Critically Ill COVID-19 Infected Patients Exhibit Increased Clot Waveform Analysis Parameters Consistent with Hypercoagulability

Authors and affiliations:

Chuen Wen Tan*[1, 2], Jenny Guek Hong Low[3, 4], Wan Hui Wong[1], Ying Ying Chua[3, 5], Sher Li Goh[2], Heng Joo Ng[1]

[1]Department of Haematology, Singapore General Hospital, Singapore

[2]Department of Pathology, Sengkang General Hospital, Singapore

[3]Department of Infectious Diseases, Singapore General Hospital, Singapore

Programme in Emerging Infectious Diseases, Duke NUS Medical School, Singapore

[5]Department of Infectious Diseases, Sengkang General Hospital, Singapore

***Corresponding author:**

Chuen Wen Tan

Department of Hematology,

Singapore General Hospital,

Outram Road,

Singapore 169608.

Email: tan.chuen.wen@singhealth.com.sg

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To the Editor:

Viral acute respiratory infections (ARI) are associated with thrombotic events.[1] and the pathophysiology of this association is multifactorial.[2] Although most ARIs are mild, subpopulation of patients can progress to severe disease with excessive proinflammatory response and downstream uncontrolled cytokine storm being partially implicated for this severe manifestation.[3] As there is extensive crosstalk between inflammation and coagulation, it is likely the prothrombotic mechanisms in viral ARI could be further exacerbated in patients suffering from severe ARI. The novel coronavirus disease 2019 (COVID-19) is an evolving pandemic. Approximately one-fifth of the infected individuals develops severe to critical disease[4] requiring intensive care support. These critically ill patients often exhibit marked elevation of proinflammatory cytokines and C-reactive protein (CRP)[4] consistent with hyperinflammation. Nonetheless, the effects of COVID-19 infection on haemostatic functions remain unknown at the present moment.

Activated partial thromboplastin time (aPTT)-based clot waveform analysis (CWA) is a form of global haemostatic assay in which lower and higher CWA parameters are associated with bleeding and hypercoagulability respectively.[5] We postulated COVID-19 patients requiring intensive care unit (ICU) support would exhibit haemostatic disturbances and interrogated their aPTT-based CWA parameters as surrogates of their haemostatic functions.

In February 2020, three COVID-19 patients were admitted to ICU of Singapore General Hospital and Sengkang General Hospital, Singapore and we examined their clinical and haematological data. APTT tests were performed as part of their routine clinical management and the associated CWA data – maximum velocity (min1), maximum acceleration (min2) and maximum deceleration (max2) were retrieved from the CS2100i and CS2500 automated coagulation analysers (Sysmex Corporation, Kobe,

Japan) from the respective hospitals. Dade Actin FSL (Siemens Healthcare, Marburg, Germany) reagent was used.

One female and two male patients aged 39, 54 and 64 were included. All three patients did not have any pre-existing malignancy, bleeding or thrombotic conditions and were not on any antithrombotic drugs on admission. Only one patient has underlying hypertension and hyperlipidemia. None had other superimposed infection or overt disseminated intravascular coagulation by the International Society of Thrombosis and Haemostasis criteria. Their clinical and laboratory features are summarised in Table 1. Only Patient 2 had a single D-dimer value of 0.64mg/L FEU (normal range: 0.19 – 0.55mg/L FEU) performed upon the ICU admission. Whilst aPTT showed mild prolongation in most of the results and no biphasic waveform was noted, analyses of their CWA revealed interesting findings. All three patients had elevated min1 when their clinical conditions deteriorated to the point of requiring ICU support. Furthermore, all their CWA parameters became markedly raised as their ICU stay progressed. Patient 1's serial CWA data shed some interesting light on how the overall dynamic haemostatic status changed with clinical deterioration – from fairly normal CWA on initial hospitalisation to having markedly raised parameters in ICU suggesting a positive association between the rise in CWA parameters and the worsening severity of COVID-19 infection.

On day 1 of hospitalisation, although Patient's 1 CWA parameters were within normal intervals, COVID-19 infection resulted in some interesting differences in CWA compared to CWA findings caused by other infections. Compared with other common viral ARI and bacterial infection (manuscript under review), min1 in COVID-19 infection was higher than other ARIs and tracked closer to bacterial infection. Min2 and max2, on the other hand, were lower than the other infections. This suggests that COVID-19 infection causes dissimilar haemostatic derangement, even in non-critical cases, compared

to other ARI. The higher min1 value could possibly suggest an overall elevated prothrombotic state in COVID-19 infection given our previous finding that min1, in comparison to min2 and max2, is more strongly associated with thrombotic events.[5]

Consistent with published reports,[4] all the patients expressed high CRP levels even on initial assessment during hospitalisation whilst procalcitonin remained unremarkable (data not shown). We did not observe a definitive pattern of association between CRP and ICU admission – Patient 3's CRP upon ICU admission was lower than that of Patient 1 upon initial hospitalisation. In contrast, as these patients' clinical conditions turned critical, min1 seemed to be the first CWA parameter to rise with all three patients exhibiting raised min1 upon ICU admission. This raises the exciting possibility that high min1 may be a useful biomarker to predict severity in COVID-19 infected patients, but further study is needed.

From second day of ICU admission onward, all the CWA parameters became markedly elevated for at least the ensuing four days of ICU stay and many of the levels were at least as high as what we noted in acute venous thromboembolism which had an odds ratio of 4 or greater for thrombotic events.[5]. Of note, although none of our cases developed thrombosis, our patients' CWA parameters remained remarkably high despite the use of thromboprophylaxis during their ICU stay. It is possible that CWA and other thrombin generation assays might not be sensitive to the detect the haemostatic changes caused by the standard prophylactic dose of low molecular weight heparin. All three patients recovered from COVID-19 infection.

Our findings of markedly raised CWA parameters in critically ill infected cases possibly consistent with hypercoagulability is not unexpected. Such patients exhibit state of hyperinflammation and cytokines overdrive and extensive crosstalk is known to exist in the cytokines and inflammatory system and

coagulation.[6] Critically ill COVID-19 patients have been shown to have increased proinflammatory cytokines including IL-2 and TNF-α[4] and these factors could upregulate the coagulation system.[6] We speculate that this could partially account for the CWA changes observed.

Although our findings are limited by the relatively few patients and data points and by the lack of other correlation studies with other coagulation assays, we believe there are still valuable points to take away. Many of the specialised and research haemostatic assays cannot be safely and easily performed on samples collected from COVID-19 patients in view of laboratory biosafety concerns. As COVID-19 infection is spreading relentlessly worldwide, there is an urgent need for rapid and readily accessible biomarkers that can aid clinical stratification and management. CWA represents a simple, automated and rapid test, which fulfils these biosafety criteria. Whenever an aPTT is performed, an aPTT waveform is generated automatically by commonly used optical analysers worldwide.

In conclusion, the rise of CWA parameters precedes and coincides with ICU admission and warrant further study to confirm its utility in the routine management of COVID-19 patients.

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Table 1: Laboratory results and clinical features of COVID-19 infected patients. Normal reference intervals of clot waveform analysis (CWA) parameters and CWA data of patients with bacterial and other viral acute respiratory tract infections.

CRP, C-reactive protein; ARI, acute respiratory tract infection; ICU, intensive care unit.

Parameters	Reference Intervals	Bacterial Infection[#]	Other Viral ARI[>]	Results of Patients with COVID-19 Infection								
				Patient 1					Patient 2			Patient 3
CRP, mg/L	0.2 – 9.1			**178.8**	**221.0**	**315.5**	**311.0**	**272.0**	**218.8**	**94.4**	**99.6**	**140**
Procalcitonin, µg/L	< 0.50			0.35	0.30	0.48	0.39	**0.50**	**0.51**	0.37	0.37	**0.63**
Platelet, x 10^9/L	140 – 440			280	332	352	293	364	232	333	381	169
PT, s	9.9 – 11.4			10.4	10.9	10.4	10.7	11.2	10.8	10.0	10.4	9.9
APTT, s	25.7 – 32.9	33.0 ± 7.3	30.0 ± 3.9	**38.4**	**36.7**	**37.4**	**34.3**	**33.3**	**36.5**	26.5	**24.6**	**34.5**
Min1, %/s	3.12 – 6.87*	6.92 ± 1.02	6.19 ± 1.32	6.74	**7.52**	**7.93**	**8.28**	**9.18**	**6.97**	**9.35**	**10.49**	**7.04**
Min2, %/s^2	0.51 – 1.05*	1.04 ± 0.28	0.95 ± 0.21	0.90	**1.08**	**1.14**	**1.22**	**1.42**	0.94	**1.49**	**1.76**	1.00
Max2, %/s^2	0.40 – 0.91*	0.82 ± 0.24	0.73 ± 0.18	0.67	0.81	**0.92**	**1.04**	**1.20**	0.72	**1.27**	**1.53**	0.73
Day of hospitalisation				**1st**	**3rd**	**4th**	**5th**	**6th**	**3rd**	**5th**	**6th**	**3rd**
Clinical features				**Admission to hospital**	**Admission to ICU**	**In ICU^**	**In ICU^^**	**In ICU^**	**Admission to ICU**	**In ICU^**	**In ICU^**	**Admission to ICU**

* Reference intervals were established locally based on 191 healthy individuals in accordance with the Clinical and Laboratory Standards Institute Guidelines.

[#] Based on data collected from 52 patients with bacterial infection (manuscript under review).[14] Data presented in mean ± standard deviation.

[>] Based on data collected from 13 patients with common viral ARI (manuscript under review).[14] Data presented in mean ± standard deviation.

^ On daily enoxaparin 40mg.