

The mechanism of injury of the abducens nerve in severe head trauma: a postmortem study

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Abstract

The aim of this study is to investigate the mechanism of injury of abducens nerve at petroclival region in severe head trauma. Twenty specimens provided from 10 autopsied cases due to severe head trauma were investigated macroscopically and histopathologically. The slices of the abducens nerve taken consecutively along its course at petroclival region were stained with Hematoxylline–Eosin and evaluated under light microscope. In addition, coexisting cervical injuries in these cases were assessed macroscopically. Edema and perineural hemorrhagia of abducens nerve were identified in all cases. Nerve injury was found more exaggerated at the sites of dural entry point and petrous apex than any other parts of the abducens nerve. Furthermore, microscopically, also remarkable perineural hemorrhage of the abducens nerve was observed at the site of its anastomoses with the sympathetic plexus on the lateral wall of the internal carotid artery (ICA). Abducens nerve is injured at the sites of dural entry point, petrous apex and lateral wall of the ICA, directly proportional with the severity of the trauma. This finding is also significant in verification of the severe head trauma.

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1. Introduction

Abducens nerve palsy, being one of the complications following severe head trauma is reported to be in the 1–2.7% of the cases [15]. The abducens nerve may be damaged directly by bone fragments in the skull base fracture. However, the mechanism of the sixth nerve palsy in severe head or cervical trauma without any fracture is a matter of controversy. Abducens nerve is composed of subarachnoid, intracavernous and intraorbital segments. The nerve is mobile in the cerebrospinal fluid for first segment. It travels between dural leaflets at skull base all through the second segment. In third segment, after leaving annulus tendineus behind, it passes through the intraorbital fat tissue and reaches up to lateral rectus muscle. In previous studies, the second segment

was of attention in the pathogenesis of the abducens nerve palsy and those cases with clinical signs were investigated to come into a conclusion [1,10,14,17]. In this study, abducens nerve at the site of petroclival region were investigated histologically as well as with the injury mechanism, in cases who expired due to head trauma.

2. Material and method

In this study, 20 specimens provided from 10 autopsied cases due to severe head trauma were investigated. The cause of severe head trauma was car accident in six cases, and high fall in the other four. The integrity of petroclival region at skull base was not violated in any case. Ages of the cases ranged from 15 to 80 years. Specimens provided at the times of postmortem 4–12 h.

Following the scalp degloving, the skull was cut circumferentially at axial plane 2 cm above the supraorbital line

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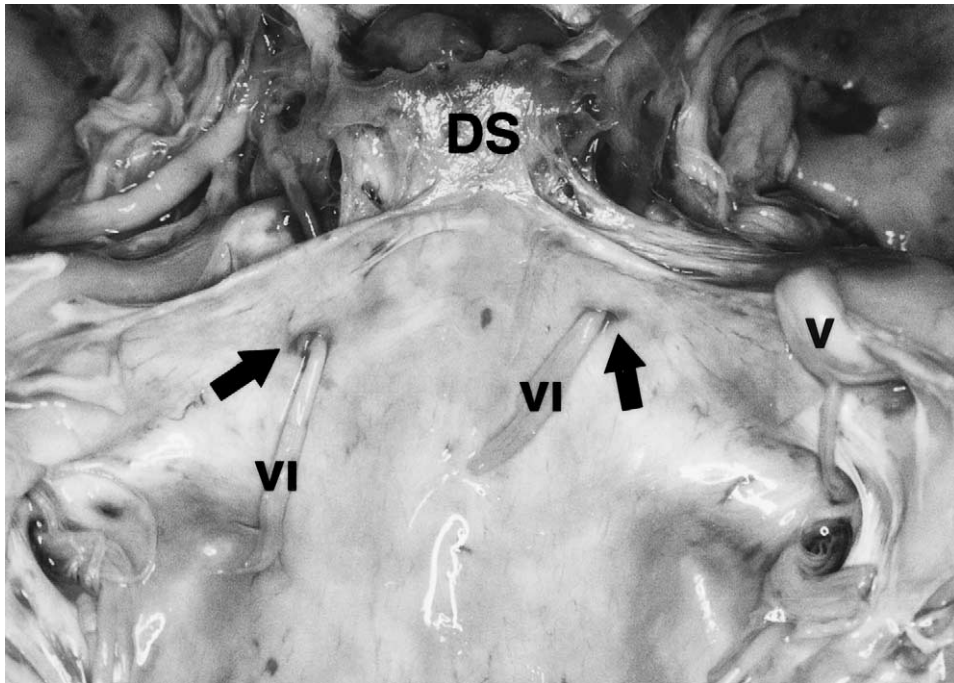


Fig. 1. Hemorrhagic circles (arrows) at the dural entrance poruses of the abducens nerves were noted on the fresh autopsy material.

without damaging the dura. The calvarium was removed, and dura was opened circumferentially. The cranial nerves were cut and the cerebrum and cerebellum were detached from their attachments to skull base. The dura overlying the region just behind the superior orbital fissure to dural entry site of the abducens nerve was carefully dissected from the skull base bone, without any harm to its own contents. Specimens were rinsed with normal saline and fixed in the solution of 10% formalin for a weeklong. Dura of the petroclival region, abducens nerve, and vertical part of cavernous segment of internal carotid artery (ICA) were evaluated macroscopically and microscopically.

Right and left sides were separately embedded in paraffin after processing in gradually increasing ethanol series from 70 to 100%, and the serially sectioning into slices of 5 μ m thickness. The slices were stained by Hematoxylline–Eosin and observed under the light microscope.

Histopathologically, the amount of cellular edema, perineural hemorrhage were investigated in abducens nerve, its dural sleeve and petroclival dura mater. Additionally, in the macroscopic sections of the brains, severe brain edema and hemorrhagic contusion areas as the evidences of the severe head trauma were investigated. Cervical vertebrae were evaluated in all cases as well Fig. 1.

3. Results

Edema, hemorrhagic contusion and hyperemic foci confirming the presence of severe head trauma were observed in

all brains in macroscopic sections. Calvarial depression fracture was noted in five cases, parietal linear fracture in two cases and blunt head trauma in three cases. Hematoma was found within longus colli muscle in five cases, C6 cervical fracture in two cases, and C5 fracture in one case. Specimens macroscopically were evaluated and hemorrhagic contusion areas were identified at the site of dural entry point of the nerve as well as the petrous apex region in 12 specimens (60%) (Fig. 1), whereas at only dural entry zone in one case (Fig. 2A). In seven cases, hemorrhagic foci was identified in the vertical segment of ICA right after existing foramen lacerum (Fig. 2B). In five specimens, dural sleeve of the abducens nerve was found to be injured at the region of petrous apex (Fig. 2C).

In microscopic evaluation, remarkable cellular edema and perineural hemorrhage were observed in the all abducens nerve along its course at the petroclival region. It was also noted that, the amount of perineural hemorrhage particularly at the sites of dural entry zone and petrous apex were in accordance with that of identified in macroscopic sections (Fig. 3).

Similarly, the extent of hemorrhage around the nerve, between nerve, arachnoid membrane and dural sleeve were found much more at these sites, which was also consistent with the correspondent macroscopic findings. Profuse erythrocytes were noted in the petroclival dura. Edema and perineural hemorrhage of the nerve was relatively minimal at the petrosphenoidal ligament region in comparison to petrous apex and dural entry point.

Significant edema and hemorrhage of the nerve was also noted in the slices taken from the lateral wall of ICA, where

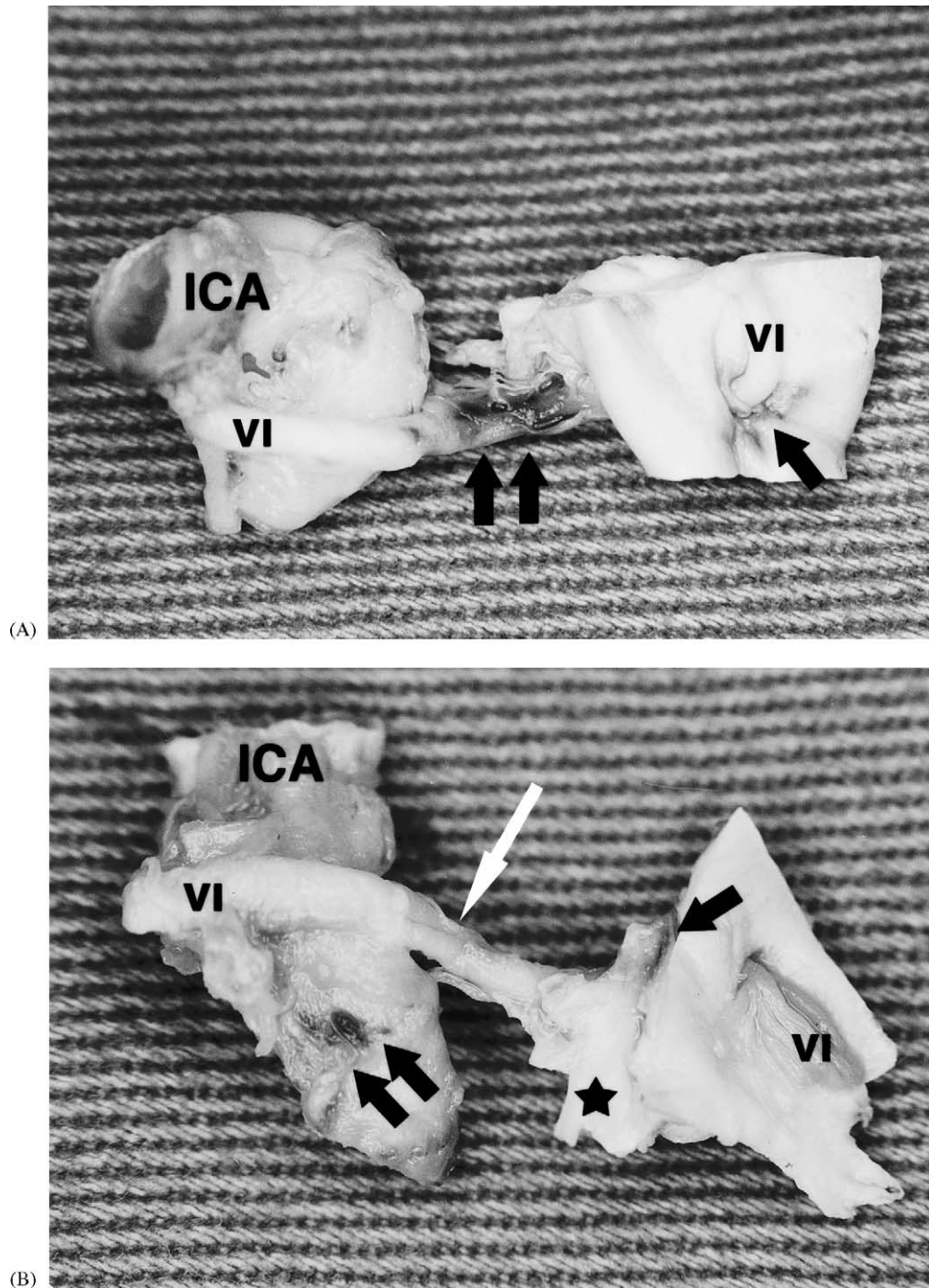


Fig. 2. (A) The macroscopic appearance of the abducens nerve segment located between dural entry point and lateral wall of the ICA demonstrates the hemorrhagic foci which developed by trauma at the sites of dural entry point and petrous apex (from left petroclival region). (B) Macroscopically, hemorrhagic areas are seen on the lateral wall of the internal carotid artery (ICA) (thick arrow) and within the extents of foramen lacerum where abducens nerve courses tangentially (double arrow), and on dura mater (white arrow) at the site of dural entry point of the abducens nerve. Additionally, the disruption of the integrity of dural sleeve of the nerve at petrous apex region (thin arrow) is observed. Star, petrosphenoidal ligament. (C) Abducens nerve compression and dural sleeve disruption (arrow) at petrous apex are observed.



Fig. 2. (Continued).

the nerve anastomoses with sympathetic plexus. Both hemorrhagic foci and lacerations were demonstrated on the walls of ICA (Fig. 4). It was of note that, the dura was edematous due to hemorrhagic contusions (Fig. 3C).

4. Discussion

After piercing the skull base dura, abducens nerve goes through three different stiff structures and reaches up to the lateral wall of the posterior part of the cavernous ICA. These structures are respectively dural entry point of the nerve at the site of petroclival region, petrosphenoidal ligament and petrous apex [10,14,9]. The portion in the cavernous sinus which extends into superior orbital fissure, is embedded in the venous medium taking place in the medial part of the lateral wall of the sinus and is relatively mobile like sub-arachnoid and intraorbital portions, in respect to that one at petroclival region.

For a long time, abducens nerve was of attention as it passes through under the petrosphenoidal ligament located between posterior clinoid process and dorsum sellae; and the region beneath this ligament was called as Dorello's canal [18]. The abducens nerve is fixed downward beneath the petrosphenoidal ligament by dura and at the apex of the petrous pyramid [14]. Considering this fixation point beneath the ligament, Schneider and Johnson [12] thought that the ligament behaved as a contusion point of the abducens nerve in case of upward and posterior displacement of the brain in cervical spine fracture cases. Reversibly,

histological results in our study revealed that the amount of injury of the nerve segment beneath the petrosphenoidal ligament was not as significant as those at dural entry point and petrous apex.

Cerebrospinal fluid suspends the brain and spinal cord in a watery medium and cushions the central venous system from external forces applied to the skull or the spine. Brain weighs only 50 g as it floats in the cerebrospinal fluid [3]. However, transmission of high velocity to the brain in case of sudden acceleration of the head in severe head trauma causes the rupture of vessels and nerve fibers [3,5].

Considering the movement of the brain within the skull, Takagi et al. [14] stated that both abducens nerves could be stretched downward by a linear accelerated force in the midsagittal plane during the impactation. Then the nerve is compressed against the petrous apex, resulting in its injury. Arias [1] stressed on the two points as the sites of abducens nerve damage in cases of traumatic bilateral abducens nerve palsy, i.e., dural entry point and petrous apex. Vectorial analysis of the flexion and extension forces in cervical injuries demonstrated that there was consistently a vertical component in both types of the injuries [17]. This finding confirms the upward movement of the brain in cervical trauma leading to functional loss of the nerve at the dural entry point of the abducens nerve. In our opinion, borders of the dural entry point forms a rigid structure, which is significant particularly in the cervical trauma leading upward movement of the brain. On the other hand, since the abducens nerve cross over the petrous apex, sudden downward displacement of the brain may cause the nerve

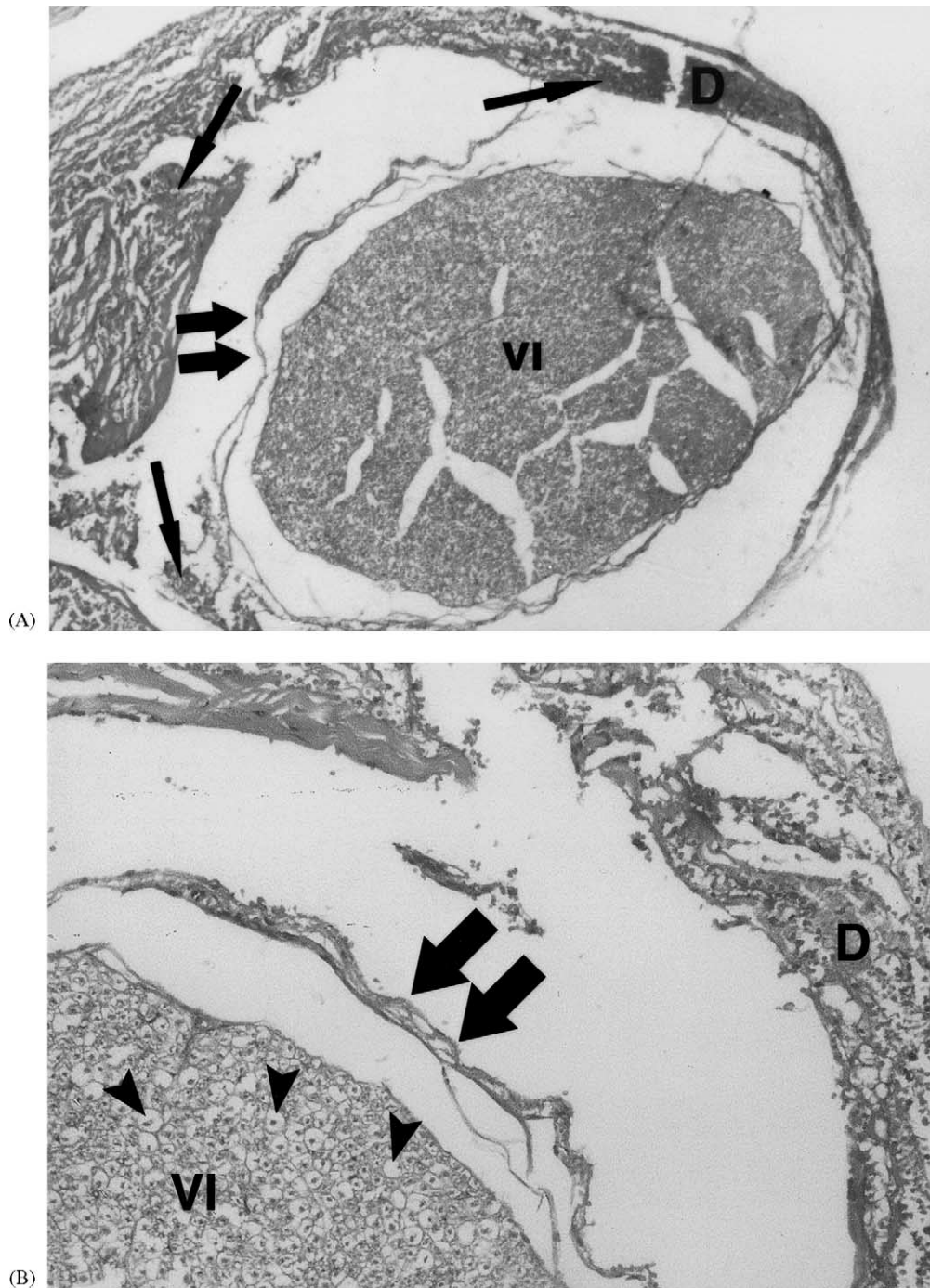


Fig. 3. (A) Erythrocyte accumulation (black arrows) is observed on arachnoid membrane (double arrow) and dural sleeve (D) of the abducens nerve (6). HEx40. (B) Cellular edema (arrowheads) is visualised characterized by swelling of the nerve cells in abducens nerve (6). Erythrocyte accumulation at perineural region without significant intraneural hemorrhage is remarkable. Arrow, arachnoid membrane; star, dural sleeve. HEx100. (C) Perineural hemorrhagic areas (arrows), edema characterized by the fibrous tissue enlargement in dura mater (star), consistent with macroscopic appearance, are demonstrated in sagittal sections of abducens nerve (6) at dural entry point. HEx100.

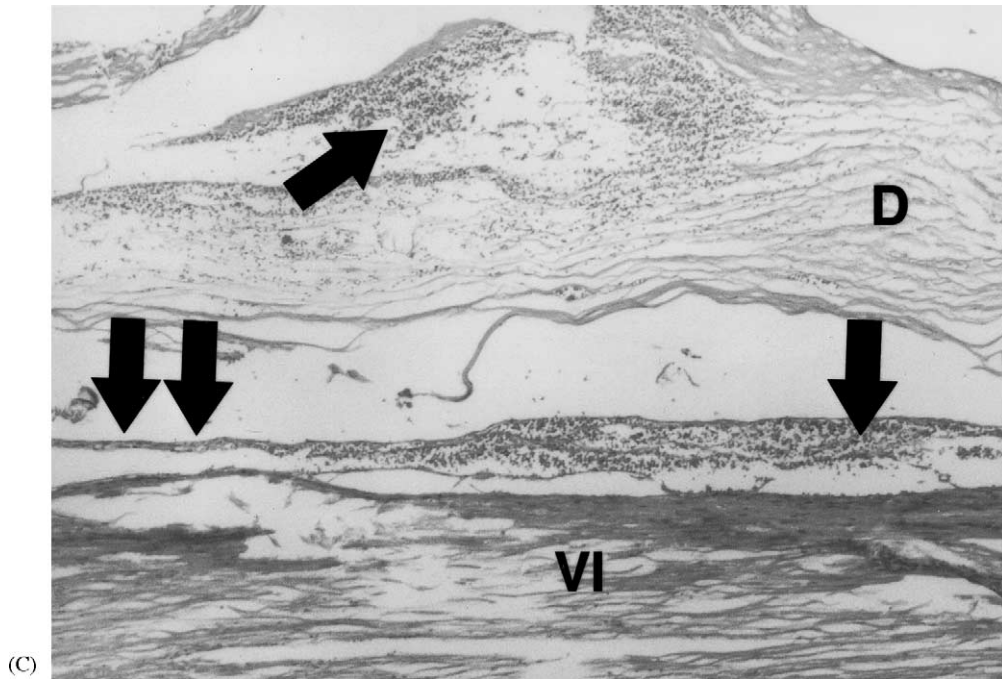


Fig. 3. (Continued).

to be compressed and injured at this location. Presence of hemorrhagic contusions of the abducens nerve at the dural entry point and the petrous apex in the specimens supports the previous outlook [1]. In addition, since both types of movements of the brain existed in severe head and cervical trauma, dural entry zone and petrous apex together damage the nerve simultaneously, as was the case and demonstrated in our study. Macroscopically, coexistence of cervical fracture in three cases out of six, together with the presence of contusions at the sites of dural entry point and petrous apex in these cases, supports the idea of nerve entrapping at these particular sites. Macroscopic hemorrhagic contusion and microscopic perineural hemorrhage at these sites in most of the cases, and cellular edema in all cases, prove their significant role in the pathogenesis of the abducens nerve trauma. Abducens nerve palsies following severe head trauma and/or cervical trauma reported in the literature, are the evidence of the entrapment of both abducens nerves at these particular sites [8,12,14,17].

Petroclival dura encircles abducens nerve at the site of dural entry point by reflecting outwards just from that point [19]. Meanwhile, arachnoid membrane surrounds the nerve within its dural sleeve. The dural sleeve of the abducens nerve, which protects the nerve from venous blood, becomes thinner at the end of the petrous apex, and the sixth nerve anastomoses with the periarterial sympathetic plexus on the lateral wall of the cavernous segment of the ICA [9–11,20]. In our specimens, disruption of the abducens nerve dural sleeve at the site of petrous region is an evidence of abducens' vulnerability to trauma due to thinning of the

dural sleeve at this particular point. The sympathetic connections with the sixth nerve were studied in detail by Parkinson [11]. He stated that the connecting fibers must possess some of the functions, the absence of which result in Horner's syndrome. [11]. Involvement of abducens nerve together with the sympathetic plexus in cases of intracavernous aneurysm, petrous apex tumor and fracture have been reported in the literature [4,10,13]. These reports indicate that the abducens nerve may be tethered by the sympathetic nerve fibers during the strong sudden backward stretching of the nerve in severe head and cervical trauma. Therefore, the anastomosis site of the abducens nerve with the sympathetic plexus forms another tethering point for the abducens nerve, aside the dural entry point and petrous apex site [9,10]. In this study, despite the remarkable macroscopic hemorrhagic contusions around the nerve at this location, cellular edema and perineural hemorrhage was observed microscopically. Relying on this finding, except for the direct effect of bone trauma at petrous apex, we hypothesize the entrapping effect of the anastomosis site between the periarterial sympathetic plexus and abducens nerve on the lateral wall of ICA, in the development of the hemorrhagic contusions of the lateral wall. Abducens nerve injuries observed at these three points following severe head trauma are correlated with those three particular points, where abducens nerve angulated [9,10,16].

In conclusion, in severe head trauma, the abducens nerve can be injured at the sites of dural entry point, petrous apex and lateral wall of the ICA directly proportional with the amount of the trauma. Abducens nerve paralysis is signifi-

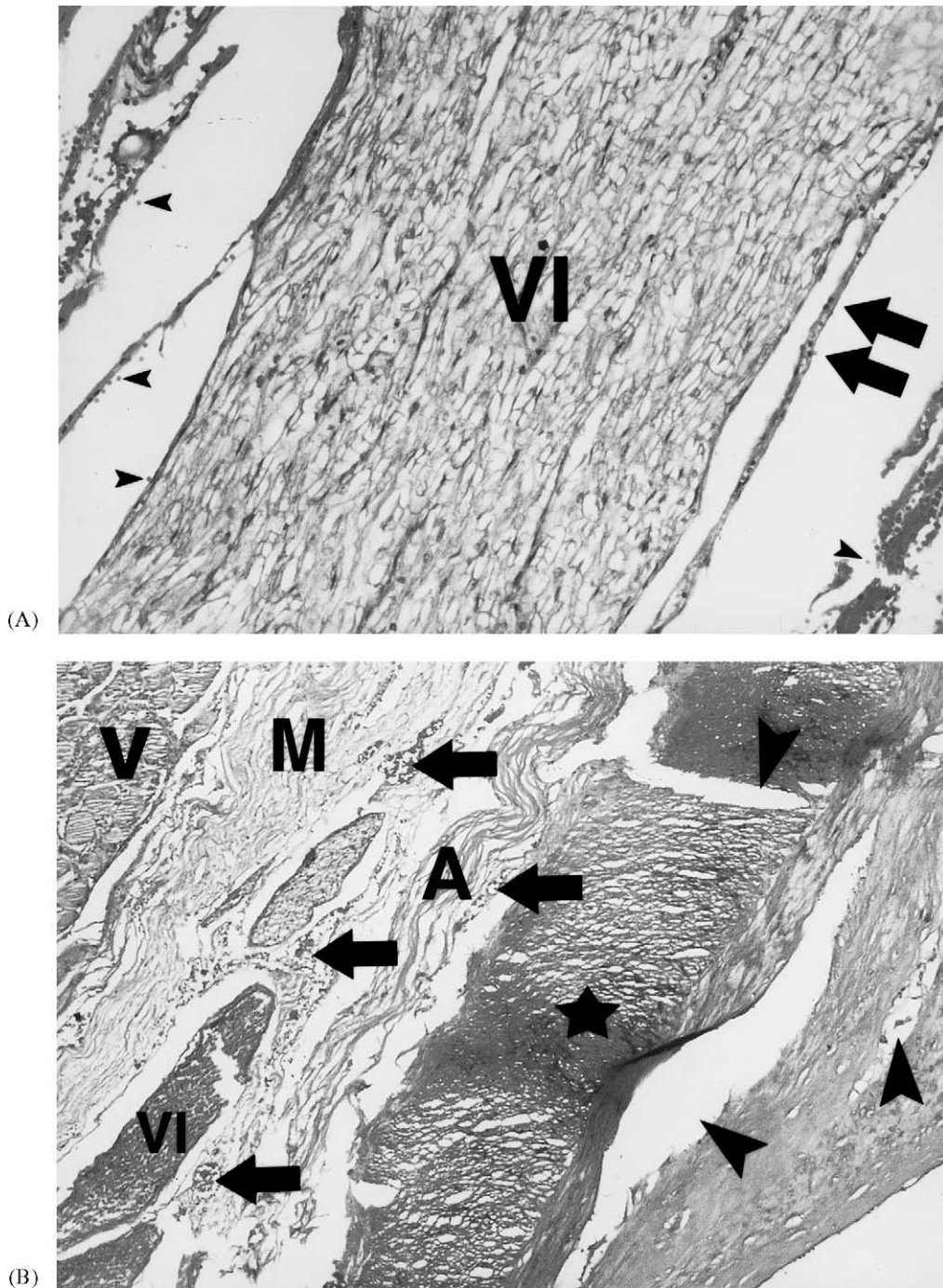


Fig. 4. Edema of the fibrous tissue constituting the medial wall (M) of Meckel's cave and internal carotid artery (ICA) (star) adventitia (A) associated with hemorrhagic foci (arrows) are observed in the region where abducens nerve (6) courses between lateral wall of ICA and medial of trigeminal nerve (5). Remarkable edema and lacerations (hollow arrows) are noted in the wall of ICA. HEx40.

cant as an indicator of the severity and the direction of the trauma applied to the head or neck. Children subjected to trauma or diagnosed as shaken baby syndrome might have abducens nerve paralysis according to the relevant literature

[2,6,7]. In our opinion, in autopsy cases suspected of shaken baby syndrome, searching for the hemorrhage and contusions at the abducens nerve entrapping points together with brain and retinae findings will support the diagnose.

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