Massive cerebral venous thrombosis due to vaccine-induced immune thrombotic thrombocytopenia

Since the breakthrough of coronavirus disease (COVID-19) more than 3 million people died worldwide[1] and different vaccines were developed, tested in phase III clinical trials and used in the general population. Few reports of moderate-to-severe thrombocytopenia and thromboses (especially cerebral-venous and splanchnic-vein thromboses) developing approximately 4-14 days after vaccination were reported. These events were related to the adenovirus vector–based DNA vaccines ChAdOx1 nCoV-19 (Oxford–AstraZeneca)[2,3,4] or Ad26.COV2.S (Johnson&Johnson/Janssen).[5] Recently, this new rare autoimmune syndrome that mimics heparin-induced thrombocytopenia (HIT)[3] was defined as vaccine-induced immune thrombotic thrombocytopenia (VITT).[4] Even though details on the pathophysiology are still scanty, diagnostic and therapeutic recommendations were proposed by international scientific organizations.[6-8] No definite data on risk factors are reported and it is unknown whether or not the therapeutic options currently adopted for HIT are also valid for VITT.

With this background, we describe an Italian case of severe VITT-related cerebral venous thrombosis (CVT) and bi-hemispheric hemorrhage, which was successfully treated with argatroban, intravenous immunoglobulin (IVIG) and corticosteroids. The case report is described according to CARE (CAse REport)-statement and checklist.[9]

A previously healthy 26-year-old female presented to the emergency department 14 days after the first injection of ChAdOx1 nCoV-19 vaccine with a headache non-responsive to anti-inflammatory drugs. On admission, she had right-sided weakness and visual disturbances. She has been on combined (estrogen-progestogen) contraceptives for more than 10 years but her past medical history was otherwise unremarkable and there was no prior exposure to heparin.

While general examination and vital signs were normal, neurological examination found a severe right-sided weakness but no visual field defects. Computerised tomography (CT) scan at admission showed a hyperdense rectus sinus and vein of Galen (Figure 1A). Magnetic resonance imaging (MRI) venography showed multifocal venous thrombosis with bilateral occlusion of parietal cortical veins, straight sinus, vein of Galen, internal cerebral veins and inferior sagittal sinus. Transverse sinuses were also partially involved but still patent (Figure 1B). At the right parietal and left frontoparietal lobes an extensive venous infarction with hemorrhagic transformation was present (Figure 1C). D-dimer was dramatically raised to 12,204 μg/L (reference value <500 μg/L) and the platelet count was $134x10^9$/L. Given her recent exposure to ChAdOx1 nCoV-19 and clinical presentation, she was first treated with fondaparinux (5 mg subcutaneously) and admitted her to the intensive care unit. Her clinical condition rapidly deteriorated with decreased consciousness, right-sided hemiplegia and complete Balint syndrome.

In order to perform an extensive hemostasis laboratory work-up before and after therapies, blood was collected at different time points (T0=April 13; T1=April 15, and T2=April 20, 2021) into vacuum-tubes containing 1/10 volumes of trisodium-citrate 0.109 M, K-EDTA or plain tubes. Activated partial thromboplastin time (aPTT), prothrombin time (PT), D-dimer, fibrinogen and factor (F)VIII were obtained. Platelet-factor 4 (PF4)–heparin IgG antibodies (aPF4) were evaluated by a commercially-available enzyme-linked immunosorbant assay (ELISA) (Immucor, Waukesha, WI, USA). Platelet-activating antibodies were evaluated by a platelet-activation test (PAT).[2,10] Platelet function was also evaluated by using the Total Thrombus-Formation Analysis device (T-TAS®, Zacros, Fujimori-Kogyo, Tokyo, Japan),[11-12] a flow-chamber device that assesses platelet-mediated thrombus formation in capillary channels by means of the following parameters: area under the flow-pressure curve (AUC), occlusion start-time (OST) and occlusion time (OT). Thrombin generation (TG) was measured in platelet-poor plasma (PPP).[13] Controls were plasma samples from subjects negative for aPF4 and normal TG.

PT, aPTT and fibrinogen were within the normal range; FV-Leiden and G20210A-prothrombin mutations were absent; antithrombin and protein C/S were normal; lupus anticoagulant and antiphospholipid antibodies were negative. Patient serum (T1) was positive to aPF4-heparin ELISA (OD=1.918, reference value <0.4) and was inhibited (OD<0.5) by 100 U/mL heparin. Patient serum (T1) showed strong platelet activation on PPP from two controls in the presence and absence of low-dose heparin, whereas control serum showed no platelet activation. Five days afterwards (T2), the patient serum showed significant reduction of aPF4 reactivity (OD=0.6) and no longer did activate platelets (Figure 2A to C). At T0, platelet thrombus formation was impaired, AUC was smaller and OT longer than the reference range. In contrast, at T1 and T2 thrombus stability improved and T-TAS parameters as well as platelet count also improved (Figure 2D to F). Results at the time of hospital admission (T1) showed a marked state of hypercoagulability when compared to control, as indicated by short lag-time (8.5 minutes [min] *vs.* 21.3 min), increased thrombin-peak (289 nM *vs.* 115 nM), short time-to-peak (11.8 min *vs.* 26.2min), increased ETP (2,158 nM/min *vs.* 1,684 nM/min) and ETP-TM ratio (0.99 *vs.* 0.79) (Figure 3). FVIII, one of the most potent procoagulants, was higher (200 U/dL) than the upper limit of the reference range (<150 U/dL). In contrast PC, the physiological inhibitor to activated FVIII was normal (88 U/dL). The imbalance between FVIII and PC corresponded to an increased FVIII/PC ratio (2.3), considerably greater than the expected unity and consistently with the hypercoagulability shown by TG. There are potential limitations of the TG assessment. First, measurements (owing to assay complexity and limited blood volumes) were performed only in PPP. Therefore, the potential role of procoagulant platelets in supporting TG could not be assessed. Second, TG could not be assessed on samples obtained during the time course of the disease because soon after the onset of the symptoms and the preliminary diagnosis the patient was treated with anticoagulants, so that TG results would have been unreliable.

Considering the clinical conditions and laboratory results, IVIG (1 g/kg o.d. for 2 days) and dexamethasone (40 mg/day, for 4 days) were started.[6-8] Owing to the possible need for a sudden decompressive neurosurgical intervention, anticoagulation with fondaparinux was replaced by the short-acting drug argatroban (starting dosage 1 μg/kg/min with an aPTT-ratio [patient/normal] target of 1.5-2.0). Argatroban was subsequently increased to 3 μg/kg/min.

The patient's neurological conditions improved in the next few days. She was awake and fully responsive to stimuli with a progressive recovery of right upper-limb strength, partial optic ataxia and regression of apraxia.

On a follow-up CT scan, the rectus sinus and the vein of Galen showed normal density with oedema in the brain tissue on both hemispheres (Figure 1D). Follow-up MRI venography showed restored venous flow in the rectus sinus and the vein of Galen; right internal cerebral vein and bilateral frontoparietal cortical veins were still occluded (Figure 1E), and the large intraparenchimal venous infarction was unchanged (Figure 1F).

In the next few days, platelet count progressively increased to $339x10^9$/L and D-dimer decreased to normal levels, in parallel with a significant reduction of aPF4 reactivity after 3 days (OD=0.9), and after 1 week (OD=0.6) patient serum was no longer able to activate platelets (Figure 2). Currently (nearly 2 months after the onset of symptoms), the patient has moderate disability: she has no neuropsychological deficits, can walk unassisted for short distances (sustained clonus and spasticity coexist in her right leg) and her right arm almost fully

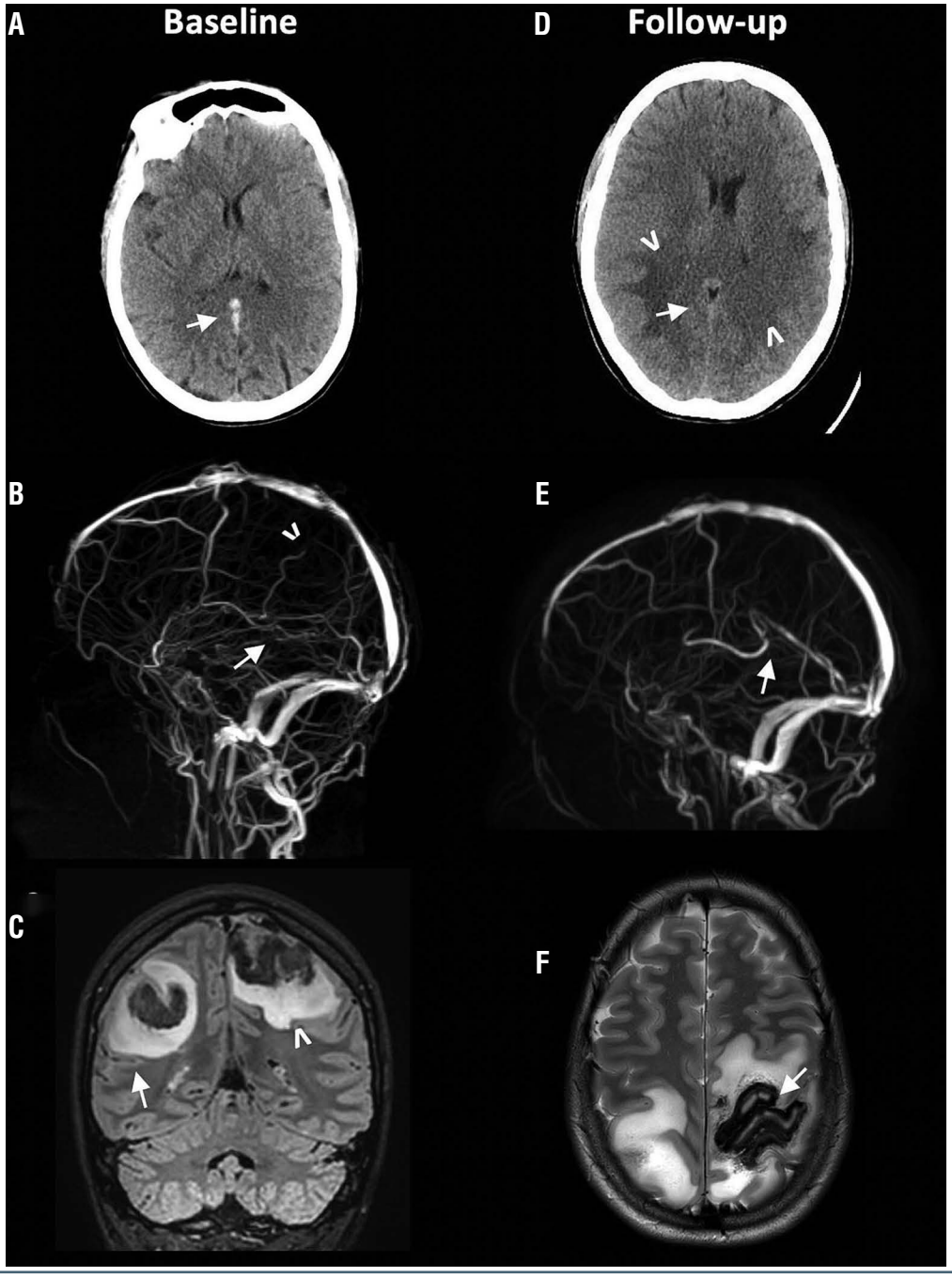

Figure 1. Neuroradiological findings at baseline and follow-up. (A) baseline computerised tomography (CT) (at admission) shows hyperdense rectus sinus and vein of Galen as signs of thrombosis (arrow). (B) Magnetic resonance imaging (MRI) examination (day 1) confirms complete occlusion of the rectus sinus, vein of Galen, right internal cerebral vein (arrow) and frontoparietal cortical veins on both sides (arrow head) on venous angiography. (C) On coronal T2-FLAIR images extensive venous infarctions with hemorrhagic transformation can be seen in right parietal (arrow) and left frontoparietal (arrow head) regions. (D) On follow-up CT (day 6) rectus sinus and vein of Galen show normal density (arrow) with oedema in brain tissue on both hemispheres (arrow head). Follow-up MRI (day 7) shows (E) restored venous flow in the rectus sinus and the vein of Galen (arrow); right internal cerebral vein and bilateral frontoparietal cortical veins are still occluded. (F) On T2 weighted images the large bilateral venous infarctions are still visible with hemorrhagic transformation in pre- and postcentral gyrus in the left side (arrow).

recovered. Fondaparinux was replaced with oral vitamin K antagonist.

In summary, we report a case of 26-year-old female who developed VITT following the first dose of ChAdOx1 nCoV-19. The patient had high-titer aPF4 and signs of platelet activation. Various treatment regimens have been suggested for this rare syndrome, being all based on HIT-derived approaches. Our treatment protocol, based upon IVIG, dexamethasone and argatroban was successful with almost complete clinical, laboratory and radiological response.

VITT should be considered in post-vaccination cases of

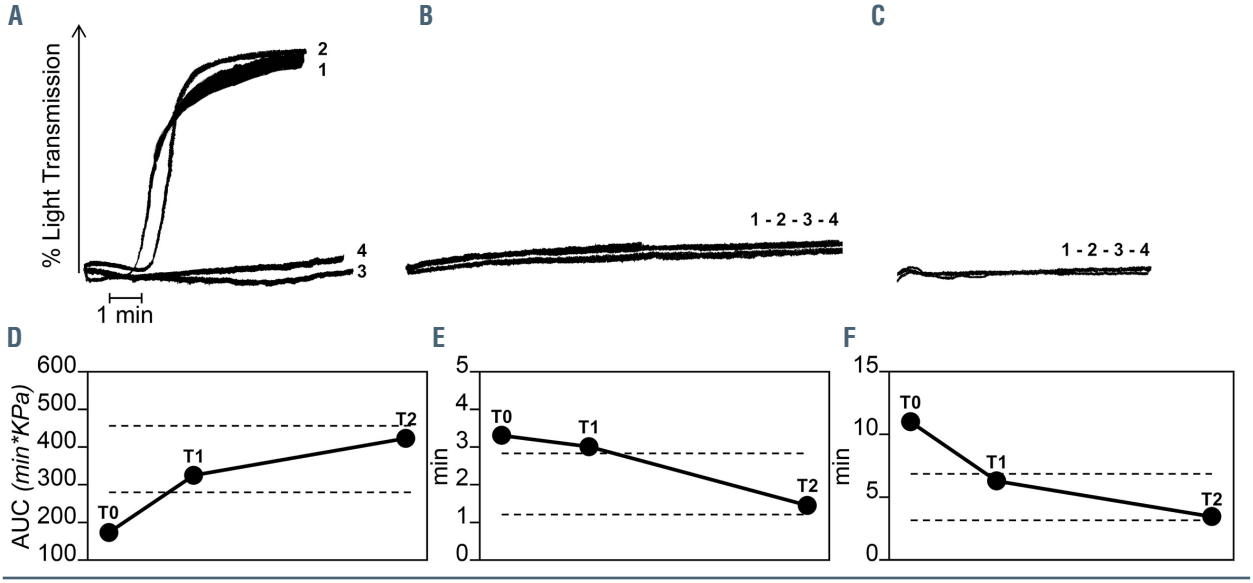

Figure 2. Platelet activation test and thrombus formation analysis. (A to C) Results of the platelet activation test (PAT) assessed under various conditions. Citrated blood from two healthy donors was collected and platelet-rich and platelet-poor plasma (PRP, PPP) were prepared by centrifugation (15 minutes [min]) at 200 g or 1,400 g, respectively and kept at 37°C.[14] Platelet counts for PRP were 5,6x10^9/L. Heat-inactivated (56°C, 30 min) serum from patient or controls (negative for aPF4) was incubated with PRP with or without LMWH 0.2 U/mL or unfractionated-heparin (UFH) 100 U/mL. Aggregation was assessed by means of a light-transmission aggregometer (Chrono-log, Mascia-Brunelli, Milano, Italy). Results were expressed as increase of light-transmission (%LT). PAT was considered positive if aggregation occurred in at least one of the two donors in the absence and presence of low LMWH and was inhibited by UFH. Panel (A) shows PAT results at T1 with patient serum that caused platelet activation in presence of LMWH (2), but also in absence of heparin (1) (85%, 77%LT, respectively), in contrast, high levels of UFH inhibited the reaction (3) (0%LT). The negative control serum did not cause aggregation (4) (0%LT). Similar results were obtained with the PRP of the other healthy donor. Panel (B) shows PAT results at T2 with patient serum that behaved like the negative control serum (i.e., it did not activate platelets under any of the conditions) (1-2-3-4) (0%LT). Panel (C) shows PAT results with serum of an asymptomatic subject positive to aPF4 enzyme-linked immunsorbant assay, but negative to PAT (1-2-3-4) (0%LT). Panels (D to F) show results of Total Thrombus Formation Analysis (T-TAS). In order to analyze thrombus formation under flowing conditions, whole blood was applied to type 1 collagen-coated chips at a flow rate of 24 μL/min which corresponds to a wall shear stress of 2,000^{s-1}. Thrombus-formation was analyzed through the following parameters: AUC, defined as the area under the flow pressure curve (D), OST (min), defined as occlusion start time (i.e, the time needed to reach the baseline pressure indicating the onset of the platelet thrombus formation) (E), and OT, defined as occlusion time (i.e., the time at which the occlusion pressure is reached (F). The dotted horizontal lines represent reference ranges (2.5th-97.5th centiles). aPF4: platelet-factor 4 (PF4)–heparin IgG antibodies.

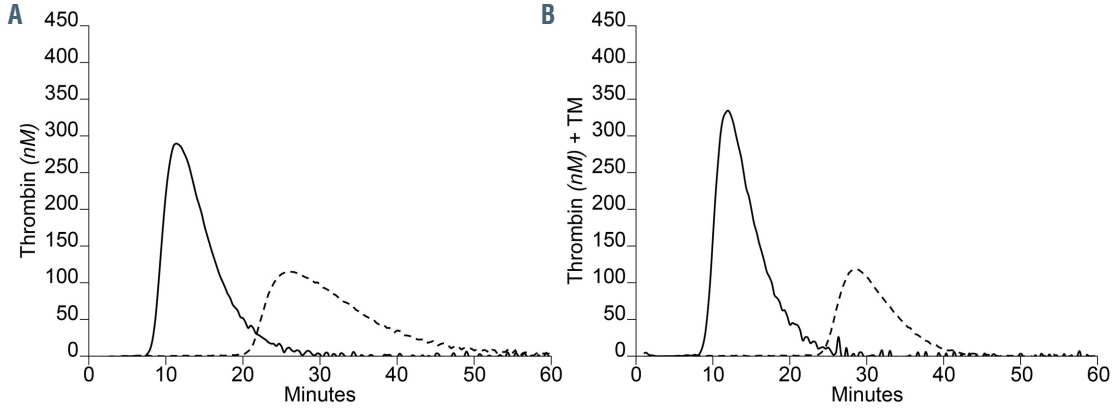

Figure 3. Thrombin generation. Thrombing generation (TG) was assessed as previously described[13] following *in vitro* coagulation activation of platelet poor plasma by calcium chloride with no addition of exogenous triggers. The TG reaction was monitored by means of fluorogenic substrate for 20 minutes (min) in a dedicated fluorimeter (Ascent, Fluoroscan, Thermolab System, Helsinki, Finland). The procedure was carried out in the absence (A) or presence (B) of soluble rabbit thrombomodulin (TM) (2 nM), which acts as the main physiological protein C (PC) activator and is located on endothelial cells. TM was titrated to reduce the ETP of the normal plasma by 50%.[13] The assessed parameters were the lag-time, defined as the time (min) needed to start TG, thrombin peak height (nM), the time to reach the peak (min) and the area under the curve, defined as endogenous thrombin potential (ETP) (nM/min). ETP represents the net amounts of thrombin that plasma can generate under the opposing driving forces of the pro- and anticoagulants operating in plasma. ETP results were also expressed as ETP-TM ratio by dividing the ETP in the absence to the ETP in the presence of TM. ETP-TM ratio represents the resistance to the anticoagulant activity of TM and is sensitive to the procoagulant imbalance between factor (F)VIII and PC (the higher the ETP-TM ratio, the greater the FVIII/PC ratio and hence hypercoagulability).[13] Solid and broken lines represent patient and control plasma.

thrombosis at unusual sites, even when apparent prothrombotic risk factors are identified (oral contraceptives in our case) and irrespective of the baseline platelet count. Indeed, this patient had mild thrombocytopenia on admission, but historical testing carried out before VITT recorded a platelet count of 275x10^9/L. Thus, the platelet count had decreased by approximately 50%, in agreement with HIT and VITT diagnostic criteria. Aware of the possible diagnosis of VITT, we initially avoided a potentially detrimental heparin treatment, and this decision is likely to have played a major role in determining the positive outcome.[2,3] Another important decision was to promptly start immune modulating therapy which caused the reduction of aPF4 titer and D-dimer. The causative prothrombotic mechanism in the reported patient is likely to be due to the antibodies to PF4 that induced a strong platelet activation even in absence of heparin exposure. The fact that the patient started to improve soon after the antibody titer decreased strongly supports this mechanism. One of the potential mechanisms that can explain the loss of serum activity in the functional assays (PAT) could be the IVIG blockade of FCγ platelet receptors and/or the antibody suppression. Interestingly, platelets' ability to promote thrombus formation *in vitro* was greatly reduced at admission, probably as a consequence of *in vivo* platelet activation and the formation of exhausted platelets as observed in other pathological conditions such as disseminated intravascular coagulation or sepsis. Laboratory tests correlated well with the clinical and radiological course. All in all, our experience supports the application of an early and multidisciplinary therapeutic approach in cases of VITT, with the possibility to avoid fatalities and obtain a resolution of the syndrome as in this case.

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Contributions: SB managed the clinical case, collected clinical data and wrote the clinical part of the manuscript; AA, GS, CG and GPC managed the clinical case, collected clinical data and critically reviewed the manuscript; AL performed the laboratory assays, interpreted the results and contributed to writing the manuscript; SLM, LP and MC performed the laboratory assays; AT organized the hemostatic assays, interpreted the results and contributed to writing the manuscript; FP designed the study and wrote the manuscript. All authors read and approved the final manuscript.

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