Traumatic aneurysms and arteriovenous fistulas of intracranial vessels associated with penetrating head injuries occurring during war: principles and pitfalls in diagnosis and management

A survey of 31 cases and review of the literature

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In the early days of the war between Iran and Iraq, reports of the sudden deaths of soldiers who previously had survived a penetrating head injury suggested the possibility that a late complication, traumatic aneurysm (TA), could be the cause of this catastrophe. In response, the authors planned a prospective study to perform cerebral angiography in victims with penetrating head trauma, especially in those who had artillery shells or bone fragments passing through areas of dense vasculature. Thirty-one TAs and arteriovenous fistulas were documented. Not all of the lesions, however, were deemed appropriate for surgical intervention. Six aneurysms (19.4%) healed spontaneously and shrank or disappeared on repeated serial angiograms. The authors present their cases and discuss the incidence of TAs, their natural course and behavior, and the special problems encountered in managing these interesting and potentially fatal complications of penetrating head injuries.

KEY WORDS • traumatic aneurysm • arteriovenous fistula • brain injury • cerebral angiography • cerebral hemorrhage • missile head wound

Clinical Material and Methods

During the 9-year period spanning the Iran–Iraq conflict, approximately 1150 war victims with penetrating head wounds were referred to two major neurosurgical centers and one frontier base hospital affiliated with Tehran Medical University, and were treated by the authors. These cases comprise the material for our analysis. To provide a clear statistical analysis the cases were divided into three groups on the basis of whether the TAs were found at the time of surgery without a preoperative angiogram, following angiography performed on a random basis, or following angiography performed in selected patients. Group A included 49 patients who were treated at a frontier base hospital during a heightening of the war attacks that lasted 25 days. In these patients angiograms were performed irrespective of the site of injury and the pathway of the missiles. Angiography was performed in these cases on a random basis and without any selection. All victims were injured in the supratentorial region and no vertebral angiography was needed. The time interval to angiography in this group varied from 12 hours to 7.5 days after injury (mean interval 6 ± 1.3 days.
standard deviation (SD)). Among these victims four TAs were detected in three patients (6.1%). Angiography was performed before primary debridement of wounds in 13 cases (26.5% of victims) and after primary thorough debridement in 36 cases (73.5% of victims). Three TAs occurred in the undebrided group, whereas only one TA occurred in the debrided group of patients. Group B consisted of three cases of TAs that were resected during early debridement performed between Day 1 and 3 after injury. In these cases, no preoperative angiography was performed and the TAs were discovered incidentally by the surgeon. The TAs were located along the peripheral arterial branches around the entrance wound tract suspected by the surgeon and were resected. Group C included 27 cases of TAs and AVFs that were encountered among 470 patients selected for cerebral angiography. The main criteria for selection of these patients for arteriography were the passage of missiles through the patient’s basal and parasellar cisterns, through the Sylvian fissure and from one hemisphere to the other; that is, cases in which the shells had passed through areas of dense vasculature. In this series of patients (Group C), with the exception of one patient in whom a TA was detected incidentally 1 year after injury, the timing of the first angiogram was between Day 2 and 35 after injury (mean interval 16.2 ± 9 days).

Surgical Approaches

The policy for surgical intervention in our cases was a less aggressive one. In cases in which the entrance wound was punctate or small, penetration had occurred through the base of the skull, or the number of bone fragments was not remarkable and there was no sign of a space-occupy-

Illustrative Cases and Commentaries

Case 1

This 27-year-old air force officer was referred 36 hours after sustaining a missile injury to the left pterional region. His Glasgow Coma Scale (GCS) score was 12 on admission with an accompanying right hemiparesis. A computerized tomography (CT) scan performed at that time showed the path of the missile passing from the left pterion through the sylvian fissure toward the deep parietooccipital region with a moderate amount of contusion hemorrhage and several bone fragments. Debridement of the wound was performed on the day of admission and contused necrotic tissues and bone fragments were washed out. A control postoperative CT scan revealed only a single fragment lodged deep in the parietooccipital region. Intravenous antibiotic and oral antiepileptic medications were administered and the patient improved gradually until his GCS score reached 15. On the evening of Day 15 after admission, he suddenly deteriorated and became comatose with repeated seizures. A CT scan revealed a large left temporoparietal intracerebral hemorrhage. The patient subsequently developed a unilateral left dilated pupil, and emergency evacuation of the hemorrhage was performed through a left frontoparietal craniotomy. His pupils equalized after the operation and a carotid angiogram obtained the day after evacuation of a delayed traumatic intracranial hemorrhage, confirming a traumatic aneurysm of the middle cerebral artery along the pathway of the penetrating missile wound.
angiogram obtained the next day confirmed an M2–M3 TA as the cause of the bleeding (Fig. 1). The aneurysm was explored through the previous craniotomy. There was no obvious neck for clipping, so the aneurysm was trapped and excised. When last seen 9 years after operation, the patient remained in a vegetative state.

Comment. This was the first patient in whom we could find and confirm the origin of delayed traumatic intracerebral hemorrhage (DTICH), which may occur in soldiers with penetrating head wounds. From that time forward, to prevent such an outcome, we performed angiography in patients having an entrance pathway passing through areas of dense vasculature approximately 10 to 20 days after injury.

Cases 23 and 6

Case 23. This 17-year-old soldier was wounded in the right frontal boss by several small shell fragments passing into both frontal lobes and lodging deeply throughout the ventricles. An initial angiogram obtained on Day 11 after injury confirmed the presence of a small TA in the A2 segment (Fig. 2 left). The patient was kept under strict care in the intensive care unit (ICU) and a follow-up CT scan and angiogram obtained 8 days later showed obvious expansion in the diameter of the TA (Fig. 2 center and right). The TA was trapped and excised through a right frontal craniotomy. The patient’s postoperative course was uneventful.

Case 6. This 20-year-old soldier sustained a neck injury caused by a bullet that entered the neck after striking the buckle of his helmet strap. The bullet lodged within the upper third portion of the clivus. The patient was admitted to the ear, nose, and throat department, where he had two attacks of profuse nose bleeding, which stopped after application of posterior nasopharyngeal packing. The first four-vessel angiography performed approximately 7 days after injury yielded negative findings (Fig. 3 upper left and right). The patient was transferred to the university hospital because of rapid deterioration in the vision of both eyes with primary optic atrophy and progressive right hemi-
paresis. A CT scan obtained on approximately Day 40 after trauma showed a nonhomogeneously enhanced suprasellar mass (Fig. 3 lower left). Repeated angiography performed on Day 42 showed a giant supra- and parasellar distal extracavernous carotid aneurysm with nonfilling of the carotid tributaries in the left side (Fig. 3 lower right). Hunterian ligation of the internal carotid artery (ICA) was attempted. With the patient under general anesthesia the aneurysmal neck was dissected, and what appeared to be the ICA was ligated. The patient did not regain full consciousness after surgery; his pupils became dilated and nonreactive to light and he died 12 hours after the operation. Autopsy findings included a fractured elevated bone of the base of the skull at the left parasellar and posterior clinoid level with a traumatic tear at the wall of the extracavernous left carotid artery leading to a giant TA that compressed the optic chiasm and hypothalamus. There was no detectable intracranial hemorrhage and, unfortunately, the wrong artery—one of the duplicated external carotid arteries—was ligated.

Comment. These two cases show that a TA may not be evident in the first angiogram or can initially appear as a small aneurysm that gradually expands and becomes symptomatic either because of mass effect or its eventual rupture and resultant subarachnoid hemorrhage. These cases also reemphasize what is postulated in the literature to be the natural course of TAs, that is, gradual expansion and rupture during the 2nd to 6th weeks after injury.9,27,29,30
Case 5

This 24-year-old soldier was hit in the left frontal boss. The shell fragments passed deep into the right parietal region. Debridement of the entrance wound was performed at another center and the patient was discharged on a regimen of antiepileptic medications. He was referred to the outpatient department of one of our institutions 12 months later for further control of his seizures. Contrast enhanced CT scanning (Fig. 4a) showed a homogeneous, isodense ellipsoid midline and right parafalx lesion without any perifocal edema or mass effect. Right carotid angiography disclosed the mass to be a TA of the distal right A2 segment (Fig. 4b). This TA was excised in toto (Fig. 4c) and was identified as a false TA (Fig. 4d). The patient’s postoperative course was uneventful.

Comment. This case belies the contention that expansion and rupture during the first few weeks after trauma is the mandatory behavior of TAs; instead, a TA may be an incidental finding during evaluation for other unrelated complaints. Such TAs may be resected uneventfully, as in this case, or may be left untouched in accordance with the patient’s or surgeon’s decision.

Case 15

This 16-year-old soldier was hit by multiple small shell fragments in the left orbitofacial region. He was transferred to the university hospital after 36 hours. His GCS score was 8 on admission with a purposeful best motor response and a right hemiparesis. His left eye was ecchymotic with complete extraocular muscle palsy. No bruit was audible in auscultation of his head. A plain skull x-ray film and CT scan revealed multiple small shell fragments passing into the left parasellar and deep temporoparietal region through the ethmoidal sinuses. No space-occupying hematoma was detectable. A regimen of intravenous antibiotic and antiepileptic medications was started. The patient improved gradually over 2 weeks; his GCS score became 13 and his right hemiparesis continued. Left extraocular muscle palsy was still present and he complained of a machinelike murmur in his head. A left carotid angiogram showed a large intracavernous carotid aneurysm with a carotid cavernous sinus fistula (Fig. 5 upper). The circle of Willis appeared to be insufficient for cross circulation on angiogram. Before performing an extra- to intracranial anastomosis, it was decided to place the patient under close observation for a period of time. Two angiograms performed during the next 2 months of hospitalization revealed a complete spontaneous obliteration of the AVF and shrinkage of the intracavernous aneurysm to a small, 2- to 3-mm TA (Fig. 5 lower). The patient was readmitted 6 months later and a fourth angiogram revealed no change in the size of the intracavernous TA. He continues to be quite well and has married. His extraocular movements have improved notably.

Comment. A wait-and-see policy was adopted in this case and also in the case of TA of distal superior cerebellar artery (SCA) (Case 16, Fig. 6), in which surgical exclusion of the TA could have been dangerous because of technical difficulties in reaching the lesion or risk of surgical morbidity. In our series, spontaneous healing of TAs occurred in three cases of middle cerebral M1 TA; two cases of intracavernous carotid TA, and one case of SCA TA (Cases 14–18, and 22, shown in Table 2). The follow-up period for these patients varied from 3 to 7 years, with a mean duration of 5 years. Case 16, in which the patient had an SCA TA, is the fourth such report noted in the literature. It is the second report of a TA of the SCA caused by missile injury.

Case 27

This 20-year-old soldier was hit in the left frontotemporal region and the shell passed into the deep parietal lobe. Primary debridement of the entrance wound was performed in the frontier base hospital and the first angiogram, obtained on Day 12 after injury, showed a TA of the left middle cerebral artery (MCA) trifurcation (Fig. 7A). The patient was conscious and cooperative, with improving right hemiparesis and mild global dysphasia. He was kept under close observation in the ICU and a second angiogram, obtained 10 days later, revealed expansion of the diameter of the aneurysm (Fig. 7B). This time, however, the patient was not paretic or dysphasic and only a
right facial palsy of the central type was detectable. Close observation and conservative management of the patient with sedatives and rest continued for another 10 days. The third angiogram disclosed a remarkable shrinkage in the size of the TA (Fig. 7C) and we continued conservative management of the case. The fourth angiogram, obtained 2 weeks later, showed a reexpansion of the diameter of the aneurysm (Fig. 7D). The pros and cons of the operation were explained to the patient and his family, and with their consent the patient underwent operation through a left frontoparietal craniotomy. The aneurysm, which was seated on one of the branches of the MCA, was excised. The patient became greatly hemiparetic and aphasic just postoperatively. The hemiparesis improved notably but speech problems were still present 2 years after surgical intervention.

Comment. This case shows how difficult it is to make a decision concerning surgical intervention on a TA in a patient with borderline and/or improving neurological deficits and with location of the TA in a critical area. It has to be borne in mind that most TAs are “false aneurysms” and one may not be able to find a neck for them suitable for clipping.

Cases 12 and 26

Case 12. This 19-year-old soldier was transferred to the hospital approximately 30 hours after receiving a missile injury to the left parietal parasagittal region. Plain x-ray films and a CT scan revealed contusion and several bone chips extending at least 4 cm deep into the brain. Debridement was performed through a silver-dollar left parietal craniectomy. After evacuation of the hematoma and necrotic tissue through the wound entrance path, a careful search of the area revealed a round aneurysmal sac approximately 8 mm in diameter attached to one of the cortical arteries just beside a small impacted bone chip (Fig. 8 left). The artery holding the aneurysmal sac was excised totally. Microscopic detail of the resected specimen was compatible with that of a false TA (Fig. 8 center and right).

Case 26. This 16-year-old soldier, injured in the left temporoparietal region, was admitted to the frontier base hospital with a GCS score of 11 to 12 and mild right hemiparesis. The entrance wound was small and no leakage of cerebrospinal fluid was present. Plain skull x-ray films revealed a small shell fragment lodged within the right posterior parietooccipital region. Intravenous injections of antibiotic and antiepileptic medications were initiated. At approximately 40 hours after injury, the patient rapidly became comatose and exhibited anisocoria. A left carotid angiogram revealed two separate TAs located along one of the branches of the MCA, which were lifted upward by a huge temporoparietal intracranial hematoma (Fig. 9). An emergency temporoparietal craniotomy was performed, the hematoma was evacuated, and both TAs lying over the branches of the MCA were resected. Postoperatively, the patient’s GCS score was 8 and his pupil diameters equalized. He was transferred to a city hospital and no subsequent follow-up review was performed by our group.

Comment. These cases, and also Case 24, in which the TA was visible on an angiogram obtained 12 hours after...
missile injury (Fig. 10), show that formation of a pseudo-
aneurysmal cavity within a clot attached to the injured
wall of a vessel does not require a long period of time. As
long as the intraluminal blood circulates within this cavi-
ity, it can appear as an aneurysm on the angiogram. This
false aneurysmal cavity can be coagulated or excised dur-
ing a thorough and aggressive early debridement of the
missile pathway or obliterated gradually by a new intra-
cavitary clot formation, or it can expand gradually and
present as a catastrophic event.

Results

Incidence of Traumatic Cerebral Aneurysms

The rate of occurrence of TAs in the Group A patients,
in whom angiography was performed on a random basis,
am 
was 8.2%, varying between 2.8% in patients who under-
went full debridement before angiography and 23% in
those whose wounds were not debrided. In the Group C
patients, who were “selected” for angiography, the rate of
angiograms that proved to be positive for TA was 5.7%.
The cumulative incidence of occurrence of TAs was 6%.

Radiological Findings

In this high-risk group of victims, angiography was per-
formed as soon as possible, depending on the clinical sta-
tus of the patient and the facilities available during the war
situation. Our findings showed 11 TAs along the main
trunk of the MCA and its branches, seven TAs along the
main trunk of the anterior cerebral artery and its branches,
six TAs along the petrosal, intracavernous, and intradural segments of the ICA, four TAs along the meningeal vessels, two carotid cavernous sinus fistulas, and one TA lying along the SCA. These aneurysms were all located along the trunk of the affected vessel. No obvious neck for these aneurysms could be detected on angiography, and they exhibited an irregular contour best seen in the late phases of angiography. Regardless of when it was performed, minimal spasm was seen on angiography.

**Surgical Findings**

Very few of the TAs had a neck suitable for clipping; thus the branch of the artery harboring the aneurysm had to be trapped and resected.

**Histopathological Findings**

All of the resected TAs were of the “false aneurysm type,” consisting of an aneurysmal lumen within a partly organized clot that was attached to the wall of a partially damaged vessel.

**Statistical Analysis**

Several variables were considered in the analysis of this series of victims. To compare all the variables available for analysis, 436 patients were included.

**Site of Penetration and TA Formation.** Most injured soldiers had not been wearing helmets. This was not only because of a shortage of supplies but because most of the soldiers had not been officially trained and were volunteers coming to the battlefield only after a short course of military instruction. The incidence of TA formation was significantly higher when the site of entrance was orbitobasal (seven of 38; 18.4%) and frontal (15 of 122; 12.3%). This increased chance of TA formation in patients with orbitobasal wounds should be considered much more significant in light of the fact that most had not worn helmets to cover the frontal, parietal, and temporal regions of the scalp. Comparing this with the chance of TA formation when penetration occurs in other parts of the cranium, the ratio is statistically significant (Pearson $\chi^2 = 29.6$, df = 1, $p < 0.00001$) (Table 3).

**Thorough Debridement of the Wound and TA Formation.** Seventeen (13%) of 132 patients who had a cleaned or merely sutured entrance wound developed TAs, whereas only nine (3%) of 304 who had the entrance pathway of the missile fully debrided developed a TA. This decreased...
Traumatic aneurysms from penetrating head injuries

**TABLE 3**

<table>
<thead>
<tr>
<th>Incidence of Traumatic Aneurysm</th>
<th>Location (no. of patients)</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Positive</td>
<td>15</td>
<td>2</td>
</tr>
<tr>
<td>Negative</td>
<td>107</td>
<td>136</td>
</tr>
<tr>
<td>Total Incidence Rate</td>
<td>122/28%</td>
<td>138/31%</td>
</tr>
</tbody>
</table>

**Discussion**

The body of experience dealing with war injuries, especially brain injuries, has expanded because of the recent turmoil in the Middle East. One fatal consequence of penetrating brain injuries has been DTICH or apoplexy. Local infection, physical or physiological changes in blood vessels, and softening of the brain have each been attributed as the cause of DTICH. Histological studies of TAs have demonstrated that there are mainly three types: “true,” “false,” and “mixed.” In true TAs the normal structure of the arterial wall is disrupted but an intact layer of adventitia is preserved. In false TAs none of the layers of the arterial wall is disrupted and an intact layer of adventitia is present. The aneurysmal cavity is formed by hemo-
dynamic excavation and subsequent fibrocollagenous organization within a hematoma “clot” attached to the site of laceration of the main vessel. This aneurysmal cavity

chance of TA formation in patients who received wound debridement is statistically significant (Pearson $\chi^2 = 16.1, df = 1, p < 0.00001$) (Table 4).

**Bicompartmental Damage and TA Formation.** Sixty-eight of the patients in whom angiography was obtained had shell fragments that crossed from one compartment of the cranial cavity to another or from one hemisphere to the other (15%). Five patients from this group developed a TA. The increase in the incidence of TA in patient with bicompartmental damage is not statistically significant ($\chi^2 = 16.1$) in our series of patients.

**Appropriate Time Period for Detecting the TA Before its Rupture.** According to the literature and the findings in Group A of this study, most angiograms obtained for early detection of TA were performed within 3 weeks after injury, with the exception of one TA that was detected after 1 year (Case 20); six TAs were detected on Day 10 postinjury (23%), three TAs on Day 1 (11.5%), and three on Day 5 postinjury (11.5%). This increased chance of early detection of TAs in the first 10 days after injury (Pearson $\chi^2 = 1.75, df = 4, p < 0.00001$) can be considered significant and we suggest that this period is the proper interval in which angiography should be performed in patients with penetrating head wounds and a high risk for development of TAs.

**TABLE 4**

<table>
<thead>
<tr>
<th>Incidence of Traumatic Aneurysm</th>
<th>Wound Debrided</th>
<th>Wound Not Debrided</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Positive</td>
<td>9</td>
<td>17</td>
<td>26/6%</td>
</tr>
<tr>
<td>Negative</td>
<td>295</td>
<td>115</td>
<td>410/94%</td>
</tr>
<tr>
<td>Total</td>
<td>304/69.7%</td>
<td>132/30.3%</td>
<td>436/100%</td>
</tr>
</tbody>
</table>

The results of angiography performed in our series prompts us to suggest indications for performing angiography in a group of patients deemed “high risk” for developing TAs. These indications are: 1) passage of missile or bone fragments through areas of crowded vasculature and/or through the skull base, that is, through Reil’s triangle or from one hemisphere to the other; 2) a remarkable amount of hematoma within the entrance pathway that is visible on the predebridement CT scan; 3) multiple shells or bone fragments scattered in paths that branch into various directions; and 4) the surgeon’s high index of suspicion based on observations during early debridement of the entrance wound and gutter. On this basis, the average occurrence rate of TAs in the last group of patients was 5.7%, a number we believe to be a well-substantiated and acceptable incidence of TAs after penetrating missile injuries according to the literature. The appropriate time for performing angiography to locate a TA is during the first 10 days after injury ($p < 0.00001$). Angiography should be performed as soon as possible after encountering a high-risk patient.

Histological studies of TAs have demonstrated that there are mainly three types: “true,” “false,” and “mixed.” In true TAs the normal structure of the arterial wall is disrupted but an intact layer of adventitia is preserved. In false TAs none of the layers of the arterial wall is present. The aneurysmal cavity is formed by hemo-
dynamic excavation and subsequent fibrocollagenous organization within a hematoma “clot” attached to the site of laceration of the main vessel. This aneurysmal cavity
is in communication with the lumen of the main vessel. When a true TA ruptures and a newly formed clot is reshelved into a false TA located beside the previous one, this complex is called a mixed type of TA.

All of the TAs we observed were of the false type according to either the histopathological or the angiographic and surgical points of view. In our series, the primary angiographic characteristics of TAs were that: 1) they were usually located along the harboring vessel and not over the branching points; 2) they usually had an irregular contour; 3) the false neck of the aneurysms could be seemingly well identified on angiography; 4) they usually remained opaque in later phases of angiography; and 5) their rate of angiospasm was much less than in berry aneurysms, even after bleeding.

Surgery to treat TAs is a difficult challenge because they usually do not have a neck that is suitable for clipping. Traumatic aneurysms should either be excluded from the main circulation by means of a trapping procedure or they should be coagulated. In case the harboring vessel is a major artery, coating the aneurysm with muscle or fibrin glue or excision of the TA after extracranial or intracranial bypass might be the preferred method of surgery.

Very early formation of TAs after penetrating head injuries has been mentioned in anecdotal case reports. Such TA formation has been reported to occur 4 hours after injury and was seen by the surgeon but the TA was not resected. The aneurysm formation became evident on angiography performed 2 days later. Another report described an early TA formation in a choroidal artery, which was caused by a radio antenna puncture wound. This TA was detected on an angiogram obtained within 24 hours after trauma. Based on our findings (Cases 10–12 and 24–26), we suggest that any lesion resembling a partly organized clot or TA that is attached to a hemispheric branch of an artery and/or beside an impacted missile or bone fragment visible during early debridement of a penetrating head wound should be resected and studied by a pathologist. We were able to detect small bone chips attached to the wall of a TA in at least five of our cases (Cases 2, 5, 6, 9, and 22). When a TA is found during very early angiography (Cases 3, 6, 7, 15–18, and 22) and the harboring vessel is cortically located or is in a safe and accessible location, surgical intervention and resection of the TA will prevent a catastrophe. However, the dilemma arises when the TA is situated on a main cerebral artery that perfuses an eloquent area of brain or when it is located in a deep, inaccessible part of the brain and the patient is asymptomatic. Endovascular techniques have not yet been used in such cases and we do not believe that the traumatized and fragile wall of a TA could tolerate the insertion of an endovascular balloon. In the event it did not, a premature rupture could lead to a catastrophe. Considering the characteristics of Cases 14–18 and 22 and bearing in mind the incidental finding of an asymptomatic TA as long as 10 years after a penetrating head injury, we suggest that immediate surgical intervention may not be mandatory and inevitable in some of these cases. Keeping the patient under strict ICU care with continuous intracranial pressure monitoring and performing follow-up angiography at regular intervals up to 6 to 8 weeks can be an alternative mode of management. There was an incidence rate of 19.4% (six of 31) spontaneous healing or disappearance of TAs on angiograms in our series. If healing has not occurred, alternate surgical modalities should be undertaken.

**Summary**

We have reported 31 cases of TAs and AVFs of intracranial vessels secondary to missile injury and reviewed the relevant literature. Considering the mysterious and variable natural course and behavior of TAs, we suggest that the rate of their occurrence may be higher than the 5.7% specified in this report as the acceptable rate of occurrence. The potentially devastating outcome of TAs mandates early angiography in patients deemed at high risk, the characteristics of whom have been categorized. Surgical excision is suggested as the definitive treatment. However, a 19.4% chance of spontaneous healing with conservative management supports this mode of therapy in individuals who are not good candidates for surgical intervention.

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Traumatic aneurysms from penetrating head injuries


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