ORIGINAL ARTICLE

Features of epidural hematoma in 61 patients

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Summary

Introduction: Very few studies address meningeal artery (MMA) histology, including some features of epidural hematomas (EDH).

Materials and Methods: We microscopically analyzed 238 slices from ten MMA specimens. In addition, 61 patients with EDH were enrolled and examined. Both analyses were retrospective.

Results: MMA analysis showed a larger subendothelial space and reduced media and adventitial coat, the latter continuous with the two dural parts (periosteal and meningeal layers). The 61 patients had an average age of 42.1 years. The EDH averaged 28.8 mm in diameter, but it did not affect outcomes (p=0.626). Vault bone fracture was seen in 95.1% of patients. An incidental fall was the most frequent cause (68.5%). Coma was present in 35.0%, whilst the Glasgow Coma Scale (GCS) on admission averaged 12. EDH was associated with other intracranial hemorrhages (19.7%), including subdural (9.8%), subarachnoid (4.9%), intracerebral (1.7%), or combinations thereof. Following EDH surgical evacuation, some patients had certain neurological or psychological disorders (19.7%). The mortality rate was 14%, especially in patients manifesting early neurologic symptoms (p=0.034).

Conclusion: The MMA is well protected due to its structure and dural support. However, a strong head impact, especially associated with a bony fracture, leads to MMA rupture and a dural laceration resulting in EDH. The latter can be accompanied by neurological signs, as well as a mortality rate of 14%, which mainly depends on early neurological manifestation or coma occurrence.

Keywords: middle meningeal artery, dura mater, epidural hematoma, brain trauma

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INTRODUCTION

The middle meningeal artery (MMA), originating from the maxillary artery, enters the skull and courses, along with its branches and accompanying veins, across the middle cranial fossa, then over the squamous parts of the greater wing, and the temporal and parietal bones (1,2). Its terminal division comprises the anterior and posterior stems.

MMA anatomy has been described in detail by many authors (2-5). However, few studies have described the histological features of this artery, which underlie epidural hematoma (EDH) (6-8). The opposite is true regarding the MMA relationship with the dura mater (9-13). In contrast, the literature mentions or omits some data on EDH (14-29).

Several important points stand out. First, examining the MMA structure and its relationship to the dura mater and inner bony table is clinically important. Also, comparing the obtained data with radiological findings in patients with EDH is very useful. Finally, correlating hematoma location, size, time of operation, and patient outcome is also important. These were the main reasons for our study.

MATERIAL AND METHODS

Histological examination

During 32 routine autopsies, we took 10 pieces of the MMA, 5 mm in size, and the adjacent temporal or parietal bone just distal to the foramen spinosum and in the pterion region, from individuals aged 12 to 82. We randomly selected these patients between February 2019 and June 2019, so our examination was retrospective. None of the individuals were from the Neurosurgical Clinic. We immediately fixed each of the 10 specimens in 10% formaldehyde solution, then decalcified, sectioned into 238 slices 5 μm thick, and stained with hematoxylin and eosin (H&E). We examined the sections under an Olympus BX-41 light microscope.

Patients

We enrolled 61 patients with EDH at the Clinic of Neurosurgery, of various ages, mostly males. We enrolled patients from May 15, 2024, to November 15, 2024, making this a retrospective study.

All patients provided written consent, with permission from the authorities of the Institute of Anatomy and the Institute of Pathology, particularly the Clinic of Neurosurgery.

We examined all patients neurologically and radiologically using computerized tomography (CT). Each patient was operated on after a burr hole or craniotomy, most often in the temporal and pterion region. The surgeon evacuated the EDH by aspiration and cauterized the injured MMA or its branches.

Radiological examination

All patients were examined in a Siemens Somatom Definition AS 128-slice scanner: rotation time 0.5 s, pitch 0.5, slice thickness 0.6 mm, 120–140 kV interval, manual 260 mA, noise index 3. EDH was diagnosed in all patients.

Statistical analysis

Numerical variables are presented as mean ± standard deviation or as median (range), depending on data distribution. We evaluated normality using mathematical (Shapiro-Wilk test) and graphical (histogram and box-plot) methods. Categorical variables are expressed as counts and percentages. We assessed differences between groups using the Chi-square test, the independent-samples t-test, and the Mann-Whitney U test. We used Kaplan–Meier analysis to estimate cumulative survival during the follow-up period. For deaths, we recorded the event time; for censored observations without a fatal outcome, we used the last follow-up time. Standard errors and 95% confidence intervals were calculated where appropriate. We descriptively assessed differences in survival probabilities over time. We used univariate Cox regression to identify predictors of mortality. We defined statistical significance as a two-sided p-value < 0.05. All statistical analyses were performed using IBM SPSS Statistics software, version 29 (IBM Corp., Armonk, NY, USA).

RESULTS

Histological features of the MMA and the dura

In transverse sections of the MMA, or its divisions, three standard layers were noted: the intima (inner) coat, the middle (media) layer, and the outer (adventitial) coat **(Figure 1)**. The intima consisted of endothelial cells; the large subendothelial space contained rare smooth muscle elements, other cells, and some extracellular matrix with collagen fibers. There was also a wavy internal elastic lamina **(Figure 1)**.

The media coat consisted of several layers of parallel smooth muscle cells with elongated nuclei **(Figure 1)**. The media coat was reduced compared with that of other muscular arteries (personal observation), especially in some cases **(Figure 1)**. The adventitial coat, which was mainly built of fibroblasts, collagen bundles, and small vasa vasorum (Figure 1), was also somewhat thinner than in other muscular arteries.

The dura mater consisted of two main connective tissues made of collagen fibers and rare fibroblasts: the outer (periosteal) and inner (meningeal) membranes.

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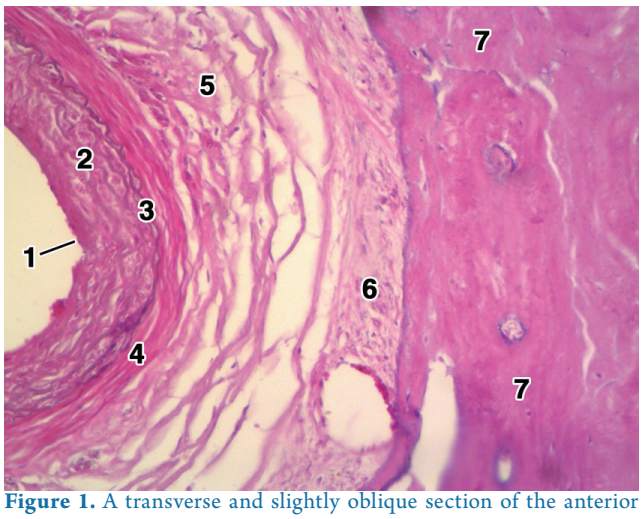


Figure 1. A transverse and slightly oblique section of the anterior branch of the middle meningeal artery. Note the endothelial lining (1), the fibrous subendothelial space (2), and the internal elastic lamina (3). Also note the reduced media (4) and adventitia (5), the periosteal dural layer (6), and the inner table of the parietal bone (7). (H&E. Original magnification × 40).

Table 1. Demographic, clinical, radiological and temporal variables

Variable	n(%)
Age (years)*	42.1 ± 19.8
Gender	
Male	49(80.3)
Female	12(19.7)
Early neurologic symptoms	
Present	39(63.5)
Absent	22(36.5)
GCS at admission*	12(3–15)
Time from injury to symptom onset (min)*	0(0–1110)
Time from symptom onset to surgery (min)*	351(110–1399)
Total time from injury to surgery (min)*	426(110–1399)
Clinical presentation	
Coma	21(35.0)
Concussion syndrome	16(26.7)
Headache	10(16.7)
Headache with concussion syndrome	7(11.7)
Sopor	6(10.0)
Mydriasis	16(26.2)
CT imaging findings	
Skull fracture	58(95.1)
Subdural hematoma	6(9.8)
Cerebral contusions	37(60.7)
EDH size (mm)*	28.08 ± 8.75
Mechanism of injury	
Fall	41(68.5)
Traffic accident	14(24.1)
Other	6(7.4)
GCS postoperative*	15(3–15)
Treatment outcome	
Survival	49(86.0)
Mortality	8(14.0)

*Continuous data are presented as mean ± SD or median and range.

The former layer was continuous with the adventitia of the MMA (**Figure 1**). At the same time, it was more or less firm with the inner table of the greater wing and the squamous part of the temporal and parietal bones. The MMA, along with the accompanying veins, is intradural. The potential epidural space lies between the periosteal layer and the inner bony table of the skull.

Patients with epidural hematomas

The 61 enrolled patients averaged 42.1 years of age; only 19.7% were female, and the rest were male (80.3%) (**Table 1**), with no statistical significance (p=0.686 and 0.941). EDH averaged 28.8±8.75 mm in transverse diameter. Its size did not differ between patients with a fatal outcome and survivors (p=0.626).

EDH can occur in different locations: temporal, frontal, parietal, occipital, or combined (**Figure 2**). A cranial fracture was seen in 95.1% of patients. The most frequent cause was an incidental fall (68.5%), followed by car or motor accidents (24.1%), and, less frequently, fights, explosions, or unknown causes (7.4%) (**Table 1**).

Early neurological symptoms appeared in 63.5% (p=0.034). EDH was usually associated with symptoms involving consciousness and similar alterations: headache or confusion (16.7%), concussion syndrome (26.7%), sopor (10.0%), and coma (35.0%), with coma being highly significant (p<0.001) (**Table 2**). Concussion syndrome was observed exclusively among patients with non-lethal outcomes (p=0.016). In addition, headaches and concussion syndrome were rarely combined (11.1%) (**Table 1**), as were agitation and motor deficits. Cerebral contusion was often present (60.7%). The Glasgow Coma Scale (GCS) on admission averaged 12. The time interval from injury to symptom onset was statistically significant (p=0.05) (**Table 2**).

As regards the EDH complications, it can be associated with some other intracerebral hemorrhages, e.g. subdural (9.8%), subarachnoid (4.9%), intracerebral (1.7%), or combined.

The mortality rate was 14.0%. Mortality was significantly more frequent among patients presenting with early neurological symptoms (p=0.034), as well as when the time interval from injury to symptom onset was shorter (p=0.050). A coma was strongly associated with mortality (p<0.001) (**Table 2**).

No significant associations with mortality were observed for sex, age, GCS at admission, headache, sopor, mydriasis, skull fracture, subdural hematoma, brain contusion, mechanism of injury, time interval from symptom onset to surgery, total time from injury to surgery, or postoperative Glasgow Coma Scale scores. Finally, survival probability declined somewhat during the first 60 days, mainly postoperatively (**Graph 1**).

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Table 2. Association between demographic, clinical, radiological and temporal variables with mortality

Variable	Outcome: n(%)		*p* value**
Variable	Survived (n=49)	Died (n=8)	
Sex			
Female	9 (18.4)	1 (12.5)	0.686
Male	40 (81.6)	7 (87.5)	0.686
Age	42.57 ±19.09	43.13 ± 21.50	0.941
Early neurological symptoms	23 (54.8)	7 (100.0)	**0.034**
GCS at admission*	12(3–15)	6 (3–13)	0.069
Time from injury to symptom onset (min)*	0 (0-1110)	0 (0-20)	**0.050**
Time from symptom onset to surgery (min)*	351(110–1399)	392.5 (130–884)	0.756
Total time from injury to surgery (min)*	442(110–1399)	392.5(130–884)	0.625
Headache	16 (33.3)	1 (12.5)	0.235
Concussion syndrome	23 (47.9)	0 (0.0)	**0.016**
Sopor	6 (12.5)	0 (0.0)	0.290
Coma	10 (20.8)	7 (87.5)	**<0.001**
Mydriasis	13 (26.5)	3 (37.5)	0.522
Skull fracture	47 (95.9)	8 (100.0)	0.561
Subdural hematoma	4 (8.2)	2 (25.0)	0.150
Brain contusion	30 (61.2)	5 (62.5)	0.945
EDH size (mm)*	26.49±7.43	28.75±12.25	0.626
Mechanism of injury			
Fall	27 (62.8)	7 (87.5)	0.173
Traffic accident	12 (27.9)	1 (12.5)	0.359
Other	4 (9.3)	0 (0.0)	0.369
GCS postoperative*	15 (3–15)	15 (3–15)	0.521

*Continuous data are presented as mean ± SD or median and range. **for the level of significance of 0.05 according to chi square test, Student t-test or Mann-Whitney test where appropriate

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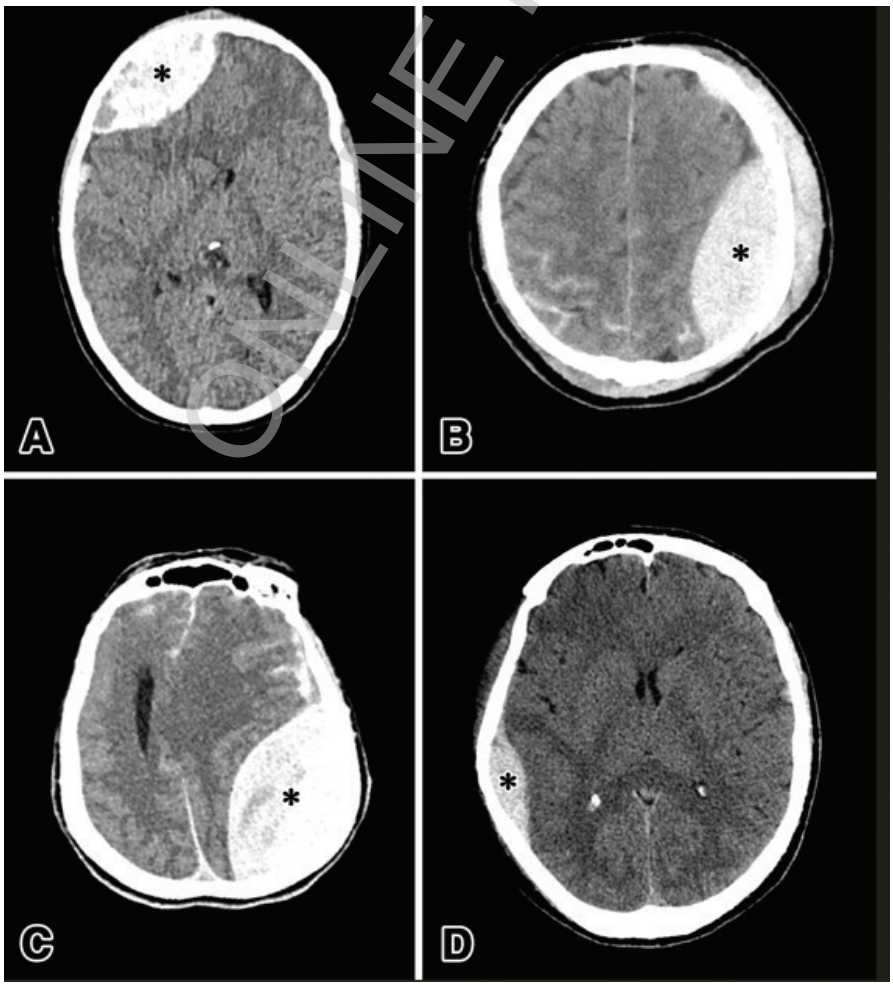
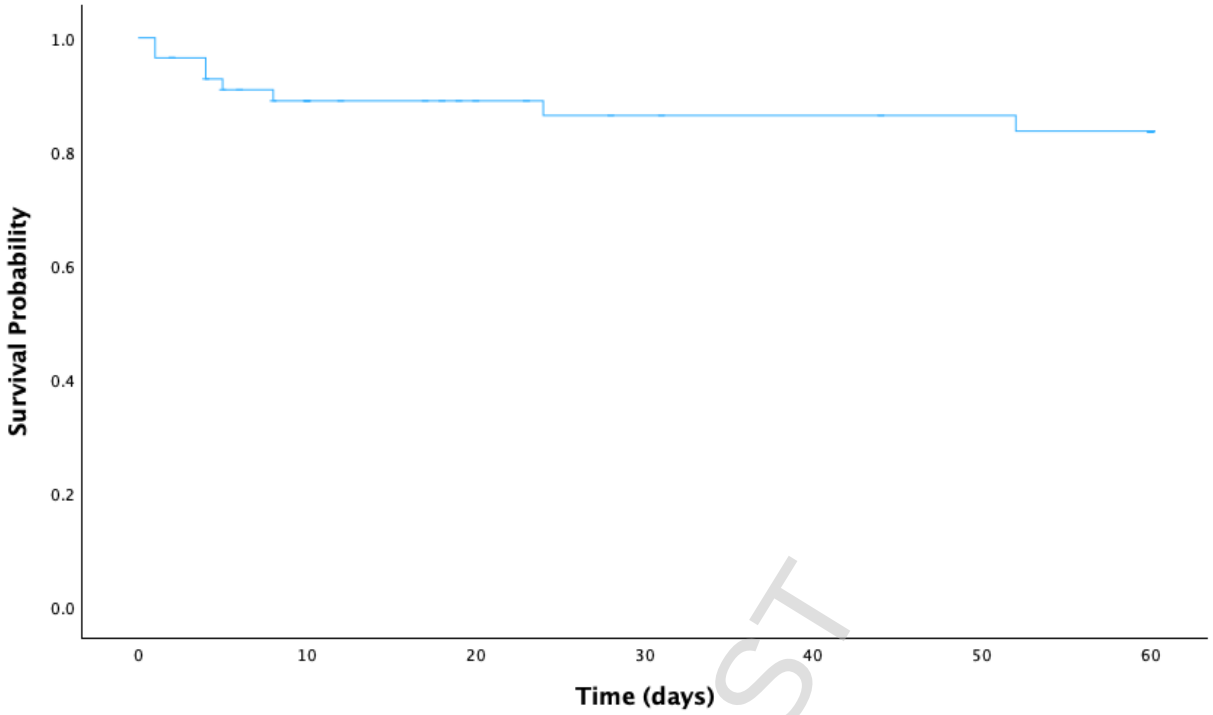


Figure 2. Axial CT scans showing a frontal epidural hematoma (*) (**A**), a frontoparietal hematoma (**B**), a large parieto-occipital hematoma (**C**), and a small temporal epidural hematoma (**D**).



Graph 1. Kaplan–Meier estimate of overall survival during follow-up

We performed univariate Cox proportional hazards regression to identify potential predictors of outcome. The analysis included demographic characteristics, clinical presentation, mechanism of injury, radiological findings, and time-related variables associated with symptom onset and surgical treatment. The results demonstrated that coma at admission was the only statistically significant predictor of adverse outcome ($p = 0.004$). Patients who were in coma had a 26.6-fold higher risk of mortality compared with those who were not in coma (OR = 26.600; 95% CI: 2.924–242.005). None of the other analyzed variables were significantly associated with the outcome. These included sex ($p = 0.775$), age ($p = 0.963$), time from injury to symptom onset ($p = 0.267$), time from symptom onset to surgery ($p = 0.978$), and total time from injury to surgery ($p = 0.527$). Clinical symptoms such as headache ($p = 0.260$), concussion syndrome ($p = 0.180$), and mydriasis ($p = 0.525$) did not significantly affect outcomes. Likewise, radiological parameters, including subdural hematoma ($p = 0.231$), brain contusion ($p = 0.851$), and epidural hematoma size ($p = 0.446$), were not statistically significant predictors. The mechanism of injury, whether fall or traffic accident, was also not significantly associated with outcome ($p = 0.279$ and $p = 0.393$, respectively). Glasgow Coma Scale (GCS) score at admission and postoperative GCS showed a non-significant trend toward a protective effect, but did not reach statistical significance ($p = 0.117$ and $p = 0.386$, respectively) **(Table 2)**.

DISCUSSION

We will first discuss the features of the MMA and the dura mater, then the EDH pathomechanism, its development, incidence, trauma, other causes, accompanying consequences and complications, location, size, symptoms, CT findings, neurosurgery, mortality, and outcome.

As for the MMA, other authors also noted its three typical coats (6-8). Some also observed a reduction of the media and adventitial coat, but did not mention a large subendothelial space for unknown reasons. The adventitial coat was continuous with the dural periosteal layer, which was a thin membrane covering the osseous inner table (9-13).

The MMA is classified as a muscular artery (1), which is consistent with our findings. However, it had an enlarged subendothelial space with certain cells and collagen fibers, a reduced media with smooth muscle cells, and a thinner fibrous adventitial coat.

The dura mater consisted mainly of a periosteal (endosteal) layer and a meningeal layer (9-13), which are fused (12). The MMA, its branches, and accompanying veins course between the periosteal and meningeal dural layers **(Figure 1)**. The periosteal layer, 0.12 mm in thickness (12), covers the bony inner table (Figure 1). The epidural space is more or less a virtual compartment between the periosteal dural layer and the inner osseous table, as noted in our study and other articles (1,8,15).

As regards a pathophysiological mechanism following a cranial trauma, an MMA pseudoaneurysm or arteriovenous fistula can develop (15,30,31), rarely a subdural bleeding, but more often an epidural hematoma (27,29). Because an MMA is weaker than the corresponding arteries and the periosteal dural layer is only 0.12 mm thick (12), traumatic MMA injury causes bleeding from laceration of the thin periosteal layer and MMA rupture, so blood enlarges and fills the epidural space (17). Bleeding is mainly caused by a fracture of a vault bone, rarely by blunt trauma with no fracture, or by a penetrating injury (17,20,26). In any case, an epidural hematoma associated with a fracture occurs in up to 85% of these cases (20), which is lower than in our patients (95.1%). Obviously, trauma was much stronger in our patients.

EDH develops in 8-19% of patients following head trauma, predominantly in males (76%) averaging 41 years of age (23). In our 61 patients, the main cause of EDH was an incidental fall (87.5%), and rarely car or motor accidents,

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aggression, or unknown causes. However, some articles report the most common causes as road traffic incidents, physical assaults, and accidental falls (15,17,23). This could probably be explained by certain inappropriate behavior of some people, or frequent alcohol abuse in our population.

EDH in our patients can be associated with other intracranial hemorrhages, subdural (9.8%), subarachnoid (4.9%), intracerebral (1.7%), or combined, similar to other cases (23). Midline shift and tentorial herniation are also possible.

The temporal region is a common location (15), as noted in our study. The frontal region, as well as the parietal and occipital areas, or their combinations, can also be affected (Figure 2) (15,23,24) because certain MMA branches are involved. EDH can occur ipsilaterally, and rarely bilaterally, or contralaterally (32).

High MMA pressure from extravasated blood first causes a smaller hematoma (28). Some of them could be treated conservatively or by MMA embolization. However, at least 65% of EDHs become larger hematomas within the following 24 hours, and rarely within 48 hours or later (20,28). They can exceed 10 cm in thickness and more than 150 mL in volume (24,27). In our group, the mean EDH diameter was 2.88±0.875 cm, ranging from 1.2 cm to 5.2 cm in transverse diameter. In most patients, a thickness over 1.5 cm (i.e., a volume over 30 mL) indicates the need for prompt neurosurgical intervention (23, 28). In addition, EDH compresses the ipsilateral cerebral hemisphere and often causes midline shift (28), as noted in some of our patients. For these reasons, we evacuated the hematoma in all patients.

A nontraumatic rupture of the MMA also may occur, either spontaneously or iatrogenically (21). In any case, a neurosurgical intervention is the technique of choice in such patients (25,34).

Early neurological symptoms appeared in 63.5% of our patients, consistent with other reports (23). A consciousness disorder may appear, which can be associated with nausea, vomiting, headaches, and certain neurological signs (23). Glasgow Coma Scale (GCS) on admission ranged from 3 to 15 (mean, 12).

Mortality was significantly more frequent among patients presenting with early neurological symptoms (p=0.034), or when the time interval from injury to symptom onset was shorter in patients with a fatal outcome (p=0.050). A coma was strongly associated with mortality (p<0.001). Other authors confirmed this (23,29), but reported mortality rates of up to 10% (15), which is somewhat lower than in our patients (14%). Some of the reasons could be a delayed EDH diagnosis in our patients, or their failure to visit a medical institution due to a longer lucid interval (23,33). The lucid interval itself can be absent, or present for a shorter or longer period (15,33).

Following a lucid interval, commonly a rapid neurological deterioration occurs to a vegetative or comatose state (15). If an urgent hematoma removal is not performed, downward transtentorial herniation will develop (15,26). This is why most EDH operations are among the most urgent interventions in neurosurgery.

In general, computerized tomography, including CT angiography, is superior and much faster than magnetic resonance imaging (MRI) for EDH visualization. A CT shows a characteristic biconvex hematoma, most often in the temporal region, which may compress and displace the brain parenchyma (26,28). We always performed CT examinations in patients with suspected EDH.

In any case, neurosurgical intervention for an early epidural hematoma larger than 30 mL is recommended (25,34). It consists of standard hematoma evacuation and hemostasis (i.e., cauterization). Minimally invasive techniques can also be applied (23).

The outcome mainly depends on the EDH type and the time of symptom onset (23,24). Thus, isolated EDH, which usually occurs in younger patients, has a better prognosis than multiple EDHs. The latter can be combined with ventricular compression or hemorrhage, including subdural, subarachnoid, intracerebral, or combined bleeding. In isolated EDH, the mortality was very low or zero, but much higher in the latter group (23). Overall, the mortality rate is up to 10%, e.g., 136,000 patients annually in the USA and Europe combined (15). This is somewhat lower than in our patients (14%), especially in those with early signs or in coma. In any case, if an EDH is surgically removed promptly, the outcome is usually very good.

CONCLUSION

MMA has a normal intima coat, but a larger subendothelial space and reduced media and adventitial coats. The artery is located between the periosteal and meningeal layers of the dura mater. EDH occurs between the periosteal layer and the inner table of the cranial bones. It can cause altered consciousness and other neurological signs, often following a short or long lucid interval. Surgical evacuation of EDH and MMA cauterization are the treatment of choice. The mortality rate in our patients is 14%.

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Author contributions: Conception and design: IM, MM, SM; Data collection: BGB, AN, ZN, SM; Statistical analysis: IM; Writing the article: IM, BGB, SM; Critical revision of the article: IM, BGB, SM; Final approval of the article: IM, MM, AN, ZN, BGB, SM. All authors reviewed and approved the final version of the manuscript and agreed to be accountable for all aspects of the work.

Ethical approval: The Ethics Committee of the Clinical Center of Serbia approved the study under decision No. 635/18 dated June 25, 2026.

Informed consent: N/A

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OSOBINE EPIDURALNOG HEMATOMA KOD 61 PACIJENTA

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Sažetak

Uvod: Veoma su retki radovi koji se bave histologijom srednje moždanične arterije (MMA), uključujući i neke osobine epiduralnih hematoma (EDH).

Materijal i metod: Mikroskopski je analizirano 238 isečaka od 10 uzoraka MMA-e. Uz to, ispitan je 61 pacijent sa EDH-om. U oba slučaja izvršena je retrospektivna studija.

Rezultati: Analiza MMA-e pokazuje veći subendotelni proctor, a redukovani su medija i adventicijalni omotač, koji je kontinuiran sa dva dela dure, tj. periostealnim i meningealnim slojem. Prosečna starost 61 pacijenta bila je 42,1 godina. EDH je imao prečnik od 28,8 mm, ali to nije uticalo na ishod (p=0.626). Fraktura kostiju krova lobanje viđena je u 95.1% pacijenata, najčešće u onih mlađih od 50 godina. Slučajni pad bio je najčešći uzrok (68,5%). Koma je postojala u 35.0%, dok je Glazgov skala kome (GCS) na prijemu bila prosečno 12. EDH je bio udružen sa drugim intrakranijalnilm hemoragijama u 19.7%, bilo sa subduralnim (9.8%), subarahnoidalnim (4.9%), intracerebralnim (1.7%) ili sa njihovim kombinacijama. Nakon hirurškog uklanjanja EDH-a, neki pacijenti imali su određene neurološke ili psihološke poremećaje (19.7%). Mortalitet je bio 14%, naročito kod osoba koji su ispoljavali rane neurolške simptome (p=0.034).

Zaključak: MMA je, zahvaljujući građi i potpori dure, dobro zaštićena. Međutim, jak udarac u glavu, naročito kad je udružen sa frakturom kosti, dovodi do rupture MMA-e i laceracije dure, što rezultuje EDH-om. On može biti praćen neurološkim znacima, kao i mortalitetom od 14%, što uglavnom zavisi od pojave ranih neuroloških manifestacija ili kome.

Ključne reči: arteria meningea media, dura mater, epiduralnil hematom, trauma mozga

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