ORIGINAL ARTICLE

Bipolar Electrocoagulation on Cortex after AVMs Lesionectomy for Seizure Control

Yong Cao, Rong Wang, Lijun Yang, Qin Bai, Shuo Wang, Jizong Zhao

ABSTRACT: ***Background:*** The findings of previous studies remain controversial on the optimal management required for effective seizure control after surgical excision of arteriovenous malformations (AVMs). We evaluated the efficacy of additional bipolar electrocoagulation on the electrically positive cortex guided by intraoperative electrocorticography (ECoG) for controlling cerebral AVMs-related epilepsy. ***Clinical Material and Methods:*** Sixty consecutive patients with seizure due to cerebral AVMs, who underwent surgical excision of cerebral AVMs and intraoperative ECoG, were assessed. The AVMs and surrounding hemosiderin stained tissue were completely removed, and bipolar electrocoagulation was applied on the surrounding cerebral cortex where epileptic discharges were monitored via intraoperative ECoG. Patients were followed up at three to six months after the surgery and then annually. We evaluated seizure outcome by using Engel's classification and postoperative complications. ***Results:*** Forty-nine patients (81.6%) were detected of epileptic discharges before and after AVMs excision. These patients underwent the removal of AVMs plus bipolar electrocoagulation on spike-positive site cortex. After electrocoagulation, 45 patients' epileptic discharges disappeared, while four obviously diminished. Fifty-five of 60 patients (91.7%) had follow-up lasting at least 22 months (mean 51.1 months; range 22–93 months). Determined by the Engel Seizure Outcome Scale, 39 patients (70.9%) were Class I, seven (12.7%) Class II, five (9.0%) Class III, and four (7.2%) Class IV. ***Conclusion:*** Even after the complete removal of AVM and surrounding gliotic and hemosiderin stained tissue, a high-frequency residual spike remained on the surrounding cerebral cortex. Effective surgical seizure control can be achieved by carrying out additional bipolar electrocoagulation on the cortex guided by the intraoperative ECoG.

RÉSUMÉ: Électrocoagulation bipolaire sur le cortex après excision de malformations artérioveineuses pour contrôler les crises convulsives. ***Contexte :*** Les observations faites lors d'études antérieures sur le traitement optimal requis pour obtenir un contrôle efficace des crises convulsives après résection chirurgicale de malformations artérioveneuses (MAV) demeurent un sujet de controverse. Nous avons évalué l'efficacité de l'ajout de l'électrocoagulation bipolaire sur le cortex électriquement positif, guidé par électrocorticographie (ECoG) pour le contrôle de l'épilepsie reliée aux MAV cérébrales. ***Méthodes :*** Soixante patients consécutifs atteints de crises convulsives dues à des MAV cérébrales, qui ont subi une excision chirurgicale d'une MAV cérébrale avec ECoG pendant l'intervention, ont été évalués. Les MAV et le tissu avoisinant teinté d'hémosidérine ont été complètement excisés et une électrocoagulation bipolaire a été appliquée sur le cortex cérébral avoisinant où des décharges épileptiques étaient observées par ECoG pendant l'intervention. Les patients ont été revus entre trois et six mois après la chirurgie et annuellement par la suite. Nous avons évalué le résultat obtenu au moyen de la classification des crises convulsives de Engel ainsi que les complications postopératoires. ***Résultats :*** Des décharges épileptiques ont été détectées avant et après l'excision de la MAV chez 49 patients (81,6%). Ces patients ont subi une excision de l'AMV et une électrocoagulation bipolaire du cortex où des pointes étaient détectées. Après l'électrocoagulation, les décharges épileptiques ont disparu chez 45 patients et ont diminué de façon évidente chez 4. Cinquante-cinq des 60 patients (91,7%) ont été suivis pendant au moins 22 mois (moyenne 51,1 mois ; écart de 22 à 93 mois). Selon la Engel Seizure Outcome Scale, 39 patients (70,9%) ont été assignés à la classe I, 7 (12,7%) à la classe II, 5 (9,0%) à la classe III et 4 (7,2%) à la classe IV. ***Conclusion :*** Une pointe résiduelle à haute fréquence était présente sur le cortex cérébral avoisinant, même après l'excision complète de la MAV, du tissu glial et du tissu avoisinant teinté d'hémosidérine. Un contrôle chirurgical efficace des crises peut être obtenu en effectuant une électrocoagulation bipolaire guidée par l'ECoG sur le cortex pendant l'intervention.

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Intracranial arteriovenous malformations (AVMs) are congenital vascular abnormalities that typically present with hemorrhage, seizures, headaches or neurological deficits. The incidence of patients with AVMs presenting with seizures without clinical evidence of hemorrhage varies between 17% and 40%.[1,2] Previously published surgical series reported varying rates of successfully controlling epilepsy after surgical excision of AVMs. Consensus on the electrophysiological approach for AVMs-related epiepsy has not yet established. [3-11] Bipolar electrocoagulation on cortex guided by intraoperative electrocorticography (ECoG) was proved to improve the treatment of intractable epilepsy.[12] In this study, we treated 60 consecutive patients with cerebral AVMs-seizure by

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Table 1: Seizure type correlated with location of AVM in 60 patients

Location of AVM	No.of Cases	partial seizure		generalized seizure	
		simple	complex	primary	secondary
Frontal	12	2	1	4	5
Temporal	22	2	2	9	9
Parietal	5	1	1	2	1
Occipital	6	0	1	4	1
Multilobular	15	1	1	5	8
Totals	60	6	6	24	24

lesionectomy plus bipolar electrocoagulation on cortex, guided by intraoperative ECoG and evaluated the results of postoperative long-term seizure control.

Clinical Material and Methods

Sixty consecutive patients with seizure due to cerebral AVMs were enrolled in this study. They were 40 males and 20 females, age ranged from 9 to 66 years. All patients were surgically treated at Department of Neurosurgery of Beijing Tiantan Hospital, affiliated to Capital Medical University, Beijing, China, from April 2003 to July 2008. The Human Research and Ethics Committee at our hospital approved the study. Patients with infratentorial and dural AVMs were excluded.

In 44 cases, epilepsy was the initial symptom (73.3%); Simultaneous cerebral hemorrhage from cerebral AVMs occurred in seven cases (11.7%) as an initial symptom, all seven patients developed epilepsy later (five hours to ten years); In six patients (10%) headache was the initial symptom, later epilepsy developed. Three patients (5%) initially presented with neurological impairment, with seizure onset one to five years later. Prior to surgery at our department three patients underwent radiotherapy for AVMs.

All patients underwent a neurological examination, magnetic resonance imaging, four-vessel digital subtraction angiography (DSA), and/or computerized tomography (CT) of brain before and after the surgery. Among them, 36 patients had right-side AVMs, 24 had left-side AVM. The diagnosis of cerebral AVMs was confirmed by cerebral angiograms and postoperative histopathology. Location of AVMs and Spetzler-Martin classification are showed in Table 1 and Table 2. Nineteen patients' AVMs involved eloquent brain.

Table 2: Distribution of the AVMs' Spetzler-Martin classification

Spetzler-Martin classification	No. of cases
Grade I	5
Grade II	49
Grade III	6
Totals	60

To determine the seizure semiology, detailed histories were taken from the patients and their relatives. Diagnosis of epilepsy relied on the patients' presentation. Six patients had simple partial seizures; six had complex partial seizures; 24 had simple/complex partial seizures with secondary generalization; 24 had generalized seizure only (Table 1). The duration of seizure history varied from six months to 30 years (mean: 18 months). Eight patients (13.3%) suffered a single initial seizure with or without hemorrhage before surgery. Forty patients underwent preoperative scalp electroencephalographic (EEG) recording. Sphenoidal electrodes were inserted in patients presenting with complex partial seizures. Twenty-four patients had focal epileptiform activities, ten had non-specific slow wave activities, and six had normal scalp EEG recordings.

Anti-epileptic drugs (AEDs) were discontinued on the morning of surgery. Anesthesia was induced by administering 5.0% sevoflurane and 95.0% oxygen without intravenous narcotic agents, and was maintained with 2.5% sevoflurane with an adequate muscle relaxant. End-tidal CO_2 levels were maintained at around 30 mmHg during ECoG monitoring. Scalp and bone flap for craniotomy were designed 3 cm larger than that of conventional ones in order to ensure full exposure of possible cortex that might discharge epilepsy activities. Intraoperative EcoG was performed before excision of the AVM. Electrodes of ECoG marked with serial numbers, were placed on the cerebral cortex from primary lesion to surrounding cortex. The number of the electrodes which detected the discharge of the epilepsy activity were noted (Figure 1). The AVMs and the associated surrounding gliotic and hemosiderinstained tissue were completely removed according to modern principles of microsurgery. After removal of the lesion, electrodes of ECoG were placed again on the surrounding cerebral cortex, the number of the electrodes which detected the discharge of the epilepsy activity were recorded. (Figure 2). Bipolar

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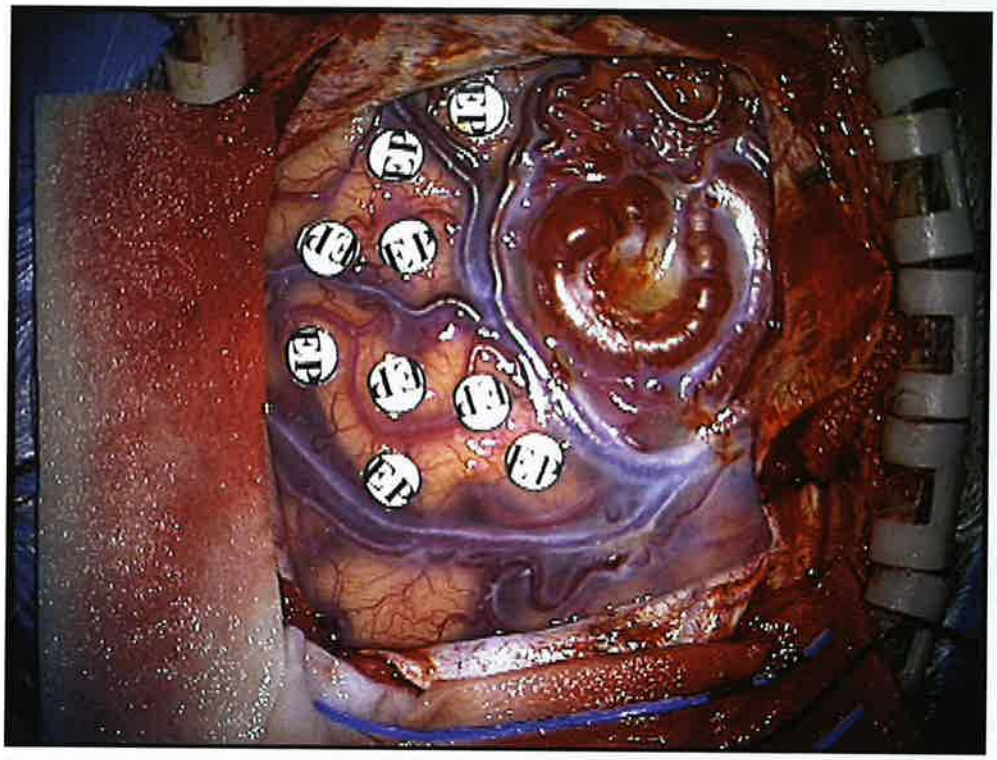

Figure 1: *Before AVMs excision, the sites of discharge of epilepsy activity, which were detected by the electrodes of intraoperative EcoG, were labeled by markers on the cerebral cortex surrounding the AVM.*

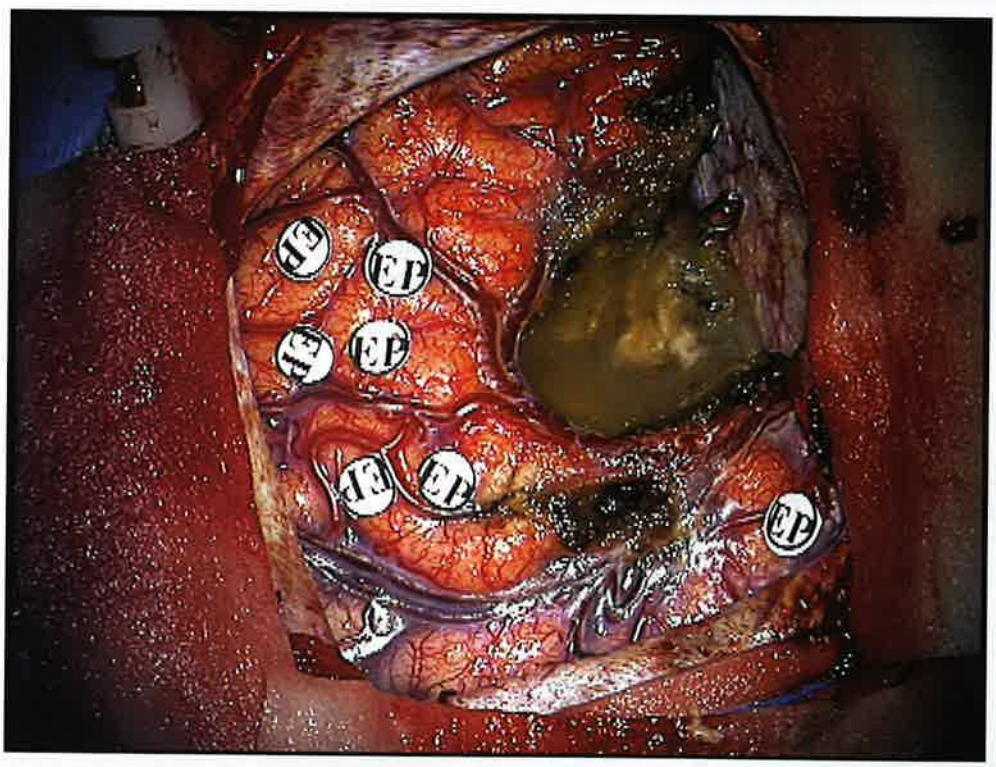

Figure 2: *After AVM excision, the sites of discharge of epilepsy activity, which were detected by the intraoperative EcoG electrodes, were labeled by markers on the surrounding cerebral cortex.*

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electrocoagulation was applied on the cortex where epileptic discharges still remained and were monitored via the ECoG after the excision. Electrocoagulation (IBBAB, Billdal Sweden) was carried out outside the arachnoid mater and was vertical on convolution, with output power of 4 U, at intervals 5 mm apart, duration 1-2 s, as previously described.[12] After electrocoagulation, the detection of ECoG was done again. If the epilepsy activity still existed, the next round was done again until the epilepsy activity disappeared or diminished significantly. The electrocoagulation should be performed perpendicular to the long axis of the gyrus and parallel to the gyrus to avoid damage to the cortical columns and cortical function.

Follow-up checkups took place three to six months after the surgery and then annually. We evaluated seizure outcome by using Engel's classification[13] and postoperative complications were recorded. Anticonvulsant therapy was withdrawn once patient had been seizure-free for half a year, otherwise it was continued indefinitely. Thirty-five patients were observed for at least three years for their seizure outcome.

Results

During the surgical procedures one (1.67%) patient was without epilepsy activity detected before the excision; ten (16.7%) patients found epilepsy activity before the excision, which disappeared after the removal of the AVMs; 49 patients (81.6%) were detected of epileptic discharges before and after AVMs excision. These 49 patients were performed with the removal of AVMs plus bipolar electrocoagulation on spike-positive site cortex. After electrocoagulation 45 patients' epileptic discharges disappeared while 4 obviously diminished (one or two sporadic epileptic discharges were found).

Postoperative four-vessel DSA and/or CT were performed for all patients. Complete excision of the AVMs was confirmed in all 60 patients.

None of the 60 patients died postoperatively. One patient developed postoperative mild aphasia, which improved to almost normal six months later. One patient suffered visual field defects. One patient with numbness and weakness of the left limb prior to surgery showed no obvious improvement after operation; one patient with decreasing visual acuity before surgery recovered significantly after surgery.

Fifty-five of the 60 (91.7%) patients had follow-up lasting at least 22 months (mean 51.1 months; range 22-93 months). We assessed seizure outcomes with the Engel Seizure Outcome Scale[13]. Engel Seizure Outcome Scale results are presented in Table 3. There were 39 Class I patients (70.9%), seven (12.7%) Class II, five (9.0%) Class III, and four (7.2%) Class IV outcomes. No patients died during the follow-up period. For the 39 cases of Class I, 11 (28.2%) were still taking antiepileptic drugs either in the process of tapering of antiepileptic drug usage or having episodes with AED discontinuation. Five patients were lost to follow-up. Their follow-up time was 3 months, 3 months, 6 months, 16 months, and 17 months respectively. On the endpoint of their follow-up their Engel Seizure Outcome Scales were all Class I.

Table 3: Engel Seizure Outcome Scale results for 55 patients with arteriovenous malformations

Engel Seizure Outcome Scale	No. of patients
Class I (free of disabling seizures)	39 (70.9%)
Class II (rare disabling seizures)	7 (12.7%)
Class III (worthwhile improvement)	5 (9%)
Class IV (no worthwhile improvement)	4 (7.2%)
Total 55	

Modified Engel Class I = seizure-free, auras only, or seizures only following withdrawal of AED; Class II = 90% reduction in seizure frequency or a single postoperative seizure; Class III = 50–90% reduction in seizure frequency; Class IV < 50% reduction in postoperative seizure frequency;

Discussion

Seizures are the second most common initial manifestation which occurs in approximately one-third of patients with AVMs.[14,15] The response to anti-epileptic drug therapy for these patients is variable.[16-18] Occurrence of seizures also increases the risk of intracranial hemorrhage (ICH). For AVMs presenting with seizures, the primary goal of surgical treatment is to entirely remove the lesion and reduce of risk of ICH. A secondary goal is to abolish the seizures. Postulated mechanisms for the pathogenesis of epilepsy in association with cerebral AVMs include secondary epileptogenesis in ipsilateral mesial temporal cortex, previous haemorrhage resulting in gliosis or hemosiderin deposition in cerebral cortex surrounding an AVM, perilesional neurochemical changes, and focal cerebral ischaemia or steal phenomenon due to AVM shunting.[19-23] In some situations the lesion of AVM is not always coincidental with the epileptogenic foci. In our study, even after the complete removal of AVM and surrounding gliotic and hemo-siderinstained tissue, a high frequency of residual spike (81.6%) monitored by the intra-operative ECoG remained on the surrounding cerebral cortex. Arteriovenous malformations lesionectomy alone seems unable to achieve freedom from epileptic discharges. The major controversy is whether lesionectomy plus corticectomy provides better seizure control.

The results reported by Cosgrove et al[24] imply that the postoperative outcome of lesionectomy plus corticectomy is slightly superior to lesionectomy alone in occult vascular malformations patients with lesional epilepsy. Yeh.[9,25] has reported excellent outcomes, achieving epilepsy control in 70.4% and 77.8% of the patients with cerebral AVMs presenting with epilepsy through lesionectomy plus corticectomy guided by the intraoperative ECoG.

However, if epileptogenic foci monitored by the intra-operative ECoG in or encroach on eloquent cortex, or it involves the cortex in extensive range, lesionectomy plus surrounding epileptic corticectomy would be risky. It might leave serious postoperative neurological deficits.

Multiple subpial transection (MST) has been widely accepted as an effective technique for the treatment of epilepsy foci that

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reside in or encroach on eloquent cortex.[26,27] However, some drawbacks about MST exist. Experience with MST is necessary to ensure that blood vessels are not injured and that the transections are perpendicular to the pial surface to prevent disruption or undercutting of the vertical columns. When larger vessels are transected, hemorrhage into the neocortex and underlying white matter may occur, resulting in large cystic lesions and focal atrophy.[28]

In common with with MST, bipolar electrocoagulation techniques can be used to cut the horizontal fibers and prevent the spread of the epileptic discharges, which is believed to improve the control of epilepsy.[12] The electrocoagulation technique involves operation only outside the arachnoid, avoiding subarachnoid hemorrhage, or splitting of the cortices, and takes less operation time than MST. The precise low-dosage output has predictable effects, and the deeper layers are spared. Animal experimental and clinical studies that were carried out have proved the safety and feasibility of this method.[12,29-31]

In our study 60 patients were treated with AVMs removal plus bipolar electrocoagulation on cortex guided by intraoperative ECoG. Satisfactory postoperative result of seizure control (Class I and Class II of Engel Seizure Outcome Scale is 83.6%) was achieved. It was believed that carrying out additional bipolar electrocoagulation on the cortex guided by the intraoperative ECoG is feasible and effective for postoperative seizure control.

Limitations of the Current Study

Although bipolar electrocoagulation on cortex guided by intraoperative electrocorticography after arteriovenous malformations lesionectomy is easily-handled and it has proven relatively successful for long-term seizure control while sparing the surrounding cortex, results are not much better than lesionectomy alone or lesionectomy and corticectomy (70.9% vs. 66%[14] or 70.4%[9]). This was only a preliminary report, and the definitive conclusions about the safety and efficacy of this technique would require further study and long-term follow-up, ideally in conjunction with randomized controls.

Conclusion

Even after the complete removal of AVM and surrounding gliotic and hemosiderin stained tissue, a high frequency of residual spike remained on the surrounding cerebral cortex. Effective surgical seizure control was achieved by carrying out additional bipolar electrocoagulation on the cortex guided by the intraoperative ECoG.

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References

1. Perret G, Nishioka H. Report on the cooperative study of intracranial aneurysms and subarachnoid hemorrhage, section VI: arteriovenous malformations: an analysis of 545 cases of craniocerebral arteriovenous malformations and fistulae reported to the cooperative study. J Neurosurg. 1966;25:467-90.
2. Moody RA, Poppen JL. Arteriovenous malformations. J Neurosurg. 1970;32:503-11.
3. Murphy MJ. Long-term follow-up of seizures associated with cerebral arteriovenous malformations. results of therapy. Arch Neurol. 1985;42:477-9.
4. Crawford PM, West CR, Shaw MDM, Chadwick DW. Cerebral arteriovenous malformations and epilepsy: factors in the development of epilepsy. Epilepsia. 1986;27:270-5.
5. Forster DMC, Steiner L, Hakinson S. Arteriovenous malformations of the brain. A long-term clinical study. J Neurosurg. 1972;37: 562-70.
6. Parkinson D, Bachers G. Arteriovenous malformations. summary of 100 consecutive supratentorial cases. J Neurosurg. 1980;53: 285-99.
7. Foy PM, Copeland GP, Shaw MDM. The incidence of post-operative seizures. Acta Neurochir. 1981;55:253-64.
8. Piepgras DG, Sundt TM, Ragoowansi AT, Stevens L. Seizure outcome in patients with surgically treated cerebral arteriovenous malformations. J Neurosurg. 1993;78:5-11.
9. Yeh H, Tew JM, Gartner M. Seizure control after surgery on cerebral arteriovenous malformations. J Neurosurg. 1993;78: 12-8.
10. Gertzen PC, Adelson PD, Kondziolka D, Flickinger JC, Lunsford LD. Seizure outcome in children treated for arteriovenous malformations using gamma knife radiosurgery. Pediatr Neurosurg. 1996;24:139-44.
11. Falkson CB, Chakrabarti KB, Doughty D, Plowman PN. Stereotactic multiple arc radiotherapy. III-influence of treatment of arteriovenous malformations on associated epilepsy. Br J Neurosurg. 1997;11:12–5.
12. Luan G, Sun Z, Bai Q, Wang Z. Surgical treatment of intractable epilepsy combined with bipolar electrocoagulation on functional cortex. Stereotact Funct Neurosurg. 2001;77:233-8.
13. Baker GA, Camfield C, Camfield P, et al. ILAE commission report, commission on outcome measurements in epilepsy, 1994–1997: final report. Epilepsia. 1998;39:213-31.
14. Hoh BL, Chapman PH, Loeffler JS, Carter BS, Ogilvy CS. Results of multimodality treatment for 141 patients with brain arteriovenous malformations and seizures: factors associated with seizure incidence and seizure outcomes. Neurosurgery. 2002;51:303-9.
15. Lunsford LD, Kondziolka D, Flickinger JC, et al. Stereotactic radiosurgery for arteriovenous malformations of the brain. J Neurosurg. 1991;75:512-24.
16. Svien HJ, McRae JA. Arteriovenous anomalies of the brain. Fate of patients not having definitive surgery. J Neurosurg. 1965;23: 23-8.
17. Parkinson D, Bachers G. Arteriovenous malformations. Summary of 100 consecutive supratentorial cases. J Neurosurg. 1980;53:285-99.
18. Dodick DW, Cascino GD, Meyer FB. Vascular malformations and intractable epilepsy: outcome after surgical treatment. Mayo Clin Proc. 1994;69:741-5.
19. Yeh H, Privitera MD. Secondary epileptogenesis in cerebral arteriovenous malformations. Arch Neurol. 1991;1122-4.
20. Kraemer D, Awad IA. Vascular malformations and epilepsy: clinical considerations and basic mechanisms. Epilepsia. 1994; 35 Suppl 6:S30-43.
21. Lv X, Li Y, Jiang C, Yang X, Wu Z. Brain arteriovenous malformations and endovascular treatment: effect on seizures. Interv Neuroradiol. 2010;16(1):39-45.
22. Hammen T, Romstöck J, Dörfler A, Kerling F, Buchfelder M, Stefan H. Prediction of postoperative outcome with special respect to removal of hemosiderin fringe: a study in patients with cavernous haemangiomas associated with symptomatic epilepsy. Seizure. 2007;16(3):248-53.
23. Upchurch K, Stern JM, Salamon N, et al. Epileptogenic temporal cavernous malformations: operative strategies and postoperative seizure outcomes. Seizure. 2010;19(2):120-8.
24. Cosgrove GR. Occult vascular malformations and seizures. Neurosurg Clin N Am. 1999;10(3):527-35.
25. Yeh HS, Kashiwagi S, Tew JM Jr, Berger TS. Surgical management of epilepsy associated with cerebral arteriovenous malformations. J Neurosurg. 1990;72:216-23.

https://doi.org/10.1017/S0317167100120785 Published online by Cambridge University Press

26. Morrell F, Whisler WW, Bleck TP. Multiple subpial transection: a new approach to the surgical treatment of focal epilepsy. J Neurosurg. 1989;70:231-9.
27. Liu Z, Zhao Q. The surgical technique research of multiple subpial transection for seizures with extensive foci in cortexes. Chin J Neurosurg. 1997;13:156-9.
28. Smith MC. Multiple subpial transection in patients with extra-temporal epilepsy. Epilepsia. 1998;39 Suppl 4:S81-9.
29. Yang Z, Luan G. Treatment of symptomatic epilepsy with lesionectomies combined with bipolar coagulation of the surrounding cortex. Chin Med J. 2003;116(12):1930-2.
30. Meng H, Luan G. The experimental surgical technique research of cats' sensorimotor area cortex epileptogenic focus induced by penicillin. part one: observation of electrophysiology and behavior. Chin J Stereotact Funct Neurosurg. 1999;12:1-6.
31. Luan G, Zhang W, Yan L, Wang Z. A pilot study of bipolar coagulation technique for treatment of epilepsy. Chin J Neurosurg. 1999;15:329-32.

https://doi.org/10.1017/S0317167100120785 Published online by Cambridge University Press