MPO (R&D systems), citrullinated histone H3 (CitH3; Cayman chemical) and proteinase 3 (PR3, R&D systems) were measured by ELISA. Comparisons across the three study groups utilised the Kruskal-Wallis test while proportions were compared by Chi-square test. Discrimination for clinical outcomes was determined using the area under the receiver operator characteristic (ROC) curve (AUC). $p < 0.05$ was considered statistically significant for all analyses. For comparison of cytokine levels between two groups, Mann-Whitney test and $FDR < 0.05$ were utilised. Ethical approval was obtained from the East of Scotland Research Ethics Committee (REC number: 20/ES/0055).

225 hospitalised patients were included; 158 patients (mean \pm SD age 64.5 \pm 13 years, 60.5% male) with PCR-confirmed COVID-19 patients and 67 hospitalised patients with non-SARS-CoV-2 LRTI (69.4 \pm 13.3 years, 49.2% male). The control group consisted of 52 non-infection matched controls (62.5 \pm 14.3 years, 48.1% male). LRTI patients were significantly older than COVID-19 patients ($p=0.01$) and the control group ($p=0.0126$). There was no significant difference in gender between these groups ($p=0.145$). In the COVID-19 and LRTI groups, day 1 WHO scores were: 34 (21.5%) and 32

(47.8%) with WHO 3; 97 (61.4%) and 31 (46.3%) with WHO 4; and 26 (16.5%) and 3 (4.5%) with WHO 5, respectively.

S100A8/A9 levels in serum were significantly increased in COVID-19 (LFT/ELISA [$\mu\text{g/ml}$]: $8.3\pm 2.4/7.7\pm 5.6$) vs. LRTI patients ($4.67\pm 2.74/1.98\pm 2.65$) and controls ($4.0\pm 2.5/2.5\pm 2.8$) ($p\leq 0.0001$) (figure 1A). S100A8/A9 levels measured by ELISA and LFT assays were strongly correlated ($r=0.87$ $p\leq 0.0001$) (figure 1B). In COVID-19 patients, ROC analysis showed that both S100A8/A9 ELISA and LFT values were moderately predictive of lack of recovery at day 29 (defined as ongoing requirement for supplemental oxygen or death at day 29 (WHO groups 4-7) (ELISA AUC=0.66, 95%CI 0.57–0.77; LFT AUC=0.69 95%CI 0.60–0.78) (figure 1C). LFT S100A8/A9 levels were also moderately predictive of 29-day mortality ($n=25$) in COVID-19 which was not demonstrated for the ELISA (ELISA AUC= 0.59 95%CI 0.47-0.70; LFT AUC= 0.63, 95%CI 0.53–0.73) (figure 1D). Combining day 1 WHO score with LFT S100A8/A9 level of above or below $10\mu\text{g/ml}$ (the optimal cut-off identified using Youden's index) increased the predictive power for severe disease or mortality by day 29 (Combined AUC = 0.779 95%CI 0.694-0.864; compared to Day 1 WHO alone AUC = 0.718 95%CI 0.598-0.777; or LFT alone AUC = 0.693 95%CI 0.515-0.822) (Figure 1 E) Neither LFT or ELISA S100A8/A9 levels had significant predictive value for mortality or severity in LRTI (data not shown).

Intravascular neutrophil activation and inflammation has been reported to be higher in COVID-19 compared to other respiratory infections including influenza pneumonia, which may explain the increased levels of serum S100A8/A9 in these patients(14). Therefore, we focused on the COVID-19 group to further understand the associations between S100A8/A9 and inflammation. We divided patients into high (>quartile 1) and low (<quartile 1) S100A8/A9 levels based on their distribution in COVID-19 patients. Key cytokines with significant differences between these groups included the chemokine (C-C motif) ligand 7 (CCL7) ($p<0.0001$) (figure 1Fi), interleukin 15 (IL-15) ($p=0.0003$) (figure 1Fii) CXC-motif chemokine ligand 10 (CXCL10/IP-10) ($p=0.0026$) (figure 1Fiii), CXCL9 ($p=0.003$) (figure 1Fv) and IL-6 ($p=0.006$); and 13 cytokines were significantly different ($\text{FDR}<0.05$) in total (data not shown).

Based on blood neutrophil count and neutrophil-associated serum markers, two clusters were identified (cluster 1 and 2) within the COVID-19 group (figure 1Gi). Principal component analysis (PCA) demonstrated that cluster 2 was driven by high levels of neutrophil markers including neutrophil extracellular trap markers, DNA-MPO complexes and CitH3, as well as the neutrophil proteins MPO, HBP and PR3 (figure Gii). Cluster 2 had significantly higher S100A8/A9 levels than cluster 1 ($p<0.0001$) (figure Giv). S100A8/A9 showed significant, moderate correlation with multiple other neutrophil markers (figure Gv).

Our results therefore show that a rapid LFT for S100A8/A9, which can provide a result within 1 hour, is moderately associated with severity of COVID-19 and indicates a hyperinflammatory subset with multiple increased neutrophil markers and proinflammatory cytokines at baseline. Our results support other findings that reported serum S100A8/A9 levels predicted the need for invasive mechanical ventilation and ICU admission in hospitalised COVID-19 patients (15), and can be used in combination with day 1 WHO score to enhance predictive power of this routinely used clinical score. Our study is limited by the LFT upper limit of quantification being $10\mu\text{g/ml}$ which could be improved by use of an extended-range test or by further sample dilution. Our study was performed during the first and second waves of COVID-19 in the UK and so does not include data from patients with the current circulating omicron variant or following vaccination. Nevertheless, this study suggests the potential for use of a point-of-care prognostic biomarker, which may be relevant to investigate further in other severe, acute neutrophil-associated diseases. The potential application of such a biomarker to clinical decision making requires further study.

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Abbreviations: HBP= heparin binding protein, PR3= proteinase-3, MPO= myeloperoxidase, CitH3= citrullinated histone H3, ROC= receiver operating characteristic.

References

1. Keir HR, Shoemark A, Dicker AJ, Perea L, Pollock J, Giam YH, et al. Neutrophil extracellular traps, disease severity, and antibiotic response in bronchiectasis: an international, observational, multicohort study. *Lancet Respir Med.* 2021;9(8):873-84.
2. Aschenbrenner AC, Mouktaroudi M, Krämer B, Oestreich M, Antonakos N, Nuesch-Germano M, et al. Disease severity-specific neutrophil signatures in blood transcriptomes stratify COVID-19 patients. *Genome Med.* 2021;13(1):7.
3. Sprenkeler EGG, Zandstra J, van Kleef ND, Goetschalckx I, Versteegen B, Aarts CEM, et al. S100A8/A9 Is a Marker for the Release of Neutrophil Extracellular Traps and Induces Neutrophil Activation. *Cells.* 2022;11(2).
4. Gao RY, Jia HM, Han YZ, Qian BS, You P, Zhang XK, et al. Calprotectin as a diagnostic marker for sepsis: A meta-analysis. *Front Cell Infect Microbiol.* 2022;12:1045636.
5. Norman GL, Navaz SA, Kanthi Y, Albesa R, Mahler M, Knight JS, et al. Circulating Calprotectin as a Predictive and Severity Biomarker in Patients with COVID-19. *Diagnostics (Basel).* 2022;12(6).
6. Mao Q, Wang C, Wen W, Zhou M, Tang J, Chen C, et al. A meta-analysis of the association between calprotectin and the severity of COVID-19. *J Infect.* 2022;84(3):e31-e3.
7. Renieris G, Karakike E, Gkavogianni T, Droggiti DE, Stylianakis E, Andriopoulou T, et al. IL-1 Mediates Tissue-Specific Inflammation and Severe Respiratory Failure in COVID-19. *J Innate Immun.* 2022;14(6):643-56.
8. Havelka A, Sejersen K, Venge P, Pauksens K, Larsson A. Calprotectin, a new biomarker for diagnosis of acute respiratory infections. *Sci Rep.* 2020;10(1):4208.
9. Titova EV, Løffblad L, Åsberg A, Henriksen AH. Calprotectin as a biomarker of pneumonia in patients hospitalized with AECOPD. *European Respiratory Journal.* 2019;54(suppl 63):PA2895.
10. Machahua C, Guler SA, Horn MP, Planas-Cerezales L, Montes-Worboys A, Geiser TK, et al. Serum calprotectin as new biomarker for disease severity in idiopathic pulmonary fibrosis: a cross-sectional study in two independent cohorts. *BMJ Open Respir Res.* 2021;8(1).
11. Cardiero G, Palma D, Vano M, Anastasio C, Pinchera B, Ferrandino M, et al. Calprotectin Levels and Neutrophil Count Are Prognostic Markers of Mortality in COVID-19 Patients. *Diagnostics (Basel).* 2022;12(10).
12. Meizlish ML, Pine AB, Bishai JD, Goshua G, Nadelmann ER, Simonov M, et al. A neutrophil activation signature predicts critical illness and mortality in COVID-19. *Blood Adv.* 2021;5(5):1164-77.
13. Maruchi Y, Tsuda M, Mori H, Takenaka N, Gocho T, Huq MA, et al. Plasma myeloperoxidase-conjugated DNA level predicts outcomes and organ dysfunction in patients with septic shock. *Crit Care.* 2018;22(1):176.
14. Nicolai L, Leunig A, Brambs S, Kaiser R, Joppich M, Hoffknecht ML, et al. Vascular neutrophilic inflammation and immunothrombosis distinguish severe COVID-19 from influenza pneumonia. *J Thromb Haemost.* 2021;19(2):574-81.

15. García de Guadiana-Romualdo L, Rodríguez Rojas C, Morell-García D, Andaluz-Ojeda D, Rodríguez Mulero MD, Rodríguez-Borja E, et al. Circulating levels of calprotectin, a signature of neutrophil activation in prediction of severe respiratory failure in COVID-19 patients: a multicenter, prospective study (CalCov study). *Inflamm Res.* 2022;71(1):57-67.

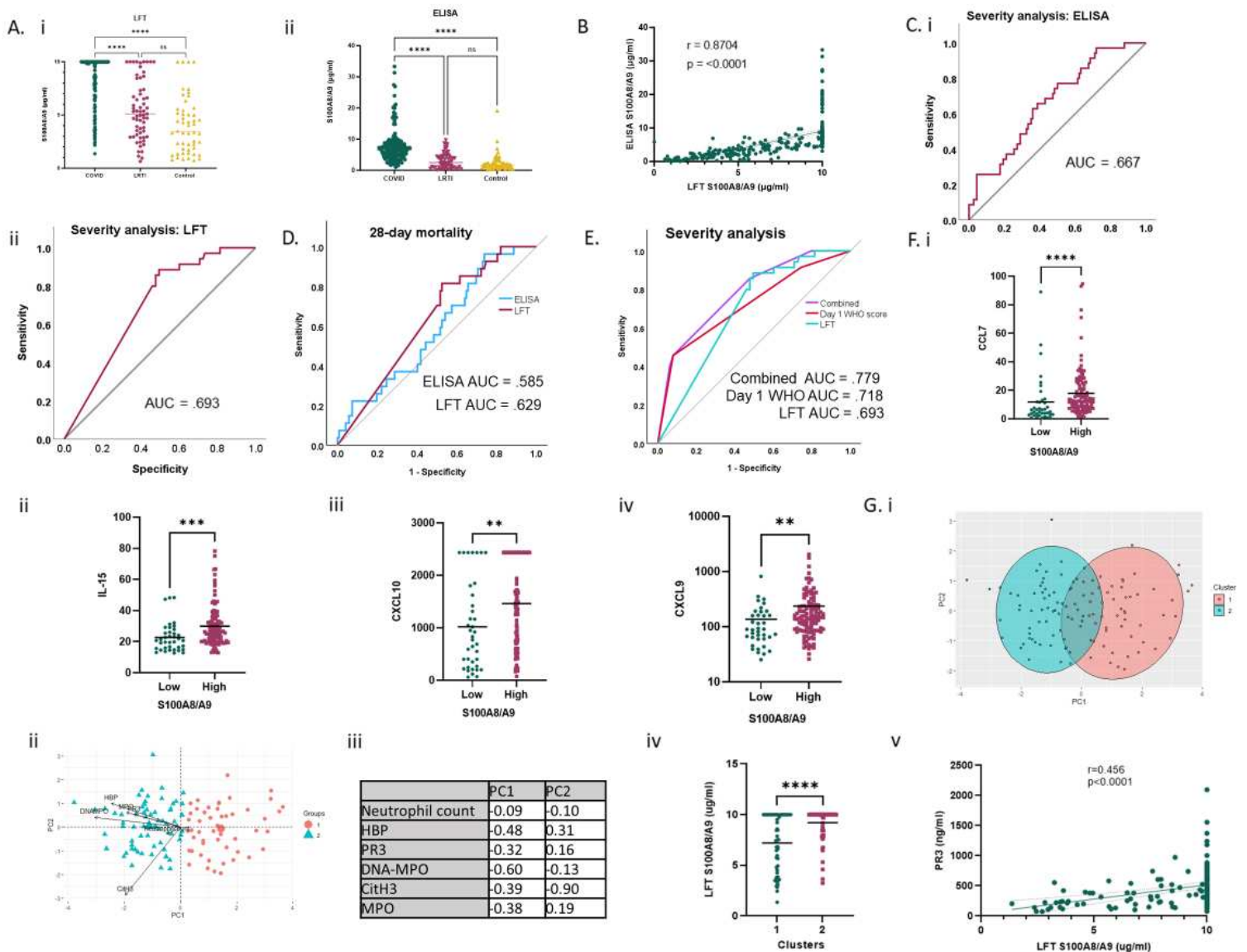


Figure 1. Serum S100A8/A9 (a.k.a calprotectin) measured by quantitative lateral flow test and ELISA in acute lung infection, and associations with inflammation and clinical outcomes.

A S100A8/A9 levels in COVID-19 (n=157), matched control (n=52), non-COVID lower respiratory tract infection (LRTI) (n=67), measured by i) lateral flow test (LFT) or ii) ELISA. **B** Correlation between S100A8/A9 concentration from LFT and ELISA (n=274). **C** ROC curve for prediction of severe COVID-19 defined as WHO score 4-7 (i.e. requiring supplementary oxygen, ventilation, or death by day 29 (n=133 WHO score 1-3, n=37 score 4-7)) with i) S100A8/A9 ELISA ii) S100A8/A9 LFT. **D** ROC curve indicating predictive value of S100A8/A9 ELISA and S100A8/A9 LFT for COVID-19 patient 29-day mortality. **E** ROC curve for prediction of severe COVID-19 at day 29 using combination of Day 1 WHO score and 10 µg/ml s100A8/A9 LFT score **F** Levels of inflammatory cytokines i) CCL7, ii) IL-15, iii) CXCL10, and v) CXCL9 in COVID-19 patients stratified by low (n=38, quartile 1) and high (n=112, quartiles 2-4) levels of serum S100A8/A9. Mann-Whitney test; ****p<0.0001, ***p<0.001, **p<0.01. **G** i) Principal component analysis and ii) biplot indicating two clusters based on serum neutrophil associated markers PR3, HBP, CitH3, DNA-MPO and peripheral blood neutrophil count (cluster 1 n=49, cluster 2 n=65); K-means clustering. iii) PC1 and PC2 scores for each neutrophil marker. iv) LFT S100A8/A9 levels of individuals in cluster 1 and 2; Mann-Whitney test, p<0.0001. v) Correlation between serum LFT S100A8/A9 levels and neutrophil protease PR3 with COVID-19.