
Grigoris T. Gerotziafas1,2* Mariella Catalano3 Mary-Paula Colgan4 Zsolt Pecsvarady5
Jean Claude Wautrecht6 Bahare Fazeli7 Dan-Mircea Olinic8 Katalin Farkas9 Ismail Elalamy1,2,10
Anna Falanga11 Jawed Fareed12 Chryssa Papageorgiou13 Rosella S. Arellano14
Petros Agathagelou15 Marco Antic16 Luciana Auad17 Ljiljana Banfi18 John R. Bartolomew19
Bela Benicz20 Melissa B. Bernard21 Francesco Boccardo22 Renate Cifkova22 Benilde Cosmi23
Sergio De Marchi24 Evangelos Dimakakos25 Mлети A. Dimopoulos26,27 Gabriel Dimitrov1
Isabelle Durand-Zaleski28 Michael Edmonds29 Essam Abo El Nazar30 Dilek Erer31
Omar L. Espinda22 Paolo Gresele33 Michael Gschwandtner34 Yongquan Gu35
Mónica Heinzmann17 Naomi M. Hamburg36 Amer Hamadé37 Noor-Ahmed Jatoi38 Oguz Karahan39
Debora Karetova40 Thomas Karplus41 Peter Klein-Weigel42 Endre Kolossvary9 Matija Kozak43
Eleftheria Lefkou44 Gianfranco Lessianni45 Aaron Liev46 Antonella Marcoccia47 Peter Marshang48
George Marakichnelakis49 Jiri Matuska50 Luc Moraglia51 Sergio Pillon52 Pavel Poredos53
Manlio Prior54 David Raymund K. Salvador14 Oliver Schlager55 Gerit Schernthaner55
Alexander Sieron56,57 Jonas Spaak58 Alex Spyropoulos59 Muriel Stryneger60 Dusan Suput61
Agata Stanek62 Viera Stvrtinova63 Andrezj Szuba64 Alfonso Tafur65 Patrick Vandreden2
Panagiotis E. Vardas66 Dragom Vasic67 Milka Vitska68 Paul Wennberg69 Zhengu Zhai70,71

Scientific Reviewer Committee*

1 Hematology and Thrombosis Center, Hôpital Tenon, Hôpitaux Universitaires de l’Est Parisien, Assistance Publique Hôpitaux de Paris, Faculté de Médecine, Sorbonne Université, Paris, France
2 Research Group Cancer, Haemostasis and Angiogenesis, INSERM U938, Centre de Recherche Saint-Antoine, Institut Universitaire de Cancérologie, Faculty of Medicine, Sorbonne University, Paris, France
3 Research Center on Vascular Disease & Angiology Unit, Department of Biomedical Science, Sacco Hospital, University of Milan, Milan, Italy
4 Department of Vascular Surgery, St. James’s Hospital/Trinity College Dublin, Dublin, Ireland
5 Department of Vascular Medicine, Flor Ferenc Teaching Hospital, Kistarcsa, Hungary
6 Service de Pathologie Vasculaire, Hôpital ERASME, Université Libre de Bruxelles, Brussels, Belgium
7 Immunology Department, Avicenna (Bu-Ali) Research Institute, Mashhad University of Medical Sciences, Iran
8 Medical Clinic No. 1, University of Medicine and Pharmacy, Cluj-Napoca, Romania
9 Department of Angiology, St. Imre University Teaching Hospital, Budapest, Hungary
10 Department of Obstetrics and Gynecology, I.M. Sechenov First Moscow State Medical University (Sechenov University), Moscow, Russia
11 Department of Immunohematology and Transfusion Medicine, Thrombosis and Hemostasis Center, Hospital Papa Giovanni XXIII, Bergamo, Italy
12 Department of Pathology, Loyola University Medical Center, Maywood, Illinois, United States

Address for correspondence Grigoris T. Gerotziafas, MD, PhD, VAS Board, VAS-European Independent Foundation in Angiology/Vascular Medicine (www.vas-int.net). INSERM U938 Bâtiment Kourilsky, 34 rue Crozatier, Hôpital Saint Antoine, Paris, Cedex 75012, France (e-mail: grigorios.gerotziafas@inserm.fr).

© 2020. Thieme. All rights reserved. DOI https://doi.org/10.1055/s-0040-1715798. ISSN 0340-6245.

Published online: 2020-09-13

received May 28, 2020
accepted after revision July 23, 2020

Received 2020-05-28
Accepted after revision 2020-07-23

This document was downloaded for personal use only. Unauthorized distribution is strictly prohibited.
Gerotziafas et al.

Practice Guidance for Vascular Complications in Patients with COVID-19

13 Service Anesthésie, Réanimation et Médecine Périopératoire, Hôpital Tenon, Hôpitaux Universitaires de l’Est Parisien, Assistance Publique Hôpitaux de Paris, Faculté de médecine, Sorbonne Université, Paris, France

14 Philippine Society of Vascular Medicine, Manila, Philippines

15 Department of Interventional Cardiology, American Heart Institute of Cyprus, Nicosia, Cyprus.

16 Clinic for Hematology, Clinical Center of Serbia, Faculty of Medicine, University of Belgrade, Belgrade, Serbia

17 Medicina Vascular, Sanatorio Allende Córdoba, Ciencias Médicas, Universidad Católica de Córdoba, Argentina

18 University Hospital Center, School of Medicine University of Zagreb, Croatia

19 Cleveland Clinic, Cleveland, Ohio, United States

20 Balassa Janos County Hospital, University Medical School, Szeged, Hungary

21 Department of Cardio-Thoracic Vascular and Endovascular Surgery, University of Genoa, Italy

22 Department of Preventive Cardiology, Thomayer Teaching Hospital, Prague, Czech Republic

23 Angiology and Blood Coagulation, Department of Specialty, Diagnostic and Experimental Medicine, S. Orsola-Malpighi University Hospital, University of Bologna, Bologna, Italy

24 Angiology Unit, Cardiovascular and Thoracic and Medicine Department, Verona University Hospital, Verona, Italy

25 Vascular Unit of 3rd Department of Internal Medicine, Sotiria Hospital, National and Kapodistrian University of Athens, Athens, Greece

26 Hellenic Society of Hematology, Athens, Greece

27 Department of Clinical Therapeutics, School of Medicine, National and Kapodistrian University of Athens, Athens, Greece

28 Université de Paris, CRESS, INSERM, INRA, URCEco, AP-HP, Hôpital de l’Hôtel Dieu, Paris, France

29 Diabetic Foot Clinic, King’s College Hospital, London, United Kingdom

30 Department of Surgery, Ministry of Health, Saudi Arabia

31 Department of Cardiovascular Surgery, Faculty of Medicine, Gazi University, Besevler/Ankara, Turkey

32 Internal Medicine Department, Hospital Perea, Mayaguez, Puerto Rico, United States

33 Section of Internal and Cardiovascular Medicine, Department of Medicine, -University of Perugia, Perugia, Italy

34 Medizinische Universität Wien, Universitätsklinik für Innere Medizin II, Klinische Abteilung für Angiologie, Vienna, Austria

35 Department of Vascular Surgery, Xuanwu Hospital, Capital Medical University, Beijing China

36 The Whitaker Cardiovascular Institute Department of Medicine Boston University School of Medicine, Boston, Massachusetts, United States

37 Vascular Medicine Unit, Internal Medicine Department, King Fahad University Hospital, Imam Abdulrahman Bin Faisal University, Dammam, Saudi Arabia

38 Department Vascular Medicine, Mulhouse Hospital Center, Mulhouse, France

39 Department of Cardiovascular Surgery, Medical School of Alaaddin Keykubat University, Alanya/Antalya, Turkey

40 Second Department of Medicine, Department of Cardiovascular Medicine, Charles University in Prague, Prague, Czech Republic

41 Department of Vascular Medicine, Concord Repatriation General Hospital, Sydney, Australia

42 Klinik für Angiologie, Zentrum für Innere Medizin II, Ernst von Bergmann Klinikum, Potsdam, Germany

43 Department for Vascular Diseases, Medical Faculty of Ljubljana, University Medical Center Ljubljana, Ljubljana, Slovenia

44 Board member of the Institute for the Study and Education on Thrombosis and Antithrombotic Therapy, Athens, Greece

45 Angiology Unit, Internal Medicine Department, Città Sant’Angelo Hospital, AUSL 03, Pescara, Italy

46 Pontificia Universidad Católica de Chile, National University of Ireland Galway (NUIG), Galway, Ireland

47 Unità di Medicina Vascolare e Autoimmunità, CRIS-Centro di riferimento interdisciplinare per la Sclerosi Sistemica, Rome, Italy

48 Department of Internal Medicine, Central Hospital of Bolzano, Bolzano, Italy

49 Angiology Unit, Evangelismos General Hospital, Athens, Greece

50 MATMED s.r.o., Private Angiology Facility, Hodonín, Czech Republic

51 Angiologie Centre Cours du Médoc, Médecine Vascular, Bordeaux, France

52 UOSD Angiology, San Camillo-Forlanini Hospital, National Health Institute ISS, Rome, Italy

53 Medical Association of Slovenia and SMA, Slovenia Academic Research Centre, Slovenian Medical Academy, Ljubljana, Slovenia

54 Angiology Unit, Azienda Ospedaliera Universitaria Integrata di Verona, Verona, Italy

55 Division of Angiology, Department of Internal Medicine 2, Medical University of Vienna, Vienna, Austria

56 Department of Internal Medicine, Angiology and Physical Medicine, Medical University of Silesia, Katowice, Poland

57 Specialist Hospital, Bytom, Jan Długosz University in Częstochowa, Częstochowa, Poland

58 Department of Clinical Sciences, Danderyd Hospital, Division of Cardiovascular Medicine, Karolinska Institutet, Stockholm, Sweden

59 Department of Medicine, Anticoagulation and Clinical Thrombosis Services, Northwell Health at Lenox Hill Hospital, The Donald and Barbara Zucker School of Medicine at Hofstra/Northwell, The Feinstein Institute for Medical Research, New York, New York, United States

60 Cardiology Department, University Hospital Sart Tilman, Liege, Belgium

61 Center for Clinical Physiology, Faculty of Medicine, University of Ljubljana, Ljubljana, Slovenia

62 Department of Internal Medicine, Angiology and Physical Medicine, Faculty of Medical Sciences in Zabrze, Medical University of Silesia, Bytom, Poland

63 Faculty of Medicine, Comenius University, Bratislava, Slovak Republic

64 Department of Angiology, Hypertension and Diabetology, Wroclaw Medical University, Wroclaw, Poland

65 Department of Medicine, Vascular Medicine University of Chicago, Northshore Cardiovascular Institute, Skokie, Illinois, US Army

66 Medical School of Crete, University of Crete and Heart Sector, Hellenic Healthcare Group, Athens, Greece

67 Department of Noninvasive vascular laboratory, Clinic of Vascular and Endovascular Surgery, Clinical Centre of Serbia, Belgrade, Serbia

68 Human Molecular Genetics, de Duve Institute, University of Louvain, Brussels, Belgium

69 Department of Cardiovascular Medicine, Gonda Vascular Center, Mayo Clinic, Rochester, Minnesota, United States

70 Department of Pulmonary and Critical Care Medicine, Center of Respiratory Medicine, China-Japan Friendship Hospital, Peking University Health Science Center, Capital Medical University, Beijing, China

71 Institute of Respiratory Medicine, Chinese Academy of Medical Sciences, Beijing, China

Thromb Haemost 2020;120:1597–1628
COVID-19 is also manifested with hypercoagulability, pulmonary intravascular coagulation, microangiopathy, and venous thromboembolism (VTE) or arterial thrombosis. Predisposing risk factors to severe COVID-19 are male sex, underlying cardiovascular disease, or cardiovascular risk factors including noncontrolled diabetes mellitus or arterial hypertension, obesity, and advanced age. The VAS-European Independent Foundation in Angiology/Vascular Medicine draws attention to patients with vascular disease (VD) and presents an integral strategy for the management of patients with VD or cardiovascular risk factors (VD-CVR) and COVID-19. VAS recommends (1) a COVID-19-oriented primary health care network for patients with VD-CVR for identification of patients with VD-CVR in the community and patients’ education for disease symptoms, use of eHealth technology, adherence to the antithrombotic and vascular regulating treatments, and (2) close medical follow-up for efficacious control of VD progression and prompt application of physical and social distancing measures in case of new epidemic waves. For patients with VD-CVR who receive home treatment for COVID-19, VAS recommends assessment for (1) disease worsening and prioritized hospitalization of those at high risk and (2) VTE risk assessment and thromboprophylaxis with rivaroxaban, betrixaban, or low-molecular-weight heparin (LMWH) for those at high risk. For hospitalized patients with VD-CVR and COVID-19, VAS recommends (1) routine thromboprophylaxis with weight-adjusted intermediate doses of LMWH (unless contraindication); (2) LMWH as the drug of choice over unfractionated heparin or direct oral anticoagulants for the treatment of VTE or hypercoagulability; (3) careful evaluation of the risk for disease worsening and prompt application of targeted antiviral or convalescence treatments; (4) monitoring of D-dimer for optimization of the antithrombotic treatment; and (5) evaluation of the risk of VTE before hospital discharge using the IMPROVE-D-dimer score and prolonged post-discharge thromboprophylaxis with rivaroxaban, betrixaban, or LMWH.
coagulation (DIC) may occur in patients with critical illness and is a relevant predictor of death. Immunothrombosis with pulmonary intravascular coagulation (PIC) and vascular occlusion in the microcirculation of the lungs are frequent findings reported in autopsies of patients died from COVID-19. Last but not least, patients with COVID-19 are also at increased risk for arterial thrombosis (ischemic stroke, myocardial infarction, limb ischemia). Accordingly, COVID-19 is a systematic disease involving blood coagulation and vessels. Patients with cardiovascular disease (CVD) or cardiovascular risk factors are the most vulnerable for deterioration to severe COVID-19 and critical illness following SARS-CoV-19 infection.

CVD—including ischemic stroke, carotid artery disease, coronary artery disease, peripheral artery disease (PAD)—is according to the WHO a pathology of the circulatory system which involves endothelial cell dysfunction.16 CVD has an age-standardized prevalence from 5,000 to 9,000 cases per 100,000 persons varying by country. The prevalence of cardiovascular risk factors (i.e., obesity, diabetes mellitus, or arterial hypertension) is even higher.17

The term “patients with vascular disease or cardiovascular risk factors” (VD-CVR) refers to patients with a personal history of arteriopathy or arterial thrombosis, including patients with a history of ischemic stroke, carotid artery disease, coronary artery disease, PAD, or arterial thrombosis of rare localization (i.e., mesenteric artery thrombosis) and patients with a history of deep vein thrombosis (DVT), PE, or vein thrombosis of rare localization (i.e., cerebral vein thrombosis, splanchnic vein thrombosis, upper limb thrombosis). Obese individuals (body mass index [BMI] > 30) and patients with diabetes mellitus or arterial hypertension are also included.

Following SARS-CoV-19 infection, patients with VD-CVR are at risk for severe COVID-19 and critical illness, which during the epidemic periods may destabilize the health systems. The guidelines and position papers published so far concern COVID-19 patients in general and focus mainly on the prevention and treatment of VTE and some of them propose therapeutic guidance for DIC.

Facing the magnitude and the duration of the SARS-CoV-2 epidemic and the absence of a specific vaccine, there is an urgent need for an integral and targeted strategy for patients with CVD, aiming the prevention of SARS-CoV-2 infection and the management of the COVID-19 vascular complications which may lead to disease worsening.

The VAS-European Independent Foundation in Angiology/Vascular Medicine responds to this challenge with the present guidance providing (1) the principles for the organization of a primary health care network focused on patients with VD-CVR, (2) the methodology for the identification of patients with vascular disease among patients with COVID-19 and the evaluation of the risk for disease worsening, (3) the necessary information for pharmacological and pharmacodynamic issues of antithrombotic agents and vascular regulating treatments which are potentially influenced by COVID-19 or the associated treatments, (4) the strategies for the management of the hypercoagulable state and the diagnosis and treatment of DIC, and (5) the recommendations for the prevention and treatment of VTE adapted for patients with VD-CVR.

Methods


We reviewed manuscripts on three servers (https://www.medrxiv.org/, https://www.preprints.org/, and https://www.ssrn.com/index.cfm/en/coronavirus/). The last literature research was performed on July 14, 2020. Relevant articles were screened and analyzed by G.T.G. and M.C. Subsequently, the initial document with the guidelines was formulated by the members of the VAS Board (G.T.G., M.C., M.P.C., Z.P., J.C.W., B.F., D.M.O., K.F.). The initial document was subsequently submitted to the VAS Advisory Board and circulated to all the authors for comments. Recommendations and suggestions were formulated with the unanimous accordance of the ensemble of the authors. Due to the limited clinical experience in patients with COVID-19 and the absence of randomized clinical trials controlling the efficacy and safety of various antithrombotic treatment regimens and the other interventions in the context of COVID-19, the ensemble of the proposed recommendations has a low grade of evidence. This guidance will be updated, and the relevant algorithms will be formulated as soon as new epidemiological evidence and results of ongoing clinical studies will be published. In the meanwhile, the VAS web site (www.vas-int.net) and its links with various national medical societies in relation with the management of patients with VD-CVR will be the key vectors for the implementation of this guidance. At the actual phase of SARS-CoV-2 epidemic and facing the urgent situation produced by the vast wave of patients with COVID-19 worldwide, there are no means for cost evaluation of the interventions proposed by the guidance as well as for the audit to assess the guidance implementation.

Hypercoagulability and Endothelial Activation: Key Elements in Deterioration of COVID-19

Structural Elements of SARS-CoV-2 and Activation of Endothelial Cells and Coagulation

SARS-CoV-2 receptor binding occurs via the spike (S) protein (encoded by the structural S gene) which has two subunits: subunit S1 mediates binding and a trimeric S2 stalk mediates
fusion to the infected cell. The S1 subunit is divided into two domains, the N-terminal domain (S1-NTD) and the C-terminal domain (S1-CTD). These regions mediate binding to a variety of cellular receptors. Endothelial cells of arteries and veins, arterial smooth muscle cells, cardiomyocytes, and type I and type II alveolar epithelial cells in human lung tissue express ACE2 and are targets of SARS-CoV-2 infection spread. The S1-CTD binds with high affinity to the ACE2 receptor and the TMPRSS2. Cell infection with SARS-CoV-2 requires coexpression of ACE2 and TMPRSS2. Cleavage of the S protein by the TMPRSS2 is necessary for binding of SARS-CoV-2 to ACE2. The TMPRSS2 is abundantly expressed by cells in the lung tissue and makes the respiratory system vulnerable to virus infection. Following entry to alveolar epithelial cells, components of the SARS-CoV-2 trigger immune response via different pathways, including immunological receptors on and inside immune cells, retinoic acid-inducible gene-I (RIG-I)-like receptors (RLRs), toll-like receptors (TLRs), NOD-like receptors (NLRs), and cyclic GMP-AMP synthase (cGAS), which activate intracellular signaling cascades, leading to the secretion of proinflammatory cytokines and chemokines. Additional endogenous adjuvant activity is provided by pyroptotic cell death regulated by the nod-like receptor family, pyrin domain containing 3 (NLRP3) inflammasome activation. The endogenous adjuvant activity following SARS-CoV-2 infection is caused by the direct activation of NLRP3 by the viral protein viroporin protein 3a. Infiltration, accumulation, and activation of defense cells (i.e., neutrophils, monocytes, lymphocytes, macrophages, and dendritic cells) amplify the immune reaction and lead to cytokines secretion. The cytokines interleukin (IL)-1, IL-6, interferon gamma, and tissue necrosis factor α are major effectors of the cytokine storm induced by the SARS-CoV-2.

**Activation of Complement in SARS-CoV-2 Infection**

SARS-CoV-2 either directly or through the immune reaction induces activation of the complement system which is a part of the innate immune system. Natural (immunoglobulin M) antibodies that recognize viral antigens or neoantigens exposed on damaged host tissues activate the classical pathway. Viral components such as the nucleic protein (N protein) directly interact with mannose-binding lectin-associated proteases 2 (MASP2) leading to the activation of the mannose-binding lectin pathway. Debris from dying cells in multiple ischemic organs likely shed lipid-anchored membrane complement regulatory proteins (such as DAF and CD59), and lose glycosaminoglycans (GAGs) allowing complement activation by the alternative pathway. Activated complement promotes inflammation. The anaphylatoxins C3a and C5a are likely major contributors to cytokine storm syndrome through their intrinsic proinflammatory activities in leukocyte activation and trafficking, and by synergizing with other innate immune sensors, such as TLRs. C3a and C5a, and direct cell lysis with the assembly of the membrane attack complex C5b-9. Both immunologic and nonimmunologic tissue damage can initiate the kinin formation and the activation of the intrinsic pathway of blood coagulation (for review see Song and FitzGerald).

**Direct Procoagulant Activity of SARS-CoV-2**

The vascular system is also a target of the virus because TMPRSS2 is expressed by endothelial cells. Accordingly, endothelial cells at least at the level of lung vasculature are exposed to SARS-CoV-2 infection and are subjects of activation. The TMPRSS2 is the most important, but not the unique, protease that cleaves S protein. Other proteases such as cathepsins and activated factor X (FXa) also effectively cleave the full-length S protein. SARS-CoV-2 may directly induce activation of coagulation through the highly conserved main protease (Mpro)—also known as 3Clpro—that catalyzes the viral polyprotein processing, a necessary procedure for SARS-CoV-2 infection. According to three-dimensional structure analysis, the active site of the Mpro from SARS-CoV-2 shares structural similarities with the active site of FXa and thrombin and it may activate blood coagulation. Mpro is unique in the virus and not found in the host cells, being a prominent target for the development of antiviral agents. In silico modelization experiments showed that the direct FXa inhibitors apixaban and betrixaban and the direct thrombin inhibitor argatroban are potential inhibitors of the SARS-CoV-2 invasion. Presumably heparins by amplifying antithrombin (AT) activity against FXa and thrombin or a direct binding to these extracellular membrane receptors might also compromise SARS-CoV-2 Mpro pathways.

**Activation of Blood Coagulation in SARS-CoV-2 Infection**

Platelet activation and contact-system-initiated thrombin generation are involved in the pathogenesis of immunothrombosis in several critical pathological states such as septicemia, bacterial DIC, or ARDS. Hypercoagulability in patients with COVID-19 is also initiated by activation of the contact system, which is composed of three groups of serine proteinases: (1) plasma prekallikrein (PPK); (2) the clotting factors XII (FXII) and XI (FXI), and (3) the nonenzymatic cofactor “high-molecular-weight kininogen” (HMWK). Cleavage of free HMWK by plasma kallikrein (PK) releases bradykinin, a potent inflammatory mediator and an activator of the complement and contact system. The contact system components bind to vascular endothelium, platelets, and neutrophils, with the HMWK serving as a docking site for PPK.

GAGs at the surface of endothelial cells regulate bradykinin generation. HMWK bound to GAGs is “protected” from PK and generation of bradykinin is therefore reduced. Low availability of GAGs (i.e., in the case of endothelial cell activation) results in an increased concentration of free HMWK available for bradykinin generation upon exposure to PK.

Contact system activation leads also to FXII activation (FXIIa), which in its turn binds to negatively charged phospholipids and activates FXI triggering the sequential activation of FIX and FX, leading to thrombin generation which amplifies its generation by activating factors V and VIII and platelets that offer procoagulant phospholipids for the formation of the intrinsic tenase and prothrombinase.
Among the negatively charged surfaces present in blood and vessels (i.e., collagen, cholesterol sulfate, sulfatides, acid phospholipids, fatty acids, and several charged carbohydrates), the polyphosphates (polyP) released by activated platelets appear to play a major role in FXII activation.

An increase of polyP and a decrease of GAG lead to amplification of the thrombin generation process, inflammatory response, and vasoconstriction at the level of lung microcirculation. The enhanced cytokine production during virus infection also stimulates additional procoagulant reactions, with increased tissue factor (TF) expression, a major initiator of the coagulation. The GAGs' availability on endothelial cell membranes and the release of polyP from activated platelets regulate the contact system protein assembly, bradykinin formation, and FXII activation. Thrombin in its turn leads to fibrin formation, activates FVII and FXII, enhances platelet activation, alters fibrinolysis, and is a major mediator of inflammatory reactions. Initiation of a vicious cycle of thrombin generation may lead to consumption of natural coagulation inhibitors (i.e., AT, protein C [PC], and protein S) and to a compensated DIC. Unbalanced activation of endothelial cells either by a direct effect from the SARS-CoV-2 infection or as a result of the inflammatory procedure results in further TF expression.

Neutrophil extracellular traps (NETs) and damage-associated molecular patterns may also be involved in the procoagulant profile in patients with COVID-19. In some cases, the presence of antiphospholipid antibodies that can also induce arterial thrombosis has been reported, but this is a controversial issue.

- Fig. 1 summarizes the principal mechanisms triggered by SARS-CoV-2 infection leading to enhanced thrombin generation and pulmonary intravascular coagulation.

### Endothelial Cell Activation and Pulmonary Intravascular Coagulopathy in COVID-19

Emerging data underline the crucial role of endothelial cell activation during SARS-CoV-2 infection, as a direct target of the virus and inflammatory cytokines as well as the main actors in orchestrating a proinflammatory and procoagulant state in COVID-19 patients. The increased number of circulating endothelial cells in the blood from patients with COVID-19 corroborates the concept of the involvement of endothelial cell activation. Autopsies in COVID-19
patients document thrombotic microangiopathy involving the lungs as an important mechanism that contributes to death. The pulmonary pathological changes of fatal COVID-19 are diffuse alveolar damage (DAD), accompanied by thrombosed small vessels with capillary hyaline thrombi, intravascular mixed thrombi, and significant associated hemorrhages. Endothelial cells, megakaryocytes, and platelet activation with microcirculation abnormalities implicating blood hypercoagulability are orchestrated in the process of disease aggravation and death. Patients present a high density of alveolar megakaryocytes and platelet-rich clot formation, in addition to fibrin deposition. Patients who had a more protracted hospital course had extensive and early organized fibrin network, with degenerated neutrophils within the alveoli possibly representing NETs.\(^{40-44}\) Lung microcirculation is characterized by the presence of viral elements within endothelial cells, accumulation of inflammatory cells, and endothelial inflammatory cell apoptosis. The ensemble of these histological and morphological abnormalities documents the existence of endotheliitis in several organs as a direct consequence of SARS-CoV-2 involvement and the host inflammatory response.\(^{45}\) The diffuse bilateral pulmonary inflammation observed in COVID-19 is associated with a novel pulmonary-specific vasculopathy which has been termed “pulmonary intravascular coagulopathy” (PIC) as distinct to DIC.\(^{46}\) The clinical and computed tomography (CT) characteristics of PE in patients with COVID-19 were substantially different to those from patients with PE without COVID-19.\(^{47}\) Autopsy evidence in COVID-19 patients showed rough dilatation of the pulmonary artery branches and extensive thrombosis of the small arterioles, in keeping with a PE-like pattern.\(^{48}\) Filling defects of pulmonary vessels that are detected by CT-scans are in many instances more reminiscent of pulmonary thrombi rather than emboli, because they are not fully occlusive.\(^{49}\) These initial observations were confirmed by autopsy findings in 21 hospitalized COVID-19 patients which showed severe capillary congestion (capillarostasis). Microthrombi were detected in alveolar capillaries and were linked to PIC. Moreover, 20% of the patients had PE and 18% had evidence of DIC in the kidneys, despite anticoagulation.\(^{50}\) These data provide autopsy-based evidence of the link between endotheliitis, coagulopathy, and complement-mediated multifocal microvascular injury in different organs, as well as skin injuries in concert with pulmonary capillarostasis. In addition, some evidence highlights abnormalities in lung perfusion with microvascular shunting surrounding areas of inflammation with worsening of gas exchanges.\(^{51}\)

Kidney biopsy analysis in patients with COVID-19 and associated kidney injury showed acute tubular necrosis as the dominant pathology followed by findings of thrombotic microangiopathy. However, immunohistochemical staining of kidney biopsy samples for SARS-CoV-2 was negative and an ultrastructural examination by electron microscopy showed no evidence of viral particles in the biopsy samples.\(^{52}\)

The ensemble of the data available so far indicates that in patients with severe COVID-19 the SARS-CoV-2 triggers a vicious cycle of inflammatory reaction, excessive immunological response, endothelial cell activation, and hypercoagulability leading to organ dysfunction, whereas the evolution toward clinical deterioration may not be directly related with the presence of the virus.

**Autopsy Documented Venous Thromboembolism in COVID-19**

A large series of 80 autopsies performed in Hamburg showed that the most frequent cause of death in patients with COVID-19 is pneumonia, followed by pulmonary artery embolisms combined with pneumonia.\(^{53}\) Deceased had CVDs (85%), lung diseases (55%), central nervous system diseases (35%), kidney diseases (34%), diabetes mellitus (21%), obesity (21%), and solid or hematological cancer (16%). The incidence of autopsy documented VTE was 42.5%. The incidence of PE was 21%. In 10% of patients, fatal fulminant pulmonary artery embolism was identified, whereas peripheral PE was found in other 11% of deceased patients. All cases with PE had also DVT. In additional 19% of cases, DVT was documented without PE. The male deceased also showed thrombi in the prostatic venous plexus in 15 cases and in the veins of the esophagus in one case. Importantly, 10 out of 26 patients (38%) who died at home had VTE showing that the risk of VTE is not determined only by hospitalization but mainly by SARS-CoV-2 infection and COVID-19 severity. A comprehensive review of the histological lung lesions reported in the autopic studies in patients with COVID-19 confirms the importance of VTE together with DAD, PIC, and endotheliitis in the disease-worsening process.\(^{54}\)

**VAS Statement on Hypercoagulability, Endothelial Cell Activation, and Research on the Future Targeted Therapies for COVID-19**

- SARS-CoV-2 infection leading to severe COVID-19 implicates immune response, endothelial cell dysfunction, platelets, and complement activation, which are related with worsening disease and death. These pathways lead to initiation and enhancement of thrombin generation via the contact system and the TF pathways.
- Microvascular thrombosis at the lungs and other organs and PE are major causes of morbidity and mortality in patients with severe or critical COVID-19.
- COVID-19 is a major risk factor of VTE which may occur in the outpatient setting, during hospitalization, and even after hospital discharge.
- Targets for new therapies in COVID-19 include:
  - Endothelial cell activation induced by SARS-CoV-2.
  - Inhibition of serine proteases expressed by SARS-CoV-2 and investigation of the potentially inhibitory effect of direct and indirect inhibitors of thrombin or FXa.
  - Inhibition of the complement, the contact system, and the intrinsic pathway of blood coagulation.
- Focused research is required on the possible relationship between the pre-existing activation status of endothelial
cells in patients with VD-CVR upon exposure to the SARS-CoV-2 and the risk of severe or critical illness.

- There is a need for therapeutic strategies aiming the prevention and treatment of “endotheliitis” and PIC upon SARS-CoV-2 infection. Antithrombotic agents (antiplatelet and anticoagulant drugs) and agents targeting the endothelium (i.e., statins, sulodexide, dermatan sulfate, etc.) are potential treatments requiring further investigations.

- Full pathological examination is an important tool to better understand the pathophysiology of diseases, especially when the knowledge of an emerging disorder is limited and the impact on the health care system is significant. VAS calls for performing well-conducted autopsies of deceased COVID-19 patients.

### Patients with Vascular Disease or Cardiovascular Risk Factors at Risk of COVID-19 Worsening

#### Profile of COVID-19 Patients at Risk of Disease Worsening

Patients with VD-CVR and particularly elderly patients are at high risk for severe COVID-19. Cardiovascular presentation in the setting of COVID-19 may be atypical, underpinning the importance of a high level of clinical suspicion of potential COVID-19 cases. Analysis of more than 8,900 COVID-19 patients hospitalized in North America, Europe, and Asia found that 30.5% of them had hyperlipidemia, 26.3% had arterial hypertension, 14.3% had diabetes mellitus, 16.8% were former smokers, and only 5.5% were current smokers. In terms of cardiopathy, 11.3% had coronary artery disease and 2.1% had congestive heart failure. Myocardial injury with an elevated troponin level occurred in up to 17% of patients hospitalized with COVID-19 and 22 to 31% of those were admitted to ICUs and up to 7% of the COVID-19-related deaths were attributable to myocarditis. The frequency of cardiac arrhythmia among hospitalized COVID-19 patients was approximately 3.4%, being at the same levels as the arrhythmia prevalence in general population with similar age. A meta-analysis of 1,527 patients with COVID-19 found that the prevalence of arterial hypertension or cardiac disease was 17.1% and 16.4% respectively, and that these patients were more likely to require critical care. Underlying CVD is associated with more severe COVID-19 and higher mortality. Data analysis of 44,672 patients with COVID-19 found that a history of CVD was associated with a nearly fivefold increase of case fatality rates when compared with patients without CVD (10.5 vs. 2.3%). A more recent meta-analysis of 13 studies including 3,027 patients with SARS-CoV-2 infection confirmed that age >65 years, male gender, arterial hypertension, diabetes mellitus, CVD, and respiratory disease are significant risk factors for severe COVID-19, disease worsening, and death.

Patients with diabetes mellitus and COVID-19 infection are at a higher risk of admission to the ICU and mortality. Hyperglycemia is associated with vascular endothelial cell dysfunction. Efficacious control of glycaemia in diabetic patients is mandatory for decreasing the risk of severe COVID-19. Well-controlled blood glucose levels (glycemic variability within 3.9–10.0 mmol/L) in people with type 2 diabetes mellitus was associated with a markedly lower mortality compared with individuals with poorer glycemic control (upper limit of glycemic variability exceeding 10.0 mmol/L; adjusted hazard ratio [HR]: 0.14) during hospitalization. Male gender, age >65 years, coronary artery disease, congestive heart failure, cardiac arrhythmia, and chronic obstructive pulmonary disease are associated with a higher risk of in-hospital death. The prevalence of cardiovascular risk factors for disease worsening and the relative risk of critical disease are summarized in Table 1.

#### Peripheral Arterial Disease and Risk of COVID-19 Worsening

Peripheral arterial disease has a prevalence of up to 25% in men and women older than 70 years and is largely underdiagnosed. Limited data are available on the risk for severe COVID-19 in patients with PAD. The risk for vascular complications in such COVID-19 patients might be underestimated. Reciprocally, some limited data show that COVID-19 is a risk factor for acute limb ischemia in patients with

### Table 1

<table>
<thead>
<tr>
<th>Comorbidities</th>
<th>Critical COVID-19 (%)</th>
<th>Severe COVID-19 (%)</th>
<th>Odds ratio for disease worsening (95% CI)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Diabetes</td>
<td>14–60</td>
<td>6–25</td>
<td>2.13 (2.68–5.1)</td>
</tr>
<tr>
<td>Hypertension</td>
<td>15–64</td>
<td>7–39</td>
<td>3.34 (1.72–5.47)</td>
</tr>
<tr>
<td>CVD</td>
<td>9–40</td>
<td>1–10</td>
<td>5.19 (3.25–8.29)</td>
</tr>
<tr>
<td>Respiratory disease</td>
<td>5–10</td>
<td>1–8</td>
<td>5.15 (2.51–10.5)</td>
</tr>
<tr>
<td>Malignancy</td>
<td>1.5–10</td>
<td>1–6</td>
<td>1.6 (0.81–3.18)</td>
</tr>
<tr>
<td>Obesity</td>
<td>31</td>
<td>8</td>
<td>5.4 (2.77–10.67)</td>
</tr>
<tr>
<td>Chronic renal disease</td>
<td>19</td>
<td>7</td>
<td>2.92 (1.04–6.09)</td>
</tr>
</tbody>
</table>

Abbreviations: CI, confidence interval; CVD, cardiovascular disease.
PAD. Similarly there is lack of evidence on the risk for developing severe COVID-19 in patients with other forms of vascular disease (i.e., lymphatic or microcirculatory disease).

Risk of Arterial Thrombosis in Patients with COVID-19
Surprisingly, although the CVD and the cardiovascular risk factors are major predictors of disease worsening and death, the incidence of arterial thrombosis is much lower as compared with that of VTE. In a single-center study from Madrid on 1,419 hospitalized patients with COVID-19, only 14 patients (1%) presented arterial thrombosis (acute coronary syndrome, acute ischemic stroke, transient ischemic attack, limb infrapopliteal thrombotic event) during their hospitalization period. The mortality rate in these patients was 28%. In a French study enrolling 184 patients with COVID-19 admitted at the ICU, only seven patients had arterial thrombosis (3.8%), of whom two had systemic arterial embolism.

Interestingly, 68 patients (37%) had VTE. Similarly, in a cohort of 388 hospitalized patients with COVID-19 in Milan, the incidence of arterial thrombosis (ischemic stroke and acute coronary syndrome) was also limited (3.6%) compared with the cumulative rate of VTE (21%; 27.6% in ICUs and 6.6% in conventional wards).

Skin Manifestations and Chilblains in COVID-19 Patients
Cutaneous manifestations in COVID-19 patients may present in two major groups regarding their pathogenetic mechanisms: (1) clinical features similar to viral exanthems induced by the immune response to viral nucleotides and (2) cutaneous eruptions secondary to systemic consequences caused by COVID-19, especially vasculitis and thrombotic vasculopathy. Dermatological manifestations such as skin rash, urticaria, vesicles, and purpura have been also reported.

More recently, lesions resembling chilblains have been reported. Transient livedo reticularis has also been described.

Chilblains in patients with COVID-19—described as COVID-19 toes—are being seen with an increasing frequency in children and young adults. Histopathology alterations in COVID-19 toes are characterized by variable degrees of lymphocytic vasculitis ranging from endothelial swelling and endotheliitis to fibrinoid necrosis and thrombosis. Purpura and superficial and deep perivascular lymphocytic inflammation with perieccrine accentuation or edema have been also described. The pathophysiology of chilblains is poorly understood. However, the presence of SARS-CoV-2 in endothelial cells and epithelial cells of eccrine glands has been documented by histochemistry and electron microscopy. These data indicate a potential link between endothelial cell damage induced by the virus and the manifestation of chilblains. Moreover, complement activation by the SARS-CoV-2 is probably implicated in this process but very limited data are available so far.

Studies on the clinical usefulness of the measurement of complements (particularly C3 and C5) in patients with COVID-19 toes are strongly encouraged. Similarly, there are no data on therapeutic options in patients with COVID-19 toes, including the evaluation of the efficacy of aspirin in this context.

Specific Aims of Primary Health Care in the Management of Patients with Vascular Disease or Cardiovascular Risk Factors and COVID-19:
Networking and Patient Involvement with e-Health
Lock-down policies in the case of epidemic waves should target in priority patients with VD-CVR. An emerging need is the elaboration of a COVID-19-oriented primary health care network using the tools of the e-Health (electronic health record templates, hospital information system dashboards, cloud-based medical image sharing, a mobile app, and smart vital-sign-monitoring wearable devices) for the management of these patients with nonsevere COVID-19 since some of them are at risk of disease worsening.

Telemonitoring, televisit, and teleconsulting are encouraged to limit the effect of restricted access to physicians during, but not only, the epidemic or because of geographical limitations.

The organization of the eHealth network needs a connection of COVID-19 centers, with specialists in angiology/vascular medicine, general practitioners, and hematological and biochemical laboratories for testing simple laboratory parameters mandatory for the disease evolution, image sharing facilities, utilization of “apps” offering a technology system for the follow-up of patients with VD-CVR and following the indications of the public health national systems. The network needs also to obtain an active, continue involvement of patients in disease control.

VAS Recommendations for General Measures in Patients with Vascular Disease or Cardiovascular Risk Factors during the SARS-CoV-2 Epidemic

- Patients with VD-CVR are at high risk of disease worsening and death upon SARS-CoV-2 infection. Patients with VD-CVR need to be identified at the community and registered at the regional COVID-19 centers and available angiology/vascular medicine centers.

- A regional procedure for prioritization of hospitalization of patients with VD-CVR with nonsevere COVID-19 who are at risk of disease worsening should be considered by health authorities.

- Educational programs must be elaborated for:
  - Patients with VD-CVR aiming their training on early recognition of COVID-19 symptoms and the application of social distancing and self-protection measures.
  - Physicians, particularly general practitioners and family doctors, aiming their training on early recognition of the risk of COVID-19 worsening and the implementation of the recommendations for the diagnosis and treatment of COVID-19.

- Physicians are advised to be aware of possible dermatological manifestations of COVID-19.

- Patients with VD-CVR should be under regular medical follow-up for:
Antithrombotic and Vascular Modulating Treatments in Patients with COVID-19

Blood-borne hypercoagulability in concert with endothelial cell activation and endotheliitis predisposes to severe COVID-19 and patients with VD-CVR are prone to disease worsening. Inhibition of thrombin generation and platelet activation is an emerging therapeutic strategy, adjuvant to antiviral or immunological or other compassionate therapies.

The targets of the antithrombotic treatment in patients with VD-CVR during infection with SARS-CoV-19 and COVID-19 are (1) prevention and treatment of PIC and DIC, (2) prevention and treatment of VTE, (3) prevention of arterial thrombosis recurrence, and (4) prevention of disease worsening.

The potent inhibition of thrombin generation induced by unfractionated heparin (UFH), low-molecular-weight heparins (LMWHs), and direct oral anticoagulants (DOACs) places them into the first line for management of patients with VD-CVR and COVID-19.

The pharmacological and pharmacodynamic properties of antithrombotic agents as well as the drug–drug interactions are of important relevance in these patients. Cytokine storm and inflammation, hypercoagulability and the eventual evolution to consumption coagulopathy, the rapid deterioration of the renal or hepatic function in patients with worsening disease, as well as the interactions with some of the experimental drugs might compromise the beneficial effect of some antithrombotic agents and may lead either to bleeding risk increase or treatment resistance. For these reasons, in the following section, we present the most important pharmacological and pharmacodynamic properties of the antithrombotic agents that might be proposed.

Heparins

Heparins are multitargeted antithrombotic agents. LMWHs are the most widely used antithrombotic agents for the prevention and treatment of VTE in hospitalized patients. UFH is more frequently used in patients with renal insufficiency. UFH and LMWH exert their antithrombotic effect primarily by the binding of the pentasaccharide domain (present in ~30% of the polysaccharide chains) on AT.88 UFH and LMWH stimulate the release of the TF pathway inhibitor from endothelial cells, exert a potent anti-inflammatory action, have immune modulating actions, inhibit complements and prevent the NET formation. Heparins may also competitively bind to coronaviruses and inhibit its multicellular invasion.89-92

The high degree of sulfation of GAG chains makes heparin one of the most strongly anionic biological macromolecules. Heparin will therefore interact with any basic molecule it encounters. The intensity of this interaction depends on the molecular size and results in the inhibition of the antithrombotic activity of heparin. Longer GAG chains in UFH are more sulfated and show a higher nonspecific binding to basic molecules (i.e., platelet factor 4, fibronectin, vitronectin, annexin, or plasma inflammatory proteins) as compared with the shorter GAG chains of the LMWHs.93 Nonspecific binding of UFH with inflammatory proteins compromises
the antithrombotic activity of UFH as documented by the high rates of resistance to UFH treatment in COVID-19. The smaller molecular size of polysaccharide chains in LMWHs, compared with that of UFH, involves a more predictable pharmacological action and better bioavailability after sub-cutaneous injection.

The LMWHs vary in their physicochemical properties, the anti-Xa/anti-IIa ratio, and their inhibitory effect on thrombin generation. Therefore, the dosages for each one should be administered according to manufacturers’ instructions.

Both UFH and LMWHs alter the clot firmness, an effect which is related to the physicochemical properties of GAG chains. This property of heparins might have some importance in the management of the hypercoagulable state and the risk of thrombosis in patients with COVID-19, since the inflammatory reaction in COVID-19 patients is associated with a high clot firmness.

It is well documented that in clinical practice, the correlation between activated partial thromboplastin time (aPTT) prolongation and the UFH dose is rather poor. In patients with COVID-19, who need efficient anticoagulation, the monitoring of the treatment with UFH should be done with the measurement of the anti-Xa activity in plasma because the aPTT is influenced by the high levels of FVIII and fibrinogen. The potential presence of lupus anticoagulant or the deficiency of FXII in some patients with COVID-19 will lead to misleading results and erroneous dose modifications.

UFH is cleared from macrophages and endothelial cells and is preferred in patients with renal insufficiency. The LWMHs are cleared principally by the kidneys and their use should be cautious in patients with renal insufficiency. Hence, LWMHs with intermediate molecular weight, such as tinzaparin and dalteparin, showed limited accumulation of their anti-Xa activity in patients with severe renal impairment.

The usual doses of available LMWH for the prevention and treatment of VTE as well as the adaptation of the doses according to the renal function are summarized in Table 2.

**Direct oral Anticoagulants**

DOACs are classified with specific direct FXa inhibitors (apixaban, betrixaban, edoxaban, and rivaroxaban) and one specific direct thrombin inhibitor (dabigatran). All DOACs except betrixaban are indicated for the treatment and secondary prevention of VTE, and the prevention of ischemic stroke in patients with atrial fibrillation. Rivaroxaban and apixaban have been studied in the prevention of VTE in hospitalized acutely ill medical patients as well as in extended prevention of VTE in outpatients after their hospital discharge.

DOACs are principally excreted by kidneys and are contraindicated in patients with creatinine clearance lower than 15 mL/min, whereas dose adjustment is required for patients with renal clearance between 15 and 50 mL/min (Table 2).

DOACs are substrates for ABCB1 and P-glycoprotein (P-gp) transporters. Rivaroxaban and apixaban are metabolized by CYP3A4, CYP2J2, and also CYP-independent mechanisms prior to elimination. Doses of DOACs for the prevention and treatment of VTE and dose adaptation according to renal function are summarized in Table 2. Major P-gp inhibitors can increase the absorption of DOACs inducing a significant accumulation of the drug, increasing bleeding risk. Conversely, major P-gp inducers can reduce the DOAC absorption, reducing potentially their antithrombotic efficacy.

**Antiplatelet Treatment**

Antiplatelet treatment, including aspirin, clopidogrel, prasugrel, and ticagrelor, is of major importance for secondary prevention of arterial thrombosis. Aspirin is the drug of choice for the prevention of arterial thrombosis in high-risk patients with cardiovascular risk factors.

Some in vitro studies showed that aspirin beyond the well-known antiplatelet and anti-inflammatory activities inhibits RNA virus replication also. Older studies have shown that prehospital use of antiplatelet agents and particularly aspirin has a potential beneficial effect on the risk of ARDS in acutely ill patients. A recent meta-analysis of seven studies, including 30,291 hospitalized patients, showed that those receiving prehospital treatment with antiplatelet agents (aspirin or clopidogrel) had a significantly lower risk of ARDS as compared to those with no prehospital antiplatelet therapy (odds ratio: 0.68, 95% confidence interval [CI]: 0.56–0.83; p < 0.001). However, treatment with antiplatelet agents did not affect the mortality in ARDS patients. Based on this rationale, 11 studies registered in ClinicalTrials.gov investigate the effect of early initiation of aspirin treatment if it mitigates the prothrombotic state and reduces hospitalization rates in patients with non-severe COVID-19. Moreover, a small proof-of-concept study tested the effect of antiplatelet treatment with aspirin, clopidogrel, and tirofiban on the ventilation/perfusion ratio in COVID-19 patients with severe respiratory failure and showed some encouraging results.

**Angiotensin-Converting Enzyme Inhibitors and Angiotensin Receptor Blockers and Risk of COVID-19 Worsening**

Angiotensin-converting enzyme inhibitors (ACEIs) and angiotensin II type-1 receptor blockers (ARBs) are widely used drugs for the treatment of arterial hypertension, heart failure, and chronic kidney disease. These antihypertensive agents enhance the expression of ACE2 which has a central place in cell infection by the SARS-CoV-2. From a mechanistic point of view, there is a hypothesis that treatment with ACEIs or ARBs might increase the risk of SARS-CoV-2 infection or COVID-19 worsening. However, the studies published so far did not confirm this hypothesis. The most recent study from China on 2,263 patients with arterial hypertension, receiving ≥1 antihypertensive agents, and who had a positive outpatient SARS-CoV-2 test showed that ACEI or ARB use was not associated with the risk of hospitalization or mortality. A smaller study from Italy on a cohort of 133 patients with COVID-19 worsening showed no increased risk of COVID-19 compared to the general population.
Table 2 Dosages of LMWHs, rivaroxaban, and betrixaban adapted according to renal function for VTE treatment and thromboprophylaxis in patients with COVID-19

<table>
<thead>
<tr>
<th>Creatinine clearance (mL/min)</th>
<th>Dalteparin</th>
<th>Tinzaparin</th>
<th>Enoxaparin</th>
<th>Bemiparin</th>
<th>Rivaroxaban</th>
<th>Betrixaban</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Therapeutic regimen</td>
<td>Prophylactic regimen</td>
<td>Therapeutic regimen</td>
<td>Prophylactic regimen</td>
<td>Therapeutic regimen</td>
<td>Prophylactic regimen</td>
</tr>
<tr>
<td>&gt;50</td>
<td>150–200 UI/kg s.c. o.d.</td>
<td>No dose adjustment</td>
<td>5,000 UI s.c. o.d.</td>
<td>4500 IU s.c. o.d.</td>
<td>100 UI/Kg s.c. b.i.d. or 150 UI/kg s.c. o.d.</td>
<td>4,000 UI s.c. o.d.</td>
</tr>
<tr>
<td></td>
<td>30–50</td>
<td>No dose adjustment</td>
<td>No dose adjustment</td>
<td>No dose adjustment</td>
<td>No dose adjustment</td>
<td>No dose adjustment</td>
</tr>
<tr>
<td></td>
<td>20–30</td>
<td>No dose adjustment</td>
<td>100 UI/kg o.d. monitoring of anti-Xa levels. Range of usual anti-Xa activity levels (4 hours after the s.c. injection): 0.5–1.2 IU/mL</td>
<td>2000 IU o.d. monitoring of anti-Xa levels. Range of usual anti-Xa activity levels (4 hours after the s.c. injection): 0.5–1.2 IU/mL</td>
<td>2500 IU o.d. monitoring of anti-Xa levels. Range of usual anti-Xa activity levels (4 hours after the s.c. injection): 0.5–1.2 IU/mL</td>
<td>85 IU/kg and monitoring of anti-Xa levels (4 hours after the s.c. injection): 0.2–0.5 IU/mL</td>
</tr>
<tr>
<td>&lt;20</td>
<td>Monitoring of anti-Xa levels. Range of usual anti-Xa levels (4 hours after the s.c. injection): 0.5–1.2 IU/mL</td>
<td>Monitoring of anti-Xa levels. Range of usual anti-Xa activity levels (4 hours after the s.c. injection): 0.3–0.5 IU/mL</td>
<td>Monitoring of anti-Xa levels. Range of usual anti-Xa activity levels (4 hours after the s.c. injection): 0.5–1.5 IU/mL</td>
<td>Not recommended</td>
<td>Not recommended</td>
<td>Not recommended</td>
</tr>
</tbody>
</table>

Abbreviations: b.i.d., twice a day; o.d., once a day; s.c., subcutaneous.
consecutive hypertensive subjects presenting to the emergency department with COVID-19 infection also showed that treatment with ACEIs did not negatively affect the clinical course of COVID-19.\textsuperscript{116}

**Statins in COVID-19**

Dyslipidemia is recognized as a risk factor associated with microvascular dysfunction in arterial hypertension, diabetes mellitus, and cardiovascular disorders.\textsuperscript{117} The latter two are major risk factors of severe COVID-19 and death. Cholesterol plays an essential role in the activation/dysregulation of the immune response and in the onset and pathogenesis of ARDS.\textsuperscript{118,119} Cholesterol via the transport protein apolipoprotein E (apoE) enhances the endocytic entry of SARS-CoV-2 to target cells.\textsuperscript{120} It could be involved in endothelial injury in COVID-19 patients.\textsuperscript{121}

Statin treatment might improve endothelial and vascular functions in these patients. Last, it has been suggested that statins could have a role in SARS-CoV-2 infection by blocking the virus entry to cells.\textsuperscript{122} A combination of statin/ARB treatments was used in an unconventional and poorly documented experience to target the host response and prevent endothelial barrier damage in Ebola patients during the outbreak in West Africa. A similar approach might be considered for patients with severe COVID-19 infection since both statins and ARBs upregulate ACE2 activity and counter endothelial dysfunction.\textsuperscript{123} The pleiotropic effects of statins have been studied in vitro but the clinical relevance of these findings has not been evaluated yet. At least nine clinical trials have been registered in ClinicalTrials.gov to evaluate if treatment with statin has any beneficial effect against disease worsening in patients with COVID-19 (https://clinicaltrials.gov/ct2/results?cond=Covid19&term=statin&cntry=&state=&city=&dist=&-Search=Search).

**Drug Interactions**

Patients with VD-CVR are usually under multidrug therapies (including antilipidemic agents, antihypertensive and/or antidiabetic agents, anticoagulant and/or antiplatelet agents). Therefore, drug interactions with antiviral or convalescence treatments should be systematically controlled. Among these treatments, dexamethasone, according to the preliminary report of an open label, controlled trial, significantly reduced the mortality rate in patients hospitalized with COVID–19 who were receiving either invasive mechanical ventilation or oxygen alone.\textsuperscript{124}

No interactions have been reported between LMWH, fondaparinux, UFH, or aspirin with the antiviral experimental drugs, or convalescence therapies, or dexamethasone in patients with COVID-19.

The P-gp and CYP450 systems in the liver (especially CYP3A4) are metabolic pathways of the DOACs. The same metabolic pathways are used by several antiviral drugs (especially lopinavir and ritonavir) which may alter DOACs’ pharmacokinetics of as well as those of clopidogrel and ticagrelor. Lopinavir and ritonavir may potentiate CYP3A4 or P-gp inhibition leading to reduction of clopidogrel and increase of ticagrelor effects. Prasugrel is less influenced by this drug combination.\textsuperscript{125,126} Apixaban and rivaroxaban are also influenced by CYP3A4 and P-gp inhibition, while dabigatran and edoxaban are influenced only by P-gp inhibition.

The data available so far show that in hospitalized patients with COVID-19 who are on long-term antithrombotic treatment with DOACs, administration of antiviral drugs induces up to six times increase of peak and trough levels.\textsuperscript{127} Dosage of peak and/or trough DOAC concentrations in plasma might have some clinical relevance in the evaluation of the pharmacokinetics modification in patients treated with drugs with such interactions.

The anticoagulation induced by vitamin K antagonists (VKAs) is much more instable in COVID-19 patients due to the inflammatory state and the interactions with numerous drugs used including paracetamol.

Both DOAC and VKA present potentially clinically significant interactions with dexamethasone. Consequently, hospitalized patients with COVID-19 on DOACs or VKA should be switched to treatment with a therapeutic dose of LMWH.

The degrees of interactions between antithrombotic agents or lipid-lowering agents with the most common treatments in SARS-CoV-2 infection are depicted in Fig. 2. An updated list of interactions between conventional drugs, including antithrombotic agents (antplatelets and anticoagulant agents) antidiabetic, antihypertensive, and antilipidemic drugs and the ones used for the treatment of COVID-19 is available at http://www.covid19-druginteractions.org/ (created by Liverpool Drug Interaction Group).

**VAS Recommendations for the Use of antithrombotic Agents in Patients with Vascular Disease or Cardiovascular Risk Factors and COVID-19**

- LMWHs are the first-line antithrombotic treatment in patients hospitalized with COVID-19 because they offer predictive and stable antithrombotic effect following subcutaneous injection and show less than UFH nonspecific binding with plasma proteins, particularly during the cytokine storm. These are significant advantages of LMWHs particularly in critically ill patients who may present resistance to treatment with UFH.

- Resistance to UFH is a concern for the patients with COVID–19. The aPTT is not the optimum test for monitoring and dose adjustment of UFH treatment. The measurement of the anti-Xa activity should be preferred against aPTT for the biological monitoring and dose adjustment of the UFH treatment.

- Dalteparin or tinzaparin can be used as alternative treatments for patients with severe renal insufficiency and resistance to UFH. Monitoring of the anti-Xa activity in plasma at peak and trough levels should be regular and doses should be adapted accordingly.

- The target levels of anti-Xa activity in patients receiving a prophylactic dose of LMWHs, 4 hours after the subcutaneous injection, range from 0.2 to 0.5 anti-Xa IU/mL.
• The target levels of anti-Xa activity in patients receiving a therapeutic dose of LMWHs, 4 hours after the subcutaneous injection, range from 0.5 to 1.5 anti-Xa IU/mL.

• In hospitalized patients with COVID-19, DOACs and VKA should be replaced by LMWH due to potential interactions with antiviral or convalescence treatments.

• In the case that DOACs treatment cannot be replaced by LMWH, the interactions with the other drugs should be carefully controlled using at the Web site: http://www.covid19-druginteractions.org/. If these interactions exist, monitoring of peak and trough levels of DOAC concentration in plasma is encouraged.

• Antiplatelet agents are the cornerstone treatment for primary and secondary prevention of arterial thrombosis. Physicians who take care of patients with vascular disease and COVID-19 should control adherence and compliance of the antiplatelet treatment according to the recommendations of the relevant consensus statements and scientific societies.

• Physicians should be aware for the increase of bleeding risk when antiplatelet treatment is coadministered with anticoagulant agents (i.e., LMWH or UFH). In patients receiving antiplatelet treatment and thromboprophylaxis with LMWH, the bleeding risk must be carefully evaluated and the patients need to be under close medical follow-up.

• Management of the antithrombotic treatment before interventional procedures, as well in the case of bleeding, should be done according to the recommendations of the relevant consensus statements.

• Patients should continue to be treated with the recommended antihypertensive therapy and lipid-lowering agents during their disease trajectory.

**Blood-Borne Hypercoagulability and Risk of Disease Worsening and Death in Patients with COVID-19**

Hypercoagulable states together with lymphopenia, mild thrombocytopenia, and increased biomarkers of inflammation are common alterations in patients with COVID-19 hospitalized either at the conventional medical ward or at the ICU. Hypercoagulability is based on the significant increase of D-dimer levels in the plasma as well as on the evidence of DIC; notably prolonged prothrombin time (PT) and/or aPTT, thrombocytopenia, and acquired AT deficiency.

**D-dimer in COVID-19**

Among the hematological biomarkers, D-dimers have attracted the attention of researchers and clinicians involved in the management of patients with COVID-19. Two systematic reviews highlight that D-dimer values are higher in nonsurvivors as well as in patients with severe COVID-19 than in those with mild disease. Hypercoagulability is based on the significant increase of D-dimer levels in the plasma as well as on the evidence of DIC; notably prolonged prothrombin time (PT) and/or aPTT, thrombocytopenia, and acquired AT deficiency.

**Measurement of D-dimer at hospital admission has been proposed for the evaluation of the risk for death. Statistical significance of separation between patients with D-dimer ≥2.0 μg/mL and those with D-dimer <2.0 μg/mL was achieved at 7 days after admission. Frequent monitoring of D-dimer during hospitalization might provide more information to predict death.** However, this strategy has to be validated since the derivation study suffers from several methodological limitations (i.e., retrospective design, absence of validation cohort).
D-dimers are degradation products of cross-linked fibrin, indicating enhanced fibrin formation and activation of the fibrinolytic system. D-dimers and fibrinogen concentrations in plasma are closely correlated. Moreover, D-dimer concentration indirectly reflects in vivo thrombin generation, since thrombin is the enzyme responsible for fibrinogen cleavage and fibrin monomer formation. However, D-dimer is not a specific biomarker for thrombosis. Levels of D-dimer reflect the inflammatory process and an increase in several conditions such as cancer, pregnancy, trauma, CVD, diabetes mellitus, etc. Noteworthy, levels of D-dimer are frequently increased in patients with VD-CVR independently of SARS-CoV-2 infection.

Table 3 Association between D-dimer levels and disease severity or death in hospitalized patients with COVID-19

<table>
<thead>
<tr>
<th>Study references</th>
<th>Sample size (n)</th>
<th>Conventional ward median D-dimer level (range)</th>
<th>ICU patient median D-dimer level (range)</th>
<th>Survivor median D-dimer level (range)</th>
<th>Nonsurvivor median D-dimer level (range)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Huang et al10</td>
<td>41</td>
<td>500 ng/mL (300–800 ng/mL)</td>
<td>2,400 ng/mL (600–1,400 ng/mL)</td>
<td>NR</td>
<td>NR</td>
</tr>
<tr>
<td>Fogarty et al46</td>
<td>83</td>
<td>NR</td>
<td>1,210 ng/mL (603.5–3,623 ng/mL)</td>
<td>803 ng/mL (529–1,549 ng/mL)</td>
<td>NR</td>
</tr>
<tr>
<td>Zhou et al134</td>
<td>191</td>
<td>NR</td>
<td>NR</td>
<td>D-dimer ≤ 500 ng/mL 43%</td>
<td>7%</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>D-dimer: 500–1,000 ng/mL 33%</td>
<td>11%</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>D-dimer &gt; 1,000 ng/mL 24%</td>
<td>81%b</td>
</tr>
<tr>
<td>Wu et al143</td>
<td>201</td>
<td>520 ng/mL (330–930 ng/mL)</td>
<td>1,160 ng/mL (460–5,370 ng/mL)</td>
<td>NR</td>
<td>3950 ng/mL (1150–10,960 ng/mL)c</td>
</tr>
<tr>
<td>Tang et al149</td>
<td>183</td>
<td>NR</td>
<td>Median D-dimer level: 610 ng/mL Range: 350–1,290 ng/mL</td>
<td>Median D-dimer level: 2,120 ng/mL Range: 770–5,270 ng/mL</td>
<td></td>
</tr>
<tr>
<td>Guan et al191</td>
<td>1,099</td>
<td>44% of patients had D-dimer ≥500 μg/L</td>
<td>60% of patients had D-dimer ≥500 μg/L</td>
<td>NR</td>
<td>64% of patients had ≥500 μg/L (p = 0.001 vs. nonsevere patients)</td>
</tr>
<tr>
<td>Wang et al135</td>
<td>138</td>
<td>166 ng/mL (101–285 ng/mL)</td>
<td>414 ng/mL (191–1,324 ng/mL)</td>
<td>&lt;500 ng/mL</td>
<td>1,200 ng/mL</td>
</tr>
</tbody>
</table>

Abbreviation: NR: not reported.
aICU patients and nonsurvivors.
bHigh D-dimer level was associated with a higher odds ratio of death (ODR = 18.42, 95% CI: 2.64–128.55; p = 0.0033).
cHigh D-dimer level was associated with ARDS development (HR = 1.03, 95% CI: 1.01–1.04, p < 0.001) and poor survival (HR = 1.02, 95% CI: 1.01–1.04, p = 0.002).

D-dimer dysfunction. Early reports from China underline the presence of DIC in patients with COVID-19. On admission to the hospital, nonsurvivors with COVID-19 had significantly higher D-dimer levels and longer PT compared with survivors. By late hospitalization, fibrinogen and AT levels were significantly lower in nonsurvivors, suggesting that hypercoagulability and DIC were associated with an increased risk of death.

It is important to underline that according to the ISTH Scientific Subcommittee, DIC may present as compensated activation of coagulation with subtle hemostatic dysfunction and an increase in thrombotic risk without obvious clinical symptoms. This phase is characterized by an imbalance between activation and inhibition of the coagulation system. Deficiency of natural coagulation inhibitors (principally AT and PC) and an increase of D-dimer are early coagulation abnormalities in patients with compensated DIC. (2) Overt DIC with significantly reduced hemostatic potential: this phase is characterized by the absence of normal regulatory mechanisms and collapse of hemostatic forces because of consumption of platelets, coagulation factors, and fibrinogen. This condition is also known as “consumption coagulopathy.” Overt DIC is associated with both bleeding and thrombotic manifestations including both microvascular thrombosis and thrombosis of larger vessels. Compensated DIC may progress to overt DIC.
The diagnosis of DIC is based on scoring systems including clinical and laboratory parameters. Today, there are five different diagnostic scoring systems for DIC established by (1) the ISTH, (2) the Japanese Ministry Health and Welfare, (3) the Japanese Association for Acute Medicine, (4) the British Committee for Standards in Haematology, and (5) the Italian Society of Thrombosis and Hemostasis. Among them, the DIC-ISTH score is the most widely used and has been applied in hospitalized COVID-19 patients. The DIC-ISTH score exists in two forms: (1) for diagnosis and follow up of compensated DIC and (2) for diagnosis and follow up of overt DIC.

Tang et al, using the overt DIC-ISTH score in 183 patients with COVID-19, found that overt DIC (>5 points) was diagnosed in 72% of the nonsurvivors in later stages of COVID-19. Only one survivor (0.6%) matched the overt DIC criteria during hospital stay. The nonsurvivors had significantly higher levels of D-dimer and fibrinogen/fibrin-derived proteins and longer PT and aPTT compared with survivors on admission. By late hospitalization, fibrinogen and AT levels were also significantly lower in nonsurvivors. The median time from admission to DIC manifestation was 4 days (range: 1–12 days). Wu et al analyzed clinical and biological data from 201 patients with confirmed COVID-19: 41.8% of patients developed ARDS, 26.4% were admitted to the ICU, 33.3% received mechanical ventilation, and 22% died.

Elevated C-reactive protein (CRP) and serum ferritin, prolonged PT, and high levels of D-dimer were significantly associated with a higher risk of ARDS. The median time from admission to developing ARDS was 2 days (interquartile range: 1–4 days). Patients with ARDS who died had significantly increased levels of D-dimer compared with patients with ARDS who survived (difference: 2.10 μg/mL; 95% CI: 0.89–5.27 μg/mL; p = 0.001). The difference in median levels of D-dimer between the death and survival groups was larger than that between the ARDS and non-ARDS groups, suggesting that DIC was on the pathway to death in some patients.

A study from Ireland enrolled 83 hospitalized patients with COVID-19 who routinely received thromboprophylaxis with enoxaparin (weight-adapted doses). Upon admission, PT and aPTT were within the normal range, platelet count was normal in 83% of patients, and fibrinogen was increased. D-dimers were higher than the upper normal limit in 67% of patients. The levels of D-dimer progressively increased during hospitalization, particularly in patients with disease worsening. Increases in D-dimer, fibrinogen, and CRP were significantly associated with poor prognosis. In contrast, PT and aPTT did not show any significant modification during hospitalization as compared with baseline values. None of patients either upon admission or during hospitalization in the conventional ward or in the ICU had an overt DIC (overt DIC-ISTH score ≥5). These results, which are substantially different to those reported in patients from China, are attributed to the beneficial effect of thromboprophylaxis with LMWH on the evolution of coagulopathy.

However, all studies published so far show that thrombocytopenia is not a common finding in hospitalized patients with COVID-19. Moreover, PT and/or aPTT prolongation was observed particularly in ICU patients. Similarly, the frequency of hypofibrinogenemia is rather low in patients with COVID-19 hospitalized in the ICU. Accordingly, the frequency of clinically relevant or major bleeding is low in patients with COVID-19. Only 6.4% of COVID-19 patients who died met overt DIC-ISTH criteria.

The AT level is one of the predictors of the compensated DIC-ISTH score which is mandatory for poor clinical outcome in patients with sepsis-associated DIC. The scores for DIC diagnosis have been developed and validated mainly in patients with sepsis.

Compensated DIC is an independent risk factor for disease worsening in patients hospitalized with COVID-19. This is documented by a prospective observational study enrolling...
430 hospitalized patients with COVID-19. The compensated DIC-ISTH score was ≥5 in 8.2% of patients hospitalized at the conventional ward and in 28.2% of patients in the ICU with disease worsening. However, the accuracy of the compensated DIC-ISTH score to identify patients at high risk for disease worsening was low. In hospitalized patients with COVID-19, disease worsening was also related to the presence of cardiovascular risk factors (i.e., arterial hypertension, diabetes mellitus, and obesity), chronic kidney disease, D-dimer increase, lymphopenia, anemia, and blood hypercoagulability. This study led to the derivation and validation of the COMPASS-COVID-19 risk assessment model (RAM) for early identification of patients with COVID-19 being at high risk of disease worsening. The COMPASS-COVID-19 score (Table 5), accessible online at www.medupdate.eu includes the following predictors for disease worsening: presence of obesity (BMI ≥ 30), gender, hemoglobin, lymphocyte count, and compensated DIC-ISTH score (≥5).146

So far, there is no available study proving any potential correlation between hypercoagulability, DIC-ISTH score, or D-dimer with the PIC occurrence. Moreover, beyond the autopsy studies, there is no validated surrogate marker for PIC diagnosis.

The need of serial assessments of hypercoagulability for prompt therapeutic intervention, early diagnosis of VTE, and optimization of antithrombotic treatment has already been stressed out.147,148

**Treatment of Hypercoagulability, PIC, and DIC in Patients with COVID-19**

Hypercoagulability is a common and early alteration in patients with COVID-19 related with the thrombosis risk, disease worsening, and death. Consequently, antithrombotic treatment is a cornerstone therapeutic strategy in patients with COVID-19. Heparins (LMWH or UFH) are the first-line treatment for inhibition of this thrombogenic state in hospitalized patients with COVID-19, which potentially could improve the global clinical outcome beyond the prevention of VTE. Therapeutic effect of heparin treatment has been evaluated in three studies published so far and is under evaluation in 35 trials registered in ClinicalTrials.gov.

**Heparin Therapy and Mortality in Patients with COVID-19**

Tang et al evaluated the 28-day mortality in heparin users and nonusers, among severe COVID-19 patients. In total 449 patients with severe COVID-19 were enrolled into the study. Among them, only 94 received LMWH (4,000–6,000 anti-Xa IU enoxaparin once daily) and five received UFH (10,000–15,000 IU/d), for 7 days or longer. The sepsis-induced coagulopathy (SIC) score was evaluated using the combination of PT, platelet count, and sequential organ failure assessment. D-dimers were also measured. Ninety-seven patients (21.6%) met the SIC criteria (total score ≥ 4) and they were classified as severe cases. The D-dimer, PT, and age were positively and platelet count was negatively correlated with the 28-day mortality. The mortality rate in the ensemble of the cohort was 29.8%. No difference on the 28-day mortality was found between heparin users and nonusers (30.3 vs. 29.7%, p = 0.910). Patient stratification according to the SIC score showed that heparin treatment was associated with a lower mortality in patients with SIC score ≥ 4 (40.0 vs. 64.2%, p = 0.029), but not in those with SIC score < 4 (29.0 vs. 22.6%, p = 0.419). Patient stratification according to the D-dimer levels showed a 20% reduction in mortality with heparin treatment when D-dimers were exceeding 3,000 ng/mL (sixfold of upper limit of normal; 32.8 vs. 52.4%, p = 0.017).149

### Table 5

<table>
<thead>
<tr>
<th>Predictors for risk of worsening disease</th>
<th>Score</th>
</tr>
</thead>
<tbody>
<tr>
<td>Obesity (BMI &gt; 30)</td>
<td>19</td>
</tr>
<tr>
<td>Male gender</td>
<td>10</td>
</tr>
<tr>
<td>Compensated DIC-ISTH score ≥5</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Confirmed COVID-19</th>
<th>2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Thrombocytopenia (platelet count &lt; 100,000/μL):</td>
<td>1</td>
</tr>
<tr>
<td>Prothrombin time prolongation (&gt; control + 3 sec):</td>
<td>1</td>
</tr>
<tr>
<td>D-dimer increase (&gt;500 for age &lt; 60 years; &gt;600 ng/ml for age 60–59 years; &gt;600 ng/ml for age 60–69 years; &gt;700 ng/ml for age 70–79 years; &gt;800 ng/ml for age 80–89 years; &gt;900 ng/ml for age 90–99)</td>
<td>1</td>
</tr>
<tr>
<td>Antithrombin decrease (&lt; lower normal limit established by the laboratory)</td>
<td>1</td>
</tr>
<tr>
<td>Protein C decrease (&lt; lower normal limit established by the laboratory)</td>
<td>1</td>
</tr>
<tr>
<td>Total</td>
<td>≥5</td>
</tr>
<tr>
<td>Lymphocytes &lt;10^9/L</td>
<td>8</td>
</tr>
<tr>
<td>Hemoglobin &lt;11 g/dL</td>
<td>8</td>
</tr>
<tr>
<td>Total</td>
<td>≥18: high risk</td>
</tr>
<tr>
<td></td>
<td>&lt;18: low risk</td>
</tr>
</tbody>
</table>

Abbreviations: BMI, body mass index; DIC, disseminated intravascular coagulation; ISTH, International Society on Thrombosis and Haemostasis.
A retrospective analysis from New York hospitals including 2,773 hospitalized patients with COVID-19 showed that antithrombotic treatment was systematically administered to 28% of them. However, the type of treatment, the dose, and the duration were not reported. In-hospital mortality for patients treated with anticoagulants was 22.5% with a median survival of 21 days, compared with 22.8% and a median survival of 14 days in patients who did not receive anticoagulant treatment.

In ICU patients (n = 395), the in-hospital mortality was 29.1% with a median survival of 21 days for those treated with anticoagulants as compared with 62.7% with a median survival of 9 days in patients who did not receive anticoagulant treatment. Overall, a longer duration of anticoagulant treatment was associated with a significantly reduced risk of mortality (adjusted HR of 0.86 per day, 95% CI: 0.82–0.89, p < 0.001). The rate of major and clinically relevant hemorrhage in those receiving or not receiving anticoagulant treatment was 3 and 1.9%, respectively. Bleeding events were more common among ICU patients (7.5%) than among less severe nonintubated patients (1.35%), underlining the need for careful evaluation of the bleeding risk and application of individualized anticoagulant treatment. Despite the design limitations, this study provides encouraging data for the global beneficial effect of anticoagulant treatment in hospitalized COVID-19 patients.150

Ayerbe et al retrospectively analyzed data from 2,075 patients with COVID-19 admitted in 17 hospitals in Spain. The mortality rate in 1,734 patients who received heparin was 14%, whereas in those who did not receive heparin (n = 285), it was 15.4%. Heparin was associated with a significantly lower mortality when the model was adjusted for age and gender (odds ratio [OR]: 0.55; 95% CI: 0.37–0.82; p = 0.003).151

Many centers have increased the dose of anticoagulant prophylaxis to “intermediate-intensity” doses, such as 50 IU/kg twice daily or 100 IU/kg once daily of enoxaparin, using a risk-adapted strategy with increased doses based on D-dimer levels, fibrinogen rate, ICU location, or other clinical factors associated with increased VTE risk.152,153 A Delphi method consensus document found that 31.6% of participant experts supported an intermediate-intensity dose and only 5.2% supported a therapeutic dose; the rest (63%) supported the use of standard VTE prophylaxis dose for hospitalized patients with moderate to severe COVID-19 and lack of DIC.9

The ensemble of these recommendations for the diagnosis and treatment of DIC in patients with COVID-19 is summarized in Table 6.

These studies are derived from retrospective analysis of real-life practice during the epidemic and indicate that heparin administration in hospitalized patients with COVID-19 might have some beneficial effect on patients’ mortality. However, they share several important limitations:

- The studied groups of patients were either heterogeneous or precisions on their characteristics were not provided.
- The antithrombotic regimens were not specified (i.e., type of heparin, dose, duration, dose modifications).
- The retrospective design and the absence of control group did not allow conclusions to be made on whether antithrombotic treatment has any effect on patients’ mortality.

Nevertheless, it is important to note that 35% of physicians treating COVID-19 patients consider that usual prophylactic doses of LMWH are inadequate for effective management of the global thrombotic risk in hospitalized COVID-19 patients. This finding reflects the clinical perception that antithrombotic treatment with heparin is an essential part of the global therapeutic strategy for hospitalized patients with COVID-19 and requires optimization.

Other Treatments for the Management of Hypercoagulability and PIC Prevention

AT levels’ evolution in COVID-19 patients is of particular interest since it is a major serine protease inhibitor that stoichiometrically inhibits thrombin, FXa, FVila, FIXa, and FXIa. Low AT levels may lead to failure of this procoagulant serine protease inhibition and compromise heparin efficacy since its antithrombotic activity is AT-dependent. Low levels of AT in the plasma of patients with sepsis-associated DIC are correlated with increased mortality.154 Substitution therapy with AT concentrates is a therapeutic option in patients with DIC and/or AT deficiency (<50%) as well as in certain clinical settings associated with inflammation.140,141 Ranucci et al in a small study enrolling 16 patients with COVID-19 and ARDS hospitalized in the ICU longitudinally assessed PT, aPTT, fibrinogen, D-dimer, thromboelastography, and AT activity. Upon ICU admission, all patients received LMWH thromboprophylaxis (4,000 anti-Xa IU twice daily). After the first round of standard coagulation and viscoelastic tests, the patients switched to 6,000 anti-Xa IU twice daily (8,000 anti-Xa IU twice daily if BMI was >35); AT concentrates were given to correct values <70% and the clopidogrel loading dose of 300 mg + 75 mg/day was associated with platelet count >400 G/L. AT deficiency was found in 25% of patients.155 Two of them received AT concentrate on day 2 of ICU hospitalization. Establishment of a more pronounced thromboprophylaxis (increased LMWH doses, AT correction, and clopidogrel use in the case of thrombocytosis) resulted in a significant downregulation of the hypercoagulable state. This study is a proof of concept and should be considered as pilot, since the prospective design and the longitudinal evaluation of hypercoagulability biomarkers allowed us to consider that the efficacy and safety of higher doses of LMWH and the resaturation of AT levels in COVID-19 patients are potentially effective therapeutic strategies. This should be investigated in prospective larger studies.

The need for sequential evaluation of the antithrombotic therapy efficacy in hospitalized patients with COVID-19 is emerging in an increasing number of studies showing that resistance to heparin is frequent particularly in ICU patients.94,153,156 Systemic thrombolysis with recombinant tissue plasminogen activator (tPA) has been also proposed in COVID-19 patients with ARDS aiming to the lysis of lung microcirculation thrombi. In two case series with a total of eight critically
<table>
<thead>
<tr>
<th>DIC management</th>
<th>Global COVID-19 Thrombosis Collaborative Group, Bikdeli et al&lt;sup&gt;9&lt;/sup&gt;</th>
<th>Health System Anticoagulation Task Force, Watson et al&lt;sup&gt;166&lt;/sup&gt;</th>
<th>VAS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Panel of hematological tests</td>
<td>Platelet count, PT, D-dimers, and fibrinogen</td>
<td>Platelet count, PT, D-dimers, fibrinogen, AT, and PC activity</td>
<td></td>
</tr>
<tr>
<td>Diagnostic tool for compensated DIC</td>
<td>Not proposed</td>
<td>Not proposed</td>
<td>Compensated DIC-ISTH score</td>
</tr>
<tr>
<td>Frequency of assessment for compensated DIC</td>
<td>Not proposed</td>
<td>Not proposed</td>
<td>Every 1 or 2 days</td>
</tr>
<tr>
<td>Treatment for compensated DIC</td>
<td>Not proposed</td>
<td>Not proposed</td>
<td></td>
</tr>
<tr>
<td>Diagnostic tool for overt DIC</td>
<td>Overt DICISTH score</td>
<td>Overt DICISTH score</td>
<td>Overt DICISTH score</td>
</tr>
<tr>
<td>Frequency of assessment for overt DIC</td>
<td>Not proposed</td>
<td>Not addressed</td>
<td>Every 1 or 2 days</td>
</tr>
<tr>
<td>Treatment of overt DIC</td>
<td>• Addressing the underlying hypoxia or coinfection.</td>
<td>• Prophylactic dose enoxaparin if no contraindication exists.</td>
<td>• Intermediate dose of LMWH.</td>
</tr>
<tr>
<td></td>
<td>• Transfusion thresholds similar to those recommended for other critically ill patients.</td>
<td>• There is no role for therapeutic anticoagulation in DIC, in the absence of an acute thrombotic event.</td>
<td>• Therapeutic doses of LMWH if the levels of D-dimers continue to increase (i.e., doubling of D-dimer concentration or D-dimer levels higher than 10,000 ng/mL).</td>
</tr>
<tr>
<td></td>
<td>• If invasive procedures are planned, prophylactic transfusion of platelets, fresh frozen plasma, fibrinogen, and prothrombin complex concentrate may be considered.</td>
<td>• There is no role for giving blood products to correct laboratory abnormalities in the absence of bleeding.</td>
<td>• In severe AT deficiency (&lt;50%) administration of AT concentrate should be considered.</td>
</tr>
<tr>
<td></td>
<td>• Patients requiring targeted temperature management may exhibit prolongations of both PT and aPTT without evidence of bleeding diathesis.</td>
<td>• If bleeding occurs, blood product(s) should be given to replace the depleted components.</td>
<td>• The bleeding risk needs to be carefully evaluated.</td>
</tr>
<tr>
<td></td>
<td>• Correction of coagulopathy in unselected patients without overt bleeding is not recommended</td>
<td>• Factor VIIa and prothrombin complex concentrate use is discouraged, as the risk of serious thrombosis is high.</td>
<td>• LMWH prophylaxis may decrease thrombin generation and modify the course of DIC.</td>
</tr>
<tr>
<td></td>
<td>• LMWH prophylaxis may decrease thrombin generation and modify the course of DIC.</td>
<td><strong>(Continued)</strong></td>
<td><strong>(Continued)</strong></td>
</tr>
</tbody>
</table>
ill patients, administration of tPA (25 mg intravenously over 2 hours, followed by a 25 mg tPA infusion over the subsequent 22 hours) in mechanically ventilated COVID-19-positive patients resulted in a transient improvement of the respiratory capacity without any bleeding complications.157,158 The same therapeutic protocol was applied in five patients with COVID-19 and evolutive severe respiratory insufficiency who were not under mechanical ventilation and the results showed permanent improvement of their respiratory capacity.159

**Table 6 (Continued)**

<table>
<thead>
<tr>
<th>DIC management</th>
<th>Global COVID-19 Thrombosis Collaborative Group, Bikdeli et al9</th>
<th>Health System Anticoagulation Task Force, Watson et al166</th>
<th>VAS</th>
</tr>
</thead>
<tbody>
<tr>
<td>• For patients with moderate or severe COVID-19 and an indication for dual-antiplatelet therapy (e.g., PCI within the past 3 months or recent MI) and with suspected or confirmed DIC without overt bleeding, decisions for antiplatelet therapy need to be individualized. In general, it is reasonable to continue dual-antiplatelet therapy if platelet count ≥50 G/L and to reduce to single-antiplatelet therapy if 25 G/L ≤ platelet count &lt; 50 G/L and discontinue if platelets &lt; 25 G/L</td>
<td>re-initiation of LMWH at prophylactic doses.</td>
<td>• Close monitoring of anti-Xa activity and AT levels.</td>
<td></td>
</tr>
</tbody>
</table>

**VAS Recommendations for Management of Hypercoagulability, DIC, and Risk of Disease Worsening in Patients with Vascular Disease or Cardiovascular Risk Factors and COVID-19**

- Hypercoagulability is a frequent and early manifestation of coagulopathy in patients with COVID-19.
- Among the limited number of hypercoagulability biomarkers studied so far, an increase in D-dimer is correlated with the COVID-19 severity. However, D-dimers cannot be used as a “stand-alone” test in the management of COVID-19 patients.
- The most updated COVID-19 panel of hypercoagulability tests in patients with COVID-19 (COAG-COVID-19 panel) includes hemoglobin, platelet count, lymphocyte count, PT, aPTT, fibrinogen, D-dimer, AT activity, and PC activity.
- A RAM for disease worsening adapted for SARS-CoV-2 infection is an urgent need for prompt and targeted treatment of patients with COVID-19. The COMPASS-COVID-19 score responds to this objective but needs to be externally validated.
- The application of the COMPASS-COVID-19 RAM for evaluation of the risk for disease worsening can be considered in patients with VD-CVR and nonsevere COVID-19.
- The COAG-COVID-19 panel should be evaluated routinely and repeated every 1 or 2 days from hospital admission until hospital discharge. This diagnostic strategy provides global and dynamic information for the hypercoagulable state and its evolution during patients’ trajectory.
- Consumption coagulopathy is not a frequent alteration in patients with COVID-19. Patients with COVID-19 do not present overt DIC unless hospitalization is complicated with sepsis.
- The compensated DIC-ISTH score rather than the overt DIC-ISTH score appears to be more compatible with the profile of hypercoagulability in hospitalized COVID-19 patients.
- The performance of other available scores for diagnosis of DIC in patients with COVID-19 needs to be evaluated in prospective studies.
- In patients with compensated DIC-ISTH score ≥5, treatment with LMWH at intermediate doses should be considered. Therapeutic doses of LMWH should be considered if the levels of D-dimer continue to increase (i.e., doubling of D-dimer concentration or D-dimer levels higher than 10,000 ng/mL). The bleeding risk needs to be carefully evaluated.

**Abbreviations:** aPTT, activated partial thromboplastin time; AT, antithrombin; DIC, disseminated intravascular coagulation; ISTH, International Society on Thrombosis and Haemostasis; LMWH, low-molecular-weight heparin; MI, myocardial infarction; PC, protein C; PCI, percutaneous coronary intervention; PT, prothrombin time; UFH, unfractionated heparin.
Risk of Venous Thromboembolism and Thromboprophylaxis in Patients with COVID-19

Patients with COVID-19 are classified at high risk for VTE principally because of the disease characteristics (severe stage, enhanced inflammation, and hypercoagulability) and the frequent presence of inherent predisposing risk factors, particularly CVDs, cardiovascular risk factors (obesity, diabetes mellitus, arterial hypertension), or other underlying diseases.

The risk of VTE is recognized (1) during hospitalization at the conventional ward or ICU, (2) after hospital discharge in high-risk patients, and (3) in out-of-hospital settings, in patients with mild COVID-19 who receive home-based medical care.

The WHO, very early after pandemic declaration, has drawn attention to the vascular complications associated with COVID-19 infection. The interim guidance recommends thromboprophylaxis with either UFH or LMWH.160

LMWH is the first choice for VTE prevention in hospitalized COVID-19 patients and is recommended by the international guidelines published by groups of experts summarized in – Table 7.161-166

Risk of VTE during Hospitalization of Patients with Vascular Disease or Cardiovascular Risk Factors and COVID-19

COVID-19 is a major risk factor for VTE and the presence of additional risk factors in patients with COVID-19, such ICU hospitalization, immobilization, and prolonged hospitalization, further increases the risk of VTE.3,164,167

Pharmacological thromboprophylaxis with fixed prophylactic doses of LMWHs or fondaparinux is recommended in hospitalized acutely ill patients classified at high risk for VTE with an appropriate validated RAM in medical settings (IMPROVE or PADUA).168,169

The incidence of objectively confirmed VTE in hospitalized patients with COVID-19 has been consistently reported by several groups and varies from 3–15% to 7–50% in conventional ward and ICU-hospitalized patients, respectively.147,170-176

The meta-analysis of these studies showed that the overall incidence of symptomatic, objectively confirmed VTE in hospitalized patients with COVID-19 was 22% (95% CI: 11.2–34.9). The rate of VTE in ICU patients was 31% (95% CI: 19.1–44.7).129 The classical rate of VTE in hospitalized patients in the medical ward was only 8.6% (95% CI: 1.3–21.5). Nevertheless, there is a significant discrepancy of the VTE rate among the studies on patients with COVID-19 hospitalized either at the conventional board or at the ICU.

More than 75% of the patients enrolled in these studies were receiving pharmacological thromboprophylaxis with LMWH (either at a fixed dose as recommended for acutely ill medical patients or at a weight-adjusted dose).129 The phase III placebo-controlled clinical trials MEDENOX, PREVENT, and ARTEMIS showed that the incidence of asymptomatic VTE in hospitalized acutely ill medical patients who received thromboprophylaxis with enoxaparin, dalteparin, and fondaparinux was 5.5, 5, and 2.8%, respectively.177-179 This figure is sticking lower to that observed in hospitalized patients who received LMWH thromboprophylaxis.

A retrospective multicenter observational study focused on the evaluation of the benefit–risk ratio of thromboprophylaxis with heparin in 400 hospitalized patients with COVID-19. The symptomatic objectively confirmed VTE rate was 4.8% (95% CI: 2.9–7.3%) and the overall thrombotic complication (including VTE, central vein catheter thrombosis, and continuous venovenous hemofiltration catheter) rate was 9.5% (95% CI: 6.8–12.8%).176 All patients were receiving anticoagulation with standard prophylactic doses of UFH or LMWH at the time of the event. The overall bleeding rate was 4.8% (95% CI: 2.9–7.3%). The rate of bleeding events was 3.1% (95% CI: 1.4–6.1%) in patients hospitalized at the conventional ward and 7.6% (95% CI: 3.9–13.3%) in ICU-patients. The major bleeding rate was 2.3% (95% CI: 1.0–4.2%). All but one major bleed occurred in the critically ill, for a rate of 5.6% (95% CI: 2.4–10.7%). Only three out of the 400 patients had an overt DIC (according to the respective ISTH score). Patients with thrombotic complications had higher D-dimer, fibrinogen, CRP, ferritin, and procalcitonin levels, while patients with bleeding
<table>
<thead>
<tr>
<th>Target group of patients</th>
<th>Unselected patients with COVID-19</th>
<th>Vascular patients with COVID-19</th>
</tr>
</thead>
<tbody>
<tr>
<td>In-hospital settings</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Who should receive thromboprophylaxis?</td>
<td>ICU: all patients Conventional ward: risk stratification</td>
<td>All hospitalized patients High-risk patients All hospitalized patients</td>
</tr>
<tr>
<td>Which thromboprophylaxis in COVID-19 patients?</td>
<td>LMWH over UFH Mechanical methods if contraindication to anticoagulants</td>
<td>LMWH or fondaparinux over UFH 2. LMWH or fondaparinux or UFH over DOAC Mechanical methods if contraindication to anticoagulants</td>
</tr>
<tr>
<td>What intensity of VTE prophylaxis should patients with COVID-19 receive?</td>
<td>No dose proposition</td>
<td>Current standard doses of heparins for VTE prevention Intermediate-dose LMWH in high-risk patients and obese patients</td>
</tr>
<tr>
<td>Current standard doses of heparins for VTE prevention in hospitalized acutely ill medical patients. Conventional ward: standard doses ICU: increased doses</td>
<td>Conventional doses for VTE prevention LMWH or fondaparinux over UFH 2. LMWH or fondaparinux or UFH over DOAC Mechanical methods if contraindication to anticoagulants</td>
<td></td>
</tr>
<tr>
<td>Postdischarge settings</td>
<td>High risk for VTE</td>
<td>LMWH at prophylactic, weight-adjusted dose or intermediate dose</td>
</tr>
<tr>
<td>Who should receive thromboprophylaxis?</td>
<td>High risk for VTE and low risk for bleeding (IMPROVE VTE and IMPROVE Bleeding risk, plus D-dimer)</td>
<td>Very restricted, in patients with the characteristics of the inclusion criteria at the corresponding clinical trials: Selection criteria: consensual multidisciplinary decision</td>
</tr>
<tr>
<td>Risk stratification</td>
<td>High risk for VTE and low risk for bleeding (IMPROVE VTE and IMPROVE Bleeding risk, plus D-dimer)</td>
<td>High risk for VTE and low risk for bleeding (IMPROVE VTE and IMPROVE Bleeding risk, plus D-dimer)</td>
</tr>
<tr>
<td>Not recommended</td>
<td>Systematic evaluation of VTE risk is recommended to all COVID-19 patients before hospital discharge using the IMPROVE/D-dimer score. Patients at high risk for post-discharge VTE with creatinine clearances higher than 30 mL/min can be considered for thromboprophylaxis</td>
<td></td>
</tr>
<tr>
<td>Which thromboprophylaxis?</td>
<td>LMWH over DOAC</td>
<td>LMWH, rivaroxaban, or betrixaban Duration: 14–30 days</td>
</tr>
<tr>
<td>LMWH, extended prophylaxis Duration: up to 45 days</td>
<td>Enoxaparin or rivaroxaban or betrixaban Duration: maximum 40 days</td>
<td>Rivaroxaban or betrixaban over LMWH</td>
</tr>
<tr>
<td>No</td>
<td>Rivaroxaban 10 mg or betrixaban 80 mg once daily p.o. or prophylactic weight-adjusted doses of LMWH for 40 days.</td>
<td></td>
</tr>
</tbody>
</table>
Complications had higher procalcitonin and D-dimer peak and lower platelet counts as compared with the patients without these events.

Intermediate doses of LMWH (i.e., 50 IU/kg twice daily of enoxaparin) have been proposed in some selected patients with COVID-19.152

Protocols with intermediate or weight-adjusted doses of LMWH, particularly in obese patients, have been adopted in some centers. Guided modification of LMWH dose according to D-dimer levels' evolution or to the anti-Xa activity target in plasma (i.e., 0.4–0.8 anti-Xa IU/mL measured 4 hours after the subcutaneous [s.c.] injection or trough levels at least 0.2 anti-Xa IU/mL) is a practice applied by some centers as well. However, the efficacy and safety of these practices has not been controlled. In addition, several methodological issues (i.e., post-hoc or unadjusted analysis, not clearly defined end points, or observational period, etc.) classify these studies at low quality of evidence. Nevertheless, these studies provide some signal for the elaboration of well-conducted prospective clinical trials to identify an optimal antithrombotic strategy.

The increase of D-dimer (a marker of fibrin degradation in vivo) indicates enhanced fibrin formation and is considered as an indirect marker of in vivo thrombin generation. However, in patients with COVID-19, the increase of D-dimer might be an indicator of the inflammatory reaction related to the cytokine storm.180 Theoretically, D-dimer levels should not be used as a stand-alone test for the guidance of the antithrombotic treatment. Nevertheless, until the time of the publication of this article the D-dimer is the only test which has been widely assessed for the evaluation of hypercoagulability in patients with COVID-19.

VAS strongly encourages studies aiming to identify accurate biomarkers of hypercoagulability in the evaluation of the efficacy of the antithrombotic treatment. VAS also encourages prospective studies for the derivation of accurate clinico-biological scores in the evaluation of the risk of resistance to the antithrombotic treatment in patients with COVID-19.

Indeed, 25 clinical trials, registered in ClinicalTrials.gov, are comparing the efficacy and safety of prophylactic and intermediate doses of LMWH for VTE prevention in hospitalized COVID-19 patients.181

### Post-Discharge Risk of VTE in Patients with Vascular Disease or Cardiovascular Risk Factors and COVID-19

Some of hospitalized patients with COVID-19 share common VTE risk factors with those hospitalized for severe acute medical illnesses, such as CVD and cardiovascular risk factors, elderly, obesity, or cancer.182

Studies in hospitalized acutely ill medical patients showed that the risk of VTE remains high after hospital discharge and identification of high VTE risk patients remains a challenging issue.183 Extended, post-hospital discharge thromboprophylaxis with LMWH (enoxaparin, tinzaparin, or dalteparin) or DOAC (rivaroxaban 10 mg or betrixaban 80 mg daily) has a favorable benefit/risk ratio when applied in high VTE risk patients.105,106 An IMPROVE...
D-dimer score \( \geq 4 \) combined with elevated D-dimer (greater than twofold the upper normal limit) identifies an over threefold higher VTE risk population requiring a prolonged prophylaxis. The addition of at least two clinical predictors among the predictors of age \( \geq 60 \), a personal history of VTE, active cancer, or known thrombophilia is expected to further increase the sensitivity of the RAM to identify patients at high risk of post-hospital discharge VTE. These patients will benefit from extended thromboprophylaxis after hospital discharge with rivaroxaban 10 mg or betrixaban 80 mg once daily for up to 40 days without an increase in major bleeding.\(^{185–188}\)

**VTE Risk in Out-of-Hospital Medical Care of Patients with Vascular Disease or Cardiovascular Risk Factors and COVID-19**

During the epidemic waves, hospitals are overcrowded and patients with mild or even moderate COVID-19 receive health care at home. Some of them are at high risk for VTE at least during the bedridden period. These patients should be promptly identified using the IMPROVE or the PADUA scores and receive pharmacological thromboprophylaxis in the absence of contraindication or any risk factor for bleeding.\(^{168,189}\) A prophylactic dose of LMWH, or rivaroxaban 10 mg, or betrixaban 80 mg once daily could be considered for thromboprophylaxis in high VTE risk COVID-19 outpatients. Rivaroxaban 10 mg or betrixaban 80 mg once daily is proposed because they are those among the DOACs that have been studied in the context of thromboprophylaxis in acutely ill medical patients. Oral administration of rivaroxaban and betrixaban has a significant advantage over LMWH use in this setting, in the absence of any potential drug interference or severe renal impairment, because it combines patients’ comfort and no exposure to contamination risk for nurses.

**VAS Statement for the Management of VTE Risk in Patients with WD-CVR and COVID-19**

Thromboprophylaxis with LMWH or UFH (at the recommended doses for acutely ill medical patients) has been administered in the majority of hospitalized patients with COVID-19 enrolled in the reported studies on VTE incidence and seen in this section. However, in most of these studies, the rate of VTE in hospitalized patients either in conventional wards or in ICUs was at least twofold higher as compared with the respective rates reported in phase III clinical trials in acutely ill medical patients.

VAS experts acknowledge that for methodological reasons a direct comparison between the two settings is not feasible. Nevertheless, the high rate of VTE in hospitalized patients with COVID-19 underlines the need for more intense thromboprophylaxis at least for some patients who are at obvious higher risk.

VAS experts consider that more intense pharmacological thromboprophylaxis is applicable particularly in patients with VR-CVR and COVID-19. Indeed, they present cardiovascular risk factors and/or diseases which are also significant risk factors for VTE. Moreover, patients with vascular disease are older and may be more frequently obese as compared with the nonvascular ones. Nevertheless, for the same reasons a careful evaluation of the bleeding risk is strongly recommended.

> Table 6 compares the guidelines proposed by six international groups of experts for the prevention of VTE in patients with COVID-19. VAS experts based on these guidelines proposed a strategy adapted for patients with vascular disease according to the rationale presented in the paragraph above.

**Treatment of VTE in Patients with Vascular Disease or Cardiovascular Risk Factors Hospitalized with COVID-19**

For hospitalized patients with VD-CVR and COVID-19, VAS endorses the recommendations of the ISTH Scientific Subcommittee for diagnosis and treatment of VTE. The recommendations of the international groups of experts for the treatment of VTE in patients with COVID-19 are summarized in > Table 8.

**VAS Recommendations for Thromboprophylaxis in Patients with Vascular Disease and COVID-19**

Thromboprophylaxis in Hospitalized Patients with COVID-19

- Hospitalized patients with vascular disease and COVID-19 are at high risk for VTE. LMWH at a prophylactic, weight-adjusted dose or an intermediate dose, in the absence of contraindications or active bleeding, is recommended for all patients including those with moderate renal insufficiency (creatinine clearance \( \geq 30 \) mL/min), upon admission until hospital discharge.
- In patients with contraindications for antithrombotic treatment, the use of mechanical measures for thromboprophylaxis (i.e., compression stocking, foot-pump) is recommended. The use of removable vena cava filters for the prevention of VTE is not recommended. In the case of patients at very high risk of VTE with absolute contraindication to the antithrombotic treatment, the use of removable vena cava filters could be considered for primary VTE prevention. This decision must be taken consensually by a group of experts including a vascular specialist.
- Obese patients (BMI \( > 30 \)) are at higher risk of VTE and also at high risk of COVID-19 worsening. Intermediate doses adapted according to the body weight should be considered.
- In patients with severe renal failure (creatinine clearance \( < 30 \) mL/min), UFH is the first option for thromboprophylaxis. Due to the high frequency of heparin resistance, the LMWH tinzaparin or dalteparin (which show limited accumulation in this context) at a weight-adjusted dose can be considered instead of UFH. In this case, peak and/or trough levels of anti-Xa activity in plasma should be monitored and the dose should be adapted to avoid any drug accumulation.
<table>
<thead>
<tr>
<th>VTE treatment</th>
<th>Chinese Consensus Statement Group for Prevention Treatment of VTE Associated with COVID-19, Zhai et al.\textsuperscript{161}</th>
<th>ISTH Scientific and Standardization Committee, Spyropoulos et al.\textsuperscript{162}</th>
<th>Global COVID-19 Thrombosis Collaborative Group, Bikdeli et al.\textsuperscript{163}</th>
<th>Health System Anticoagulation Task Force, Watson et al.\textsuperscript{164}</th>
<th>CHEST Guidelines for Prevention, Diagnosis and Treatment of Venous Thromboembolism in Patients with COVID-19, Moores et al.\textsuperscript{165}</th>
</tr>
</thead>
</table>
| VTE treatment | LMWH as first-line treatment                              | • Advantages of LMWH in the inpatient setting and DOACs in the post-hospital discharge setting.  
• A change from treatment-dose DOAC or VKA to in-hospital LMWH should be considered especially for patients in critical care settings or with relevant concomitant medications, and dependent on renal function and platelet counts.  
• Anticoagulant regimens should not change based solely on D-dimer levels.  
• The duration of treatment should be at least 3 months. | Parenteral therapeutic anticoagulation (e.g., UFH) is preferred.  
• LMWHs may be preferred in patients unlikely to need invasive procedures.  
• The benefit of DOACs includes the lack of need for monitoring, facilitation of discharge planning, and outpatient management.  
• The potential risk may include clinical deterioration and lack of timely availability of antidote.  
• DOACs or LMWH would be preferred to limit contact of patients with health care services required for INR monitoring in the case of VKA use. | • Treating with anticoagulation if no contraindication exists  
• Systemic or catheter directed thrombolysis in patients with high-risk PE | • Therapeutic options: weight-adjusted LMWH or intravenous UFH or apixaban or edoxaban or rivaroxaban or dabigatran or VKA.  
• LMWH or UFH are favored over oral anticoagulants.  
• In critically ill COVID-19 patients with proximal DVT or PE: LMWH or fondaparinux is favored over UFH. Minimum duration of anticoagulant treatment: 3 months. |
| Recurrent VTE | Not proposed                                              | Not proposed                                                    | Not proposed                                    | Not proposed                                    | • Recurrent VTE on LMWH treatment: increasing the dose of LMWH by 25 to 30%  
• Recurrent VTE on DOAC or VKA: switching treatment to therapeutic weight-adjusted LMWH. |

Abbreviations: DOAC, direct oral anticoagulant; DVT, deep vein thrombosis; INR, international normalized ratio; LMWH, low-molecular-weight heparin; PE, pulmonary embolism; UFH, unfractionated heparin; VKA, vitamin K antagonist; VTE, venous thromboembolism.
• Levels of D-dimer should be monitored daily during hospitalization and the dose of LMWH should be increased to therapeutic levels in patients with important rising D-dimer (i.e., doubling of D-dimer concentration or D-dimer levels higher than 10,000 ng/mL) after careful evaluation of bleeding risk. This strategy is considered to be of particular importance for ICU patients.

• Exploration of VTE with imaging methods could be considered in patients with a sharp increase of D-dimer.

• VAS strongly encourages studies aiming to identify accurate biomarkers of hypercoagulability in the evaluation of the efficacy of the antithrombotic treatment. VAS also encourages prospective studies for the derivation of clinico-biological scores accurate in the evaluation of the risk of resistance to the antithrombotic treatment in patients with COVID-19.

**Thromboprophylaxis in Patients Receiving Medical Care at Home**

• Patients with VD-CVR and COVID-19 who receive health care at home or in nonhospital settings (i.e., retirement home) should be assessed for VTE risk using the IMPROVE score.

• Patients at high risk for VTE with creatinine clearance $\geq 30$ mL/min can be considered for thromboprophylaxis with rivaroxaban 10 mg or betrixaban 80 mg once daily or LMWH at prophylactic weight-adjusted doses.

• Rivaroxaban and betrixaban present some practical advantages over LMWH, one among them is the simpler administration mode, which does not require nurse visits. Consequently, there is no risk of exposure of health care staff with contamination risk. Oral administration may improve patients’ adherence to thromboprophylaxis.

• In the case that the patient receives home treatment with antiviral or other drugs that may alter the pharmacokinetics of DOACs, thromboprophylaxis with LMWH should be considered as the first-line treatment.

**Summary**

The clinical and epidemiological data and the available evidence from autopsy studies document that hypercoagulability, endothelial cell activation, and massive inflammation are major pathways leading to worsening of COVID-19 and death of patients.
Immunothrombosis in lung microcirculation or in other organs (kidneys, liver, heart, brain, and intestine) and VTE are frequent in patients with severe COVID-19 and critical illness. Arterial thrombosis is an additional vascular complication in patients with COVID-19.

The experts of the VAS-European Independent Foundation in Angiology/Vascular Medicine elaborated an integral strategy for the management of patients with VD-CVR and COVID-19 since they are the largest cluster of patients at risk of disease worsening. This strategy is schematically represented in Fig. 3.

Patients with vascular disease or cardiovascular risk factors need to be at the epicenter for the protection of SARS-CoV-2 infection at the level of primary health care system, because they are at a higher risk of disease worsening, VTE, and post-hospital discharge morbidity.

The recommendations of VAS for patients with VD-CVR are organized as follows:

- At the level of primary health care system, there is an urgent need to organize a medical network, including eHealth technologies, aiming the management of patients with VD-CVR during SARS-CoV-2 epidemic.
- Management of patients with VD-CVR and nonsevere COVID-19 receiving home-based medical care.
- Management of patients with VD-CVR hospitalized for COVID-19.

It is evident that the antithrombotic treatment is an integral part of the therapeutic strategies for COVID-19. Beyond the prevention and treatment of VTE and the control of the hypercoagulable state, the antithrombotic agents together with drugs that downregulate the endothelial cell activation are expected to get a central place in the management of SARS-CoV-2 infection. The elaboration of prospective clinical trials for the evaluation of the safety, efficacy, and optimal use of the therapeutic strategies based on antithrombotic agents and drugs targeting the endothelium in patients with COVID-19 as recommended by the Global COVID-19 Thrombosis Collaborative Group is endorsed by the VAS experts.  

VAS with this guidance document wishes to help public health authorities in the design of targeted protection policies for vulnerable patients.

Vascular diseases are noncommunicable diseases and VAS in favor of future efforts to identify general integrated measures for chronic disease, suitable to be detailed into more specialist indication.

Acknowledging that due to the limited clinical experience in patients with COVID-19 and the absence of randomized clinical trials controlling the efficacy and safety of various antithrombotic treatment regiments and other interventions, the ensemble of the proposed recommendations has a low grade of evidence and will be updated as soon as the results of the ongoing clinical trials will be published.

**What is known about this topic?**

- SARS-CoV-2 infection induces endothelial cell activation, hypercoagulability, and enhanced inflammatory reaction.
- Immunothrombosis is a major contributor in the COVID-19 worsening process.
- Males, citizens with obesity, diabetes mellitus, or arterial hypertension, and patients with cardiovascular disease are at high risk for severe COVID-19.

**What does this paper add?**

- Adherence to the antihypertensive, antiplatelet, antidiabetic, and lipid-lowering treatment and prevention of VTE are essential for the decrease of the risk for COVID-19 worsening in patients with VD-CVR.
- For hospitalized patients with VD-CVR and COVID-19, VAS recommends early administration of thromboprophylaxis with an intermediate dose of LMWH or UFH and a regular evaluation of the biological efficacy of the treatment.

**Funding**

None.

**Conflict of Interest**

None declared.

**Acknowledgment**

The authors are thankful to Yorgos Konstantinou (imagistan.com) for designing the visuals.

**References**


Thrombosis and Haemostasis Vol. 120 No. 12/2020 © 2020. Thieme.
8 Maglakelidze N, Manto KM, Craig TJA. A review: does comple-ment or the contact system have a role in protection or patho-genesis of COVID-19? Pulm Ther 2020;6(02):169–176
19 Hoffmann M, Kleine-Weber H, Schroeder S et al. SARS-CoV-2 cell entry depends on ACE2 and TMPRSS2 and is blocked by a clinically proven protease inhibitor. Cell 2020;181(02):271–280.e8


Olle RH, Meertens NL, Henskens YM, Ten Cate H. Empirically reduced dosages of tinzaparin in patients with moderate-to-severe renal insufficiency lead to inadequate anti-Xa levels. Nephron 2017;137(02):113–123


Ufer M. Comparative efficacy and safety of the novel oral anticoagulants dabigatran, rivaroxaban and apixaban in preclinical and clinical development. Thromb Haemost 2010;103(03):572–585

Clattahar-Saalmüller B, Mair KH, Saalmüller A. Antiviral activity of aspirin against RNA viruses of the respiratory tract-in vitro study. Influenza Other Respir Viruses 2017;11(01):85–92


Thrombosis and Haemostasis Vol. 120 No. 12/2020 © 2020. Thieme.

Practice Guidance for Vascular Complications in Patients with COVID-19  
Gerotziafas et al.  1627
