Histopathological Analysis of the Brain of an Acute *Decompression Sickness* (DCS) Victim

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Abstract

We investigated histopathologically an unusual lesion which was composed of multiple small 'edematous necrosis' foci in the deep white matter of the brain in a diver who succumbed to acute decompression sickness (DCS). An analysis using a three-dimensional reconstruction of serial sections clarified the relationship between the vascular changes and the necrosis. We found vascular changes such as dilatation of the lumens due to lodgment of gas bubbles and stenosis of the lumens due to fibrin thrombosis, especially prominent in the small veins, venules, and capillaries of the venous side in the territory of the deep cerebral vein system. There were no remarkable changes in the arteries. The necrotic foci were topographically correlated with these vascular changes. We felt that the necrotic lesion in the brain of this case may be ascribed to dyshoric damage of the veins and capillaries of the venous side and that the mechanism of vascular damage was probably due to the retardation of gas bubble clearance from the deep cerebral vein system of the watershed zone in the deep cerebral white matter.

Key words: Decompression sickness (DCS), Cerebral lesion, Edematous necrosis, Deep white matter, Watershed zone.

Introduction

Cerebral damage following a rapid decrease of atmospheric pressure has been reported to occur in some fatal cases of acute decompression sickness (DCS) (HAYMAKER, 1957), but its

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pathogenesis still remains unclear. In a previous paper (KITANO *et al.*, 1990), we described the autopsy findings of four divers and discussed the pathogenesis of cerebral damage in DCS. Our conclusion for the pathogenesis was that autochthonous gas bubbles in the lipoid-rich cerebral parenchyma, alteration of the vascular permeability and marked circulatory disturbance, especially of the venous side were very important.

This paper is based upon more detailed histopathological findings of one of the previously reported four cases. This case showed an unusual lesion in the deep layer of the white matter of the brain. The dual purposes of this study are to analyze the topographical relationship between the lesion and vascular changes, and to discuss more precisely the pathogenesis of the cerebral damage.

Case Report*

An experienced 36-year-old Japanese male scuba diver dove to the bottom, at a depth of about 60 meters, off Koshiki-island, Kagoshima Prefecture on a July day. He dove four times for about 40 minutes each time and surfaced for about 15 minutes between each dive. He complained of pain in both lower limbs after surfacing from the last dive. He tried a conventional treatment, that is 'water again', for DCS two times. However, the symptoms never improved and vomiting occurred thereafter. About 20 hours later, he was transferred to Kyushu Rosai Hospital, Kitakyusyu City. Physical examinations at the admission disclosed a complete sensory loss and flaccid paralysis of the bilateral lower extremities, and hypesthesia and weakness of muscular power of the bilateral upper extremities. A vesicorectal disturbance and slight dyspnea were also noticed. His consciousness was maintained in rather good condition. He was then received into a recompression chamber. When the atmospheric pressure inside the chamber raised to 5 ATA (*atmospheric absolute*), he had a marked hematemesis and his general condition became worse. Accordingly, the recompression therapy had to be discontinued. The next morning he fell into a severe shock state losing consciousness and had a fever of up to 42°C. He expired five days after the onset of the disease without any signs of recovery from the shock. The clinical diagnosis was spinal cord type DCS (HAYASHI, *et al.*, 1975) with shock.

Autopsy Findings

Intravascular gas bubbles were not visible to the naked eye in the corpse at the time of the autopsy. Extensive and marked hemorrhagic and erosive esophagitis was found. The lungs showed congestion, edema and aspiration of blood, together with focal bronchopneumonia in association with tracheitis. A small number of fat emboli and thrombi were present in the small blood vessels of the lungs. The other visceral organs were congested. Centrilobular

* This case was described as Case 3 in our previous paper published in South Pacific Study 10: 275-285, 1990.

necrosis of the liver and degeneration of the tubular epithelium of the kidneys were observed. The bone marrow of the right femoral head showed a relatively extensive necrosis and contained numerous gas bubbles.

The brain weighed 1,320 grams and revealed marked congestion of the superficial blood vessels and moderate parenchymal edema (Fig.1). There were no visible abnormalities in the sinuses, the great vein (Galen), and its main branches.

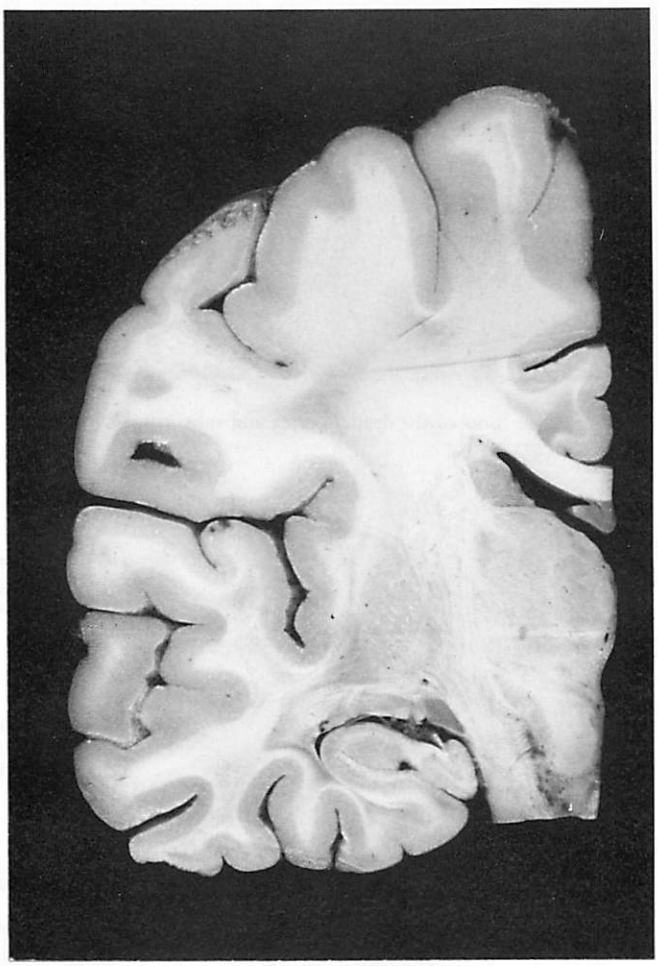

Fig. 1. Cut surface of the brain.

Histologically, there were innumerable pallor spots up to 0.5 mm in diameter around the capillaries and venules of the parenchyma especially in the deeper cortex and subcortical white matter (Figs. 2 & 3). Pyknotic changes in the nuclei of the nerve cells and glial cells in the affected areas were observed. From the size and location of the spots, we deduced that very small gas emboli intimately contributed to the formation of the spots, as we discussed previously (KITANO *et al.*, 1990). There were no detectable fat embolism in the brain, although

Fig. 2. Pallor spots of the deeper cortex and subcortical white matter.

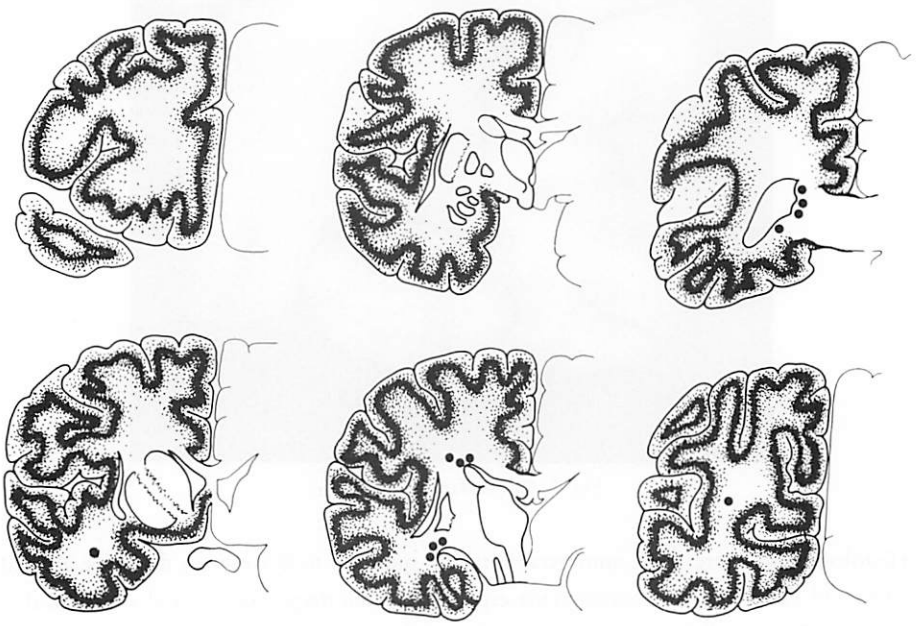

Fig. 3. Schematic drawing of distribution of the lesions. Dark spots show the pallor spots while dark circles the foci of edematous necrosis.

perivascular hemorrhage was focally seen.

Several, small, up to 3 mm in the longest diameter, relatively-sharply demarcated foci of necrosis were present in the deep layer of the white matter of the cerebrum, especially in the periventricular layer (Figs. 3 & 4). The foci showed tissue rarefaction with a marked edema. Destrution of the myelin sheaths and anomalous swelling of the axons were characteristic. Mesenchymal cell reaction was slight in and around the necrotic foci, but a slight hemorrhage was seen in the necrotic tissues.

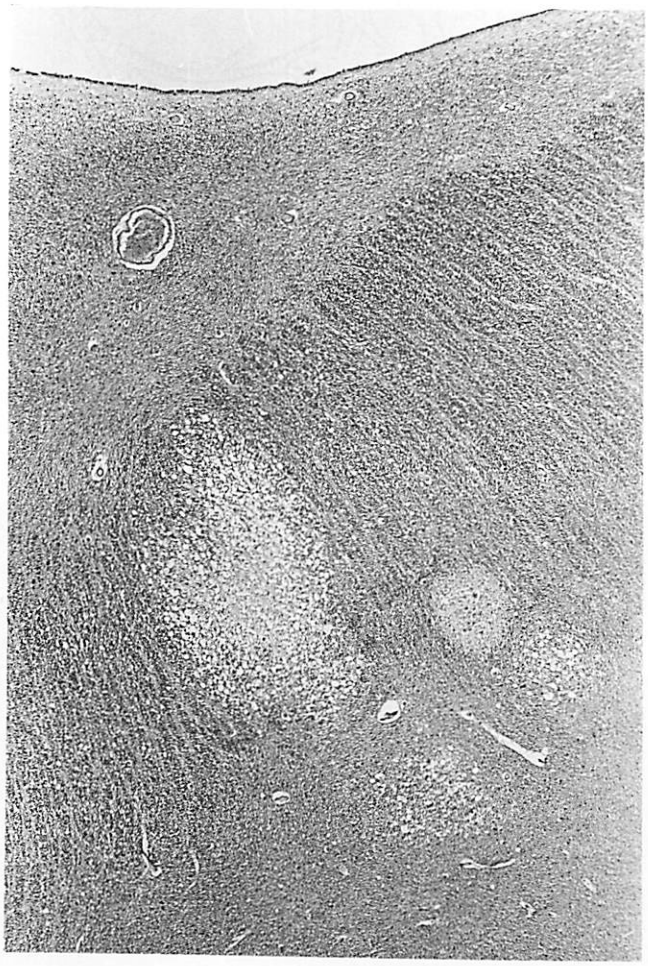

Fig. 4. Periventricular foci of edematous necrosis. Dilatation of a congested vein is seen.

Vascular alterations were observed in a three-dimensional reconstruction of serial sections of one of the periventricular foci of the edematous necrosis (Fig. 5). The results of tracing the arteries and veins contributing to the necrotic focus were as follows: 1) slight swelling of the endothelial cells without remarkable changes at the media and adventitia in the small arteries

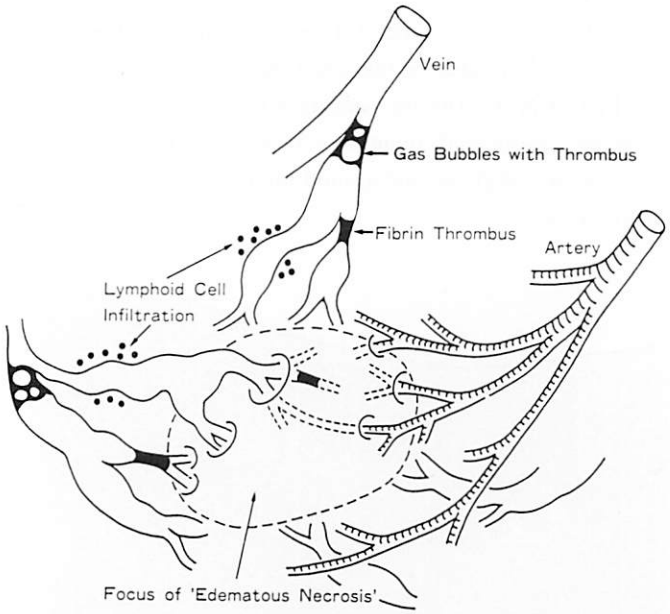

Fig. 5. Illustration of the topographical relationship between a focus of edematous necrosis and vascular changes.

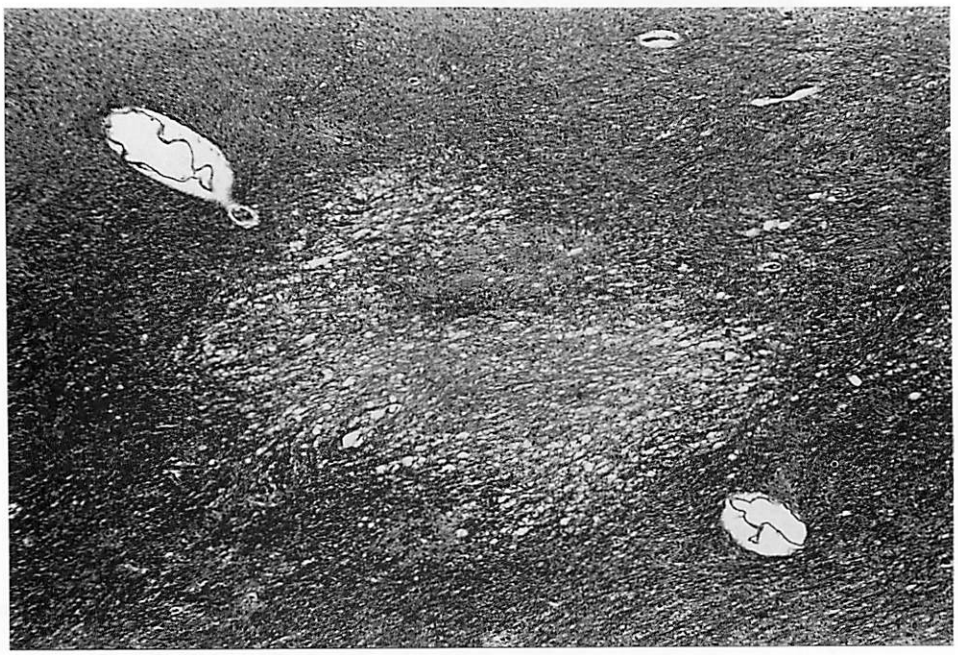

Fig. 6. A focus of edematous necrosis. Dilatation of veins with empty lumens leads us to suggest of the lodgment of gas bubbles.

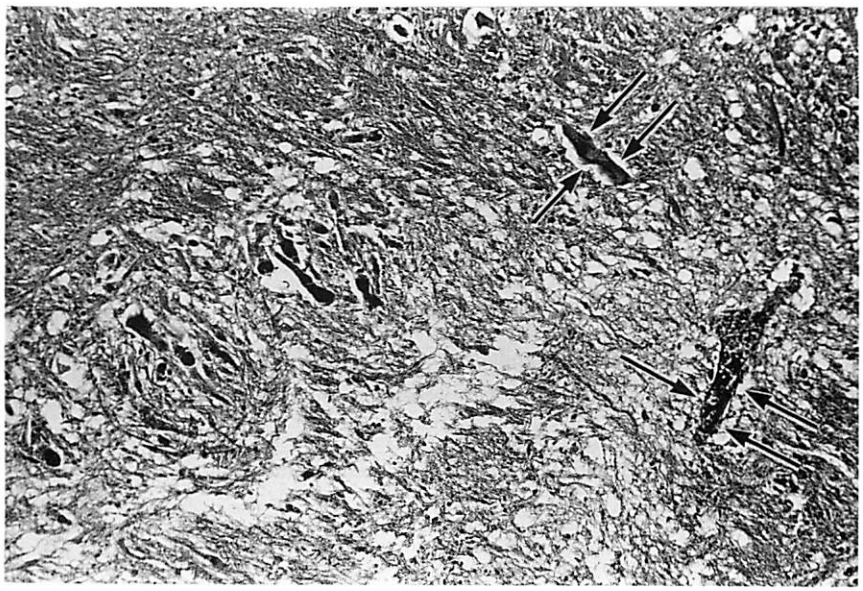

Fig. 7. Thrombotic capillaries and venules (arrows) in and around a focus of edematous necrosis.

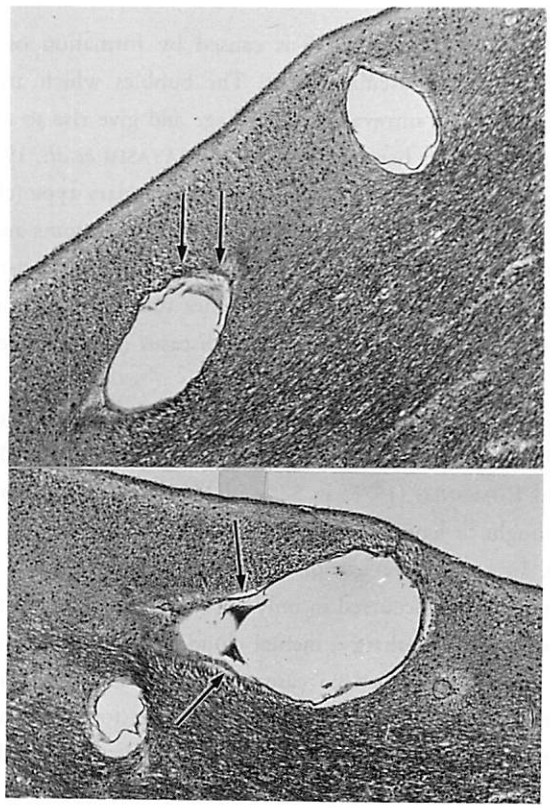

Fig. 8a (upper) and 8b (lower). Periventricular veins (around foci of edematous necrosis) seemingly associated with lodgment of gas bubbles. Thrombus-formation (arrows) is observed in them. See also the Fig. 7 in our previous paper (KITANO *et al.*, 1990).

and arterioles, 2) luminal narrowing due to edematous thickening of the wall and segmental cystic dilatation of the capillaries, both of which were particularly more prominent in the venous than in the arteriolar side, 3) tortuous and knotty dilatation of the veins and venules around the necrotic focus. The lumens of these vessels seemed to be empty, fully suggesting a lodgment of gas bubbles (Figs. 4 & 6). Narrowing and obstruction of the venules by fibrin thrombi (Fig. 7), some of which were closely attached to the empty spaces (gas bubbles, most likely) (Fig. 8a, b) were also seen. As for the three-dimensional relationship between this small necrotic focus and the vascular changes, the necrosis seemed to be closely and directly associated to the small veins, venules and capillaries of venous side. Fibrin thrombi which were seen in the venules draining the necrotic foci were absent in the venules draining the well preserved areas.

The spinal cord showed an extensive and marked edematous necrosis, especially in the lower thoracal segments (KITANO *et al.*, 1975). The features of the necrotic lesion of the spinal cord was typical for DCS as described in many other papers (HAYMAKER, 1957).

Discussion

It has been widely accepted that DCS is caused by formation of nitrogen-gas bubbles within the intravascular or extravascular spaces. The bubbles which are created in tissue or blood produce local damage and intravascular blockage and give rise to a wide variety of clinical symptoms and signs. DCS has been divided by us (HAYASHI *et al.*, 1975) into 1) brain type, 2) spinal cord type, 3) Meniere's disease type, 4) cardiopulmonary type (chokes), and 5) musculoskeletal type (bends), based upon the predominant clinical symptoms and signs. DCS, however, has been customarily divided into type I (mild, peripheral pain, non-neurological) and type II (serious, neurological). The second category includes the more florid manifestations of cardiopulmonary, vestibular, cerebral, and spinal cord diseases (GOLDING *et al.*, 1960). The present case belonged to type II DCS.

On frequency of type II DCS, the opinions vary considerably by different investigators. HAYASHI *et al.* (1975) found it in 34.8% of 161 cases of DCS, SLARK (1965) in 35.0% of 137 cases, while ERDE and EDMONDS (1975) in 52% of 100 cases. In the last study, 33 (63.5% of type II cases) were thought to have cerebral involvement, but the general view is that the spinal cord is most affected. In a recent review of 1070 cases of type II DCS FRANCIS *et al.* (1988) stated that cerebral involvement occurred in only 30% of them. The frequency was based upon the patient's complaints such as lethargy, mental cloudiness, confusion, and feeling of unwellness. ADKINSSON *et al.* (1989) studied 23 cases of type II DCS by injection of $^{99}Tc^{m}$- hexamethylpropyleneamine oxime and single photon emission tomography, and found cerebral perfusion deficits in all 23 cases (100%). Their conclusion was that type II DCS should be recognized as a diffuse or multifocal central nervous system disease, and that the brain in type II DCS patients was inevitably, more or less markedly involved in pathologic changes.

The discovery of perfusion deficits in the brains of all the patients with type II DCS is of great importance. ADKINSSON *et al.* (1989) stated that even those patients with classical spinal

cord type DCS displayed clear cerebral perfusion deficits.

In our previous description of the autopsy findings of four divers' cases which died of serious acute type II DCS (KITANO *et al.*, 1990), the brains of all the four cases also showed more or less marked cerebral damage. The common findings of the brains were summarized as follows: 1) marked engorgement of the meningeal veins with a marked stasis of blood with or without the presence of intravascular gas bubbles, 2) marked edema of the cerebral parenchyma with perivascular hemorrhage and 3) pallor spots around the venules and capillaries most possibly caused by alteration of permeability of the blood vessel walls due to trapping of small gas bubble emboli.

In the present case (one of the above-mentioned four cases), a very unusual lesion was found. There were multiple foci of edematous necrosis in the deep layer of the white matter, especially in the periventricular areas of the cerebrum. Such a peculiar cerebral lesion had not been reported before. The present study disclosed a close three-dimensional relationship between the vascular changes and the parenchymal lesion. Dilatation with an empty lumen fully suggested the lodgment of the gas bubbles in addition to the fresh fibrin thrombosis occurring in the small veins, venules and capillaries which looked intimately related to the retardation of gas bubble clearance was prominent. The intravascular gas bubbles seemed to have a close correlation to the parenchymal lesion of the brain, which were characterized by the presence of localized parenchymal rarefaction with swelling of axons and destruction of myelin sheaths.

Although under the several hypotheses on the pathogenesis of DCS, the following two theories are important; arterial gas embolism and disturbance in venous blood flow due to gas bubbles together with thrombus formation. Distribution of the parenchymal necrotic foci in the present case was restricted to the areas of abnormal veins and capillaries of the venous side. Such a distribution seems to be incompatible with the hypothesis of the arterial blockage. The observations of this case support the latter passibility (HALLENBECK *et al.*, 1975; KITANO *et al.*, 1977).

The next problem to be considered is the anatomical localization of the necrotic foci. The foci were situated in the so-called watershed zone, in which the supply of arterial blood with oxygen is physiologically poorer (WODARZ, 1980). Additionally, this localization corresponded to the territory of the deep cerebral veins which drain into the rectus sinus *via* the great vein (Galen). The angiographical evidence support that the blood flow of the deep cerebral veins is considerably slow (CARPENTER, 1983). Retardation of gas bubble clearance from the deep white matter should be related to the physio-anatomical states of the deep cerebral vein system. Therefore, it seems appropriate to consider that intravascular gas bubbles associated with firbrin thrombi accelerate the retardation of venous blood flow with a subsequent increase of the tissue pressure and intimately contribute to the formation of necrotic foci in the watershed zone of the brain in this case.

The morphology of the necrotic foci of the deep layer of the brain of this case was quite similar to the necrotic changes of the spinal cord in DCS. We already analyzed and reported that intimate topographical correlation of vascular changes of the veins and venules with the parenchymal changes were revealed in the spinal cord lesion in DCS (KITANO *et al.*, 1977). Therefore, pathogenesis of the necrotic cerebral lesion in this case may be the same as that of

the spinal cord lesion, related to dyshoric changes of the veins and capillaries of the venous side.

In conclusion, we considered that the main cause of the edematous necrosis of the deep white matter of the cerebrum of the present case was the circulatory disturbance of the venous flow following an increase of the parenchymal tissue pressure associated with intravascular gas bubble lodgment with the formation of fibrin thrombi. From the findings of this study, the spinal cord lesion in DCS and the necrotic lesion of the brain in DCS were almost identical. The focal but severe circulatory disturbance in the deep cerebral vein system should play an important role for the determination of localization and character of the vascular and parenchymal changes in the watershed zone of the deep white matter of the brain.

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