Patients with Invasive Tumors and eNOS Gene Polymorphisms with Subarachnoid Hemorrhage Tend to Have Poorer Prognosis

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Abstract

Context  Endothelial nitric oxide synthase (eNOS) gene polymorphisms are found to predict predisposition to aneurysmal rupture and development of vasospasm in a patient of subarachnoid hemorrhage (SAH). eNOS gene polymorphisms are also found to predict invasiveness of malignant cells. Studies are not available in literature to describe the effect of eNOS gene polymorphisms and correlation between aneurysm and carcinoma. This study aims to investigate whether positive cancer history influences clinical outcome following SAH and eNOS gene polymorphisms.

Materials and Methods  The eNOS gene polymorphisms were analyzed in seven consecutive patients (mean age, 52.28 ± 20 years) with a diagnosis of invasive systemic tumors from 2011 to 2017. The eNOS 4a/4b eNOS -786T > eNOS894G > T polymorphisms of the eNOS gene were determined by polymerase chain reaction and restriction fragment length polymorphism.

Results  Seven patients of aneurysmal SAH in association with malignancies were studied for eNOS polymorphisms expression and outcome. Three patients had carcinoma cervix: one patient of carcinoma breast and one each of transitional cell carcinoma of urinary bladder, spindle cell carcinoma of left kidney, and untreated patient of atypical pituitary (adenoma). A genotype study of eNOS gene polymorphisms in these patients shows common polymorphisms are involved in the determination of disease progression in malignancies and aneurysmal SAH.

Conclusion  Patients who expressed 4ab, eNOS -786T > TT/CC/TC, eNOS894G > TG/GT polymorphisms did better than patients who expressed only 4bb, though both were associated with poor prognosis.

Keywords
► invasive malignancy/tumors
► eNOS gene polymorphisms
► intracranial aneurysms

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Introduction

Intracranial pseudoaneurysms are commonly described in association with chorionic carcinoma and cardiac myxoma. The cause of the subarachnoid hemorrhage (SAH) may be berry aneurysms or pseudoaneurysms. Five cases of pseudoaneurysms have been reported in association with pleomorphic adenocarcinoma of lung. We report seven patients with systemic malignancy presenting with SAH. Endothelial nitric oxide synthase (eNOS) gene polymorphisms are known to be associated with development of vasospasm and increased chances of rupture of aneurysm. eNOS gene is also thought to determine predisposition to metastasis in malignancies. We postulate that common polymorphisms are involved in the determination of disease progression both in SAH and malignancy.

Materials and Methods

Study Subjects

All patients presenting with SAH and with a diagnosis of systemic tumors attending National Institute of Mental Health and Neuro Sciences (NIMHANS) outpatient department or emergency services of NIMHANS institute, Bengaluru, Karnataka, India, were studied. All study subjects belonged to communities of Karnataka and surrounding states. Peripheral blood sample from seven patients were collected between March 2011 and February 2017. Blood sample for DNA analysis and plasma samples were collected after written consent from the patient and/or their legal guardians. The study was approved by ethical committee of Indian Council of Medical Research, Govt. of India, and NIMHANS institute.

Sample Collection

Blood was collected from the subjects in tubes containing ethylenediaminetetraacetic acid (EDTA). Genomic DNA was isolated from EDTA blood according to conventional phenol chloroform method. DNA was quantified using Nano Drop 1000 (Thermo Fisher Scientific, Delaware, United States).

Genotyping

eNOS 4a/4b Polymorphism Screening

Genomic DNA was amplified using polymerase chain reaction (PCR) (primers 5′-AGG CCC TAT GTG AGT GCC TTT -3′ (sense) and 5′-TCT CTT AGT GCT GTG GCC AC-3′ (antisense) with Taq DNA Polymerase (FIREPol DNA Polymerase, Solis BioDyne) and supplied buffer under the following conditions: 95°C for 5 minutes, followed by 35 cycles at 94°C for 30 seconds, 59°C for 45 seconds, and 72°C for 45 seconds, followed by a 10-minute 72°C final extension. PCR products of 248bps were then digested with Dpn II at 37°C for 16 hours and were electrophoretic ally separated on a 2% agarose gel. The 4/4 homozygous wild type did not undergo digestion by Dpn I and showed PCR band of 248bps. Individuals with –786 TT homozygous genotype showed both intact PCR band of 248bps and two cleaved bands of 227 and 81bps.

eNOS 894G > T Polymorphism Screening

Extracted DNA was amplified using PCR (sense primer 5′-AAG GCA GGA AGT GTA GGA TGG A-3′; anti-sense primer 5′-GCT GGC AGT CAA TCT TGG TGC TCA TGG-3′) with Taq DNA Polymerase (FIREPol DNA Polymerase, Solis BioDyne) and supplied buffer under the following conditions: 95°C for 5 minutes, followed by 35 cycles at 94°C for 30 seconds, 67.5°C for 45 seconds, and 72°C for 45 seconds, followed by a 10-minute 72°C final extension. PCR products of 248bps were then digested with Dpn II at 37°C for 16 hours and were electrophoretic ally separated on a 2% agarose gel. The 894T allele is characterized by diagnostic Dpn II restriction fragments of 163 and 85bps. Thus, the gel pattern for individuals with homozygous mutant genotype (894TT) showed 163 and 85bps bands, whereas 894 GG homozygous wild type did not undergo digestion by Dpn I and showed PCR band of 248bps. Individuals with 894 GT heterozygous genotype showed both intact PCR band of 248bps and two cleaved bands of 163 and 85bps.

Results

Seven cases of SAH with common influence of eNOS gene polymorphisms in determining their clinical course are discussed in Table 1.

Case 1

A 70-year-old lady presented with severe headache. She is a known case of stage 2b cervical carcinoma received who had chemoradiotherapy and intracavitary brachytherapy; she completed adjuvant therapy 3 months prior to presentation with SAH. On examination, she was conscious, obeying, with World Federation of Neurological Surgeons (WFNS) grade 1. Computed tomography (CT) shows diffuse SAH digital subtraction angiography (DSA)—(1) anterior communicating artery (Acom) aneurysm, (2) left frontopolar artery aneurysm, and (3) left middle cerebral artery (MCA) bifurcation aneurysm. She underwent clipping of aneurysms. Immediate postoperative Glasgow coma score (GCS) was 15(E4M6V5)
| Patient details | Previous history | SAH clinical details | SAH radiological details | Treatment | Postoperative | eNOS polymorphisms | Follow-up and outcome |
|-----------------|------------------|----------------------|--------------------------|-----------|--------------|-------------------|----------------------|
| 1) 70 y/f       | Stage 2b cervical carcinoma with right ovarian cyst had chemoradiotherapy and intracavitary brachytherapy; completed adjuvant therapy 3 months prior to presentation with SAH | Severe headache 3 days prior GCS was 15 (E₅M₆V₅) WFNS grade 1 | CT—diffuse SAH DSA— 1) Acom aneurysm 2) Left frontopolar artery aneurysm 3) Left MCA bifurcation aneurysm | Clipping | GCS was 15(E₅M₆V₅) right lower limb paresis (power [MRC]-3/5) | 4bb type in 4a/b, TT type in T786C and GG type in G894T | Right lower limb paresis (power [MRC]-3/5] persistent at 1 month of follow-up |
| 2) 50 y/f       | 10 months prior diagnosed with stage 3 carcinoma cervix and treated with chemoradiotherapy and intracavitary radiotherapy Completed adjuvant therapy 5 months prior to SAH | Headache and altered sensorium for the last 2 days with one episode of GTCS Papilledema was present. WFNS grade-4 GCS was 14(E₃M₆V₄) | CT brain—left gyrus rectus hematoma with diffuse SAH and intraventricular hemorrhage involving bilateral lateral, 3rd and 4th ventricle. DSA—single saccular Acom aneurysm | Clipping | GCS was 4(E₅M₆Vₑ₅₈) Postoperative CT showed increase in size of left frontal hematoma. Re—exploration and evacuation of contusion was done. Neurological condition deteriorated to GCS 3 (E₃M₅Vₑ₅₈) | 4bb type in 4a/b, TC type in T786C and GT type in G894T | Poor GCS of 3 at 1 week follow-up |
| 3) 45 y/f       | Insignificant | Severe headache, 3 days prior, weakness of right upper and lower limb with irrelevant talking and became unresponsive 3 days post ictus. GCS was 8 (E₅M₅V₅) with right upper motor neuron facial palsy and right sided power ([MRC]-2/5). WFNS grade was 5. General examination showed a lump in the breast of size 4 x 5 cm, irregular in shape, hard in consistency and fixed to chest wall | CT brain—diffuse SAH Chest X-ray—coin shaped lesion in right lung field CT thorax—multiple calcified lesions in breast with metastatic lesions in right lung upper lobe, suggestive of carcinoma breast DSA—Left Acom artery saccular aneurysm. Left anterior cerebral artery was in spasm with good cross-circulation | Due to the poor general condition did not consent for either clipping or coiling | --- | 4bb type in 4a/b, CC type in T786C and GG type in G894T | Poor GCS at 1 month of follow-up |
| 4) 72 y/f       | Diagnosed case of transitional cell carcinoma of urinary bladder receiving intravesical chemotherapy, date of diagnosis not available | Headache and multiple episodes of vomiting for the last 3 days GCS 15 E₄M₅V₅ (WFNS grade 1). | DSA—small saccular left MCA bifurcation aneurysm Small saccular aneurysm arising from cervical segment of the LICA | Coiling | GCS of E₄M₅V₅ with no postoperative deficits | 4ab type in 4a/b, TT type in T786C and GG type in G894T | Died one and half year post-aneurysmal surgery |

(Continued)
| Patient details | Previous history | SAH clinical details | SAH radiological details | Treatment | Postoperative | eNOS polymorphisms | Follow-up and outcome |
|-----------------|-------------------|----------------------|-------------------------|-----------|---------------|-------------------|----------------------|
| 5) 42 y/f       | Known case of spindle cell carcinoma of left kidney operated 3 years back and post RT/CT | Altered sensorium for the last 1 day with left sided weakness and multiple episodes of GTCS. Positive neck rigidity. GCS was E2M3V5aphasic (WFNS grade 5) with relative left sided paucity moving against gravity | CT—SAH in right sylvian and ambient cistem with no hydrocephalus and midline shift. DSA—right MCA bifurcation saccular aneurysm measuring 4 × 3.8 × 2.8 mm | E4M6V5 with no residual paucity | 4bb type in 4a/b, TT type in T786C and GT type in G894T polymorphisms | Died on 14/8/2014 after 7 months of aneurysm surgery |
| 6) 32 y/f       | Menstrual cycles were irregular occurring once in 3 months with scant flow. History of polyuria and polydipsia | Headache and blurring of vision for the last 1 month. Fundus showed papilledema | MRI brain (P + C)—sellar-suprasellar lesion T1 hypo, T2 hetero solid-cystic with cystic component extending anterior in right basifrontal region. Solid portion in sellar-suprasellar region was enhancing on contrast. Features suggestive of papillary type of craniopharyngioma Pituitary macroadenoma MRA—Acom aneurysm. T3—53 decreased, T4—4.3 decreased, TSH—2.72 N, FSH—5.31, and LH—0.72 decreased, GH—0.13 N. Cortisol—5.29 Field-Rt eye 6/24 with temporal hemianopia and left eye 6/60 with tubular vision. Histopathology Report was suggestive of pituitary adenoma sellar-suprasellar (features suggest atypical adenoma) | Subtotal decompression of sellar-suprasellar lesion and clipping of the A-comm aneurysm | Uneventful with follow-up serum prolactin of 4.67. Visual acuity did not deteriorate post-surgery | 4bb type in 4a/b, TT type in T786C and GG type in G894T polymorphisms | Died 1 year after aneurysm surgery |
| 7) 55 y/f       | K/c/o carcinoma cervix IIb taken radiation in 2010 (5 years back) | Severe headache giddiness and fall 2 days back E2M3V5 (WFNS grade 1) with no paucity | CT—left sylvian fissure SAH with hydrocephalus. DSA—Left ICA communicating segment aneurysm | Coiling | No postoperative deficits | 4ab type in 4a/b, TT type in T786C, and GG type in G894T polymorphisms | No deficits after one and half year of follow-up |

Abbreviations: Acom, anterior communicating artery; CT, computed tomography; DSA, digital subtraction angiography; eNOS, endothelial nitric oxide synthase; FSH, follicle-stimulating hormone; GCS, Glasgow coma scale; GH, growth hormone; GTCS, generalized tonic-clonic seizure; ICA, internal carotid artery; LH, luteinizing hormone; LICA, left ICA; MCA, middle cerebral artery; MRI, magnetic resonance imaging; SAH, subarachnoid hemorrhage; TSH, thyroid-stimulating hormone; WFNS, World Federation of Neurological Surgeons.

Abbreviation: eNOS, endothelial nitric oxide synthase.
right lower limb paresis (muscle power assessment [MRC]-3/5). Serum eNOS polymorphism analysis showed 4a/b, TT type, and GG type. Follow-up at 1 month, she was conscious, obeying, with right lower limb paresis (power [MRC]-3/5).

Case 2
A 50-year-old woman presented with sudden onset headache and altered sensorium for 2 days and one episode of generalized tonic-clonic seizures. She was diagnosed with stage 3 carcinoma cervix and received chemoradiotherapy and intracavitary brachtherapy and completed adjuvant therapy 5 months prior to presentation with SAH. On examination, papilledema was present, WFNS grade 4, GCS was 14 (E3M6V4). CT brain showed left gyrus rectus hematoma with diffuse SAH and intraventricular hemorrhage involving bilateral lateral, 3rd and 4th ventricle. DSA showed single saccular Acom aneurysm. She underwent clipping. Postoperatively patient’s GCS was 4(E1M3V(E4)). Neurological condition deteriorated to GCS 3 (E1M1V(E5)). Repeat CT showed recollection with severe cerebral edema and intraventricular hemorrhage and ventriculomegaly. It was decided not to reoperate considering poor cardiac condition and risks of re-exploration. Poor prognosis was explained to relatives. Serum eNOS gene polymorphism analysis showed 4bb type in 4a/b, TC type, in T786C, and GT type in G894T polymorphisms. She had Poor GCS of 3 at 1 week follow-up.

Case 3
A 45-year-old woman presented with severe headache for 3 days with weakness of right upper and lower limb and irrelevant talking. On examination, GCS was 8 (E2M3V(1)), disoriented, right upper motor neuron facial palsy and right upper limb and lower limb weakness (power [MRC]-2/5), WFNS grade 5. General examination showed a lump in the breast of size 4 × 5 cm, irregular in shape, hard in consistency, and fixed to chest wall. CT showed diffuse SAH. Chest X-ray showed coin-shaped lesion in right lung field (Fig. 1). CT thorax showed multiple calcified lesions in breast with metastatic deposits in right lung upper lobe. DSA showed saccular aneurysm arising from Acom (Fig. 1). Left anterior cerebral artery was in spasm with good cross-circulation (Fig. 1). Serum eNOS gene polymorphism analysis showed 4bb type in 4a/b, CC type in T786C, and GT type in G894T polymorphisms. The possible prognosis of the patient due to the poor general condition and the untreated carcinoma breast and metastasis to lungs was discussed with patient and relatives. They did not consent for either clipping or coiling of the aneurysm. She had poor GCS at 1 month of follow-up.

Case 4
A 72-year-old female with h/o sudden onset headache and multiple episodes of generalized tonic-clonic seizures for 3 days. Her systemic and CNS examination showed no evident abnormalities, while GCS showed E3M6V5 (WFNS grade 1). She was a diagnosed case of transitional cell carcinoma of urinary bladder receiving intravesical chemotherapy; date of diagnosis not available. DSA showed small saccular MCA bifurcation aneurysm (Fig. 2). Balloon-assisted coiling of left MCA aneurysm was done (Fig. 2). Also a small saccular aneurysm in cervical segment of the LICA. Serum eNOS gene polymorphism analysis showed 4ab type in 4a/b, TT type in T786C, and GG type in G894T polymorphisms. Post-coiling, she had no deficits and was discharged with a GCS of E4M6V5. She died 1 and half year later.

Case 5
A 42-year-old female presented with altered sensorium for 1 day and left-sided weakness and multiple episodes of generalized tonic-clonic seizures. General examination showed positive neck rigidity, and GCS was E3M3V(aphasic) (WFNS grade 5) with relative left-sided paucity moving against gravity. She is a known case of spindle cell carcinoma of left kidney operated 3 years back and post-chemoradiotherapy. CT showed SAH in right sylvian and ambient cistern with no hydrocephalus and midline shift. DSA showed right MCA bifurcation saccular aneurysm (Fig. 3). Serum eNOS gene polymorphism analysis showed 4bb type in 4a/b, TT type in T786C, and GT type in G894T polymorphisms. She underwent clipping of aneurysm. Post-clipping, the GCS...
improved over a period of 5 days during hospital stay to E4M6V5 with no residual paucity. She died 7 months later.

**Case 6**
A 32-year-old married lady presented with a history of headache and blurring of vision for 1 month. Her menstrual cycles were irregular occurring once in 3 months with scant flow. History of polyuria and polydipsia was present. On examination, the patient was moderately built, nourished, GCS was 15, WFNS 1. Fundus showed papilledema. Magnetic resonance imaging (MRI) of brain plain with Contrast was suggestive of a T1 hypo, T2 hetero solid-cystic sellar-suprasellar lesion T1 hypo, T2 hetero solid-cystic with cystic component extending anterior in right basifrontal region. Solid portion in sellar-suprasellar region was enhancing on contrast. Magnetic resonance angiography showed Acrom aneurysm. T3–53 and T4–4.3 were decreased, thyroid-stimulating hormone was 2.72 (normal), follicle stimulating hormone was 5.31 (normal), and luteinizing hormone was 0.72 (decreased), growth hormone —0.13 (normal), whereas cortisol was 5.29 (normal). Visual fields were as follows: right eye 6/24 with temporal hemianopia and left eye 6/60 with tubular vision. Histopathology report was suggestive of pituitary adenoma sellar-suprasellar (features suggest atypical adenoma). Patient underwent subtotal decompression of sellar-suprasellar lesion and clipping of the Acrom aneurysm. Postoperative course was uneventful with follow-up serum prolactin of 4.67. Visual acuity did not deteriorate post-surgery. She died 1 year later.

**Case 7**
A 35-year-old female K/c/o carcinoma cervix IIB taken radiation in 2010 (5 years back) presented with sudden onset of severe headache, giddiness, and fall 2 days back. She had a history of brief loss of consciousness and multiple episodes of vomiting. On examination, she was conscious obeying commands with GCS of E5M6V5 (WFNS grade 1). CT showed left sylvian fissure SAH with hydrocephalus. DSA showed left internal carotid artery (ICA) communicating segment aneurysm. She underwent endovascular coiling of left ICA communicating segment aneurysm with no postoperative deficits. Serum eNOS showed 4ab type in 4a/b, TT type in T786C and GG type in G894T polymorphisms. She had no deficits at one and half year of follow-up.

**Discussion**
Malignancy can present with SAH due to rupture of berry aneurysms or pseudoaneurysms. Embolization of tumor material into large vessels leading to aneurysm formation at the site of the occlusion is thought to be the cause of neoplastic intracranial aneurysms. It is hypothesized that tumor material embolizes to peripheral artery in brain and gets attached to the wall and later invades the wall, resulting in segmental weakening of internal elastic lamina and formation of aneurysmal dilatation. On histopathology, wall of these aneurysms shows presence of malignant cells of primary tumor. Cervical carcinoma and breast carcinoma have hematogenous metastasis and this may predispose to development of intracranial pseudoaneurysms in these patients and thus to SAH. Pseudoaneurysms from metastasis of malignancies are known to occur in association with cardiac myxomas and choriocarcinoma. Twenty cases have been described in association with choriocarcinoma and 34 cases have been described in association with cardiac myxoma, true incidence of aneurysms in choriocarcinoma and cardiac myxoma is not known. There are five cases reported in association with pleomorphic adenocarcinoma lung. Association of intracranial aneurysm has been reported with hypernephroma, papillary thyroid carcinoma, testicular carcinoma, glioblastoma multi-forme, pituitary adenoma, and meningioma. It is important to note that none of these studies have confirmed that the aneurysms were because of thromboembolic phenomenon from systemic metastasis. Shibahara et al in a retrospective analysis of 498 SAH patients spanning 6 years reported that compared with SAH patients without cancer history, those with cancer history had poorer Hunt & Hess grade at SAH presentation, and poorer modified Rankin Scale score at discharge, and positive cancer history remained an independent risk factor. From the above data, it appears patients with malignancy may present with early aneurysmal rupture.

Carcinoma cervix may be associated with brain metastasis in 0.5 to 1.2%. The route of spread from cervical cancer is hematogenous. Brain metastases are frequently seen with poorly differentiated cervical tumors. These metastatic lesions may cause SAH. Duarte et al reported a case of cervical carcinoma presenting with severe hyperprolactinemia and parhypopituitarism due to suprachinoidal aneurysm after 2 years of treatment and achievement of remission from carcinoma, but no SAH was reported. In the current study, two patients presented with aneurysmal SAH within 6 to 8 months period of detection of cervical carcinoma and completion of treatment. Breast carcinoma is the second most common cause of brain metastasis and this metastasis is more common in advanced stages of breast carcinoma. Brain metastasis from carcinoma breast occurs by hematogenous route, where tumor emboli lodge in peripheral vessels and cause secondaries that can cause SAH. In a study by Koppelmans et al on incidental findings on brain MRI in long-term survivors of breast cancer, it is found that 2.6% had an aneurysm of 191 subjects. The patient 3 of our study with undiagnosed and therefore untreated carcinoma breast was in morbid condition because of metastasis to lung and SAH.

Some studies have shown correlation between eNOS, tumors, and SAH. The evaluation of eNOS genotypes, between natural history of aneurysmal SAH and polymorphisms of eNOS gene, has shown all the seven patients were found to have 4b polymorphism in 4a/b gene that is the most common polymorphism in the population and two having 4a and 4b both. In G894T gene, five patients had GG polymorphism, which is wild phenotype and two patients had GT, which is heterozygous with one mutant allele. In T786C gene, three patients showed three different genotype: CC (mutant), TT (wild), and TC (heterozygous). In a study by Khalkhali-Ellis and Hendrix,
| Cancer type                     | eNOS gene polymorphisms                                                                 | Outcome                                                                                     | References |
|--------------------------------|-----------------------------------------------------------------------------------------|---------------------------------------------------------------------------------------------|------------|
| Invasive breast cancer         | Intron 4a/b and -786T > C, 894G > T polymorphisms                                        | eNOS -786T > C and 894G > T polymorphisms are associated with the increased risk of breast cancer | 18         |
| Bladder cancer                 | G894T polymorphisms NOS3 GT genotype                                                    | The frequency of the G894T allele was significantly higher in patients with bladder cancer (51%). No association was identified for eNOS T-786C and intron 4 VNTR 4a/b polymorphisms between patients with bladder cancer and control groups in Turkish population | 29,34      |
| Meta-analysis 1 (cancer)       | The CC of T-786C and 4a/4a of 4b/a polymorphism are associated with increased cancer risk  | The eNOS G894T polymorphism may not be a major risk factor for most types of cancers. The CC of T-786C polymorphism and 4a/4a of 4b/a polymorphism are associated with cancer risk, especially in Caucasians. There is significant association between T786C polymorphism and breast cancer risk | 36         |
| Meta-analysis 2 (cancer)       | T-786C, G894T polymorphism                                                               | The eNOS T-786C polymorphism is associated with elevated cancer risk; the G894T polymorphism contributes to susceptibility to breast cancer and cancer generally in females; and the 4a/b polymorphism may be associated with prostate cancer risk | 35         |
| Meta-analysis 3 (aneurysmal)   | eNOS T786C polymorphism                                                                  | The presence of the T786C polymorphism as a predictor for the development of IA in the cerebrovascular system | 28         |
| Cerebral vasospasm,            | eNOS T786C, VNTR intron 4 a/b, G894T; and haptoglobin (Hp) ½ phenotypes                  | eNOS VNTR and Hp polymorphisms appear to have the strongest associations with DIND and radiographic vasospasm, respectively | 30         |
| delayed ischemia (DCI),        |                                                                                        |                                                                                              |            |
| delayed ischemic neurologic     |                                                                                        |                                                                                              |            |
| deficit (DIND)                  |                                                                                        |                                                                                              |            |
| Aneurysmal                      | NOS3 27-bp-VNTR b/b genotype                                                             | NOS3 27-bp-VNTR b/b genotype independent of other risk factors act in concert with male sex to substantially increase risk of SAH. This effect is not mediated by any single NOS3 haplotype | 23         |
| Aneurysmal                      | eNOS gene T786C and IL-6 gene G572C polymorphism                                         | IL-6 gene G572C polymorphism (OR 7.08, 95% CI 2.85–17.57; p < 0.0001) both showed a significant association with ruptured/unruptured IA. The IL-6/G174C polymorphism exerted a significant protective effect against IA | 31         |
| Aneurysmal SAH and vasospasm   | eNOS single nucleotide (rs1799983, variant allele) polymorphisms                         | eNOS gene plays a role in the response to SAH, which may be explained by an influence on CV  | 17         |
| Aneurysmal SAH and vasospasm   | eNOS gene T to C substitution in the promoter at position -786 and the a-deletion/b-insertion in intron 4 | DNA sequence differences in eNOS gene influence the risk of cerebral vasospasm in subarachnoid hemorrhage | 22         |
| Vasospasm post-aneurysmal SAH  | eNOS T-786 SNP                                                                           | Genetic variation influencing NO regulation contributes to the risk of angiographic vasospasm in patients with SAH. The specific role of the promoter SNP (-786T→C) may determine the effect of NO regulated by this pathway, distinct from other known eNOS polymorphisms | 32         |
| Aneurysmal                      | Polymorphism in exon 7 of the endothelial nitric oxide synthase gene G894T               | eNOS polymorphisms were not indicative of which Japanese patients with IA would suffer an SAH | 21,27      |
| Aneurysmal SAH and vasospasm   | (eNOS 27 VNTR) predicts susceptibility to IA rupture, while the eNOS gene promoter T-786C single nucleotide polymorphism (eNOS T-786C SNP) | eNOS T-786C genotype may be a factor influencing the size at which an aneurysm rupture | 19,20      |

Abbreviations: eNOS, endothelial nitric oxide synthase; IA, intracranial aneurysm; IL-6, interleukin-6; SAH, subarachnoid hemorrhage.
it was shown that reduced levels of nitric oxide in breast carcinoma cells are associated with increased cell motility and invasion and increased NO levels can decrease this nature by inducing a gene called maspin.\(^ {37} \)

In another study by Schneider et al, it was found that eNOS\(^ {-786} \)TT and eNOS\(^ {-894} \)GG genotypes are associated with greater chances of invasive disease and eNOS\(^ {-894} \)GG genotype is associated increased chances of having metastatic disease.\(^ {38} \)

Cheon et al showed that eNOS 4b genotype occurs in significantly higher frequency in lung cancer patients.\(^ {39} \) NO levels and eNOS gene polymorphisms have been implicated in the prognosis of other malignancies like prostate cancer and colorectal carcinoma.\(^ {39} \) eNOS gene polymorphism 4a/b has been thought to predict susceptibility to rupture of intracranial aneurysms, predicting increased chances when 4a allele is expressed in genotype, while 786TC polymorphism is thought to predict post-SAH vasospasm in presence of C allele.\(^ {19,40} \)

In the current study, patient number 2 and 3, who had deteriorating clinical course, have shown C allele in their genotype, one in homozygous state and other in heterozygous state. In the patient with breast carcinoma, the genotypes, 4bb, GG and CC, show the possibility of genetic predisposition to invasive breast carcinoma and poor WFNS grade SAH and development of vasospasm. Reduced levels of NO are postulated to be the cause of vasospasm, which is major cause of mortality in patients with SAH. Though there exists a controversy on whether these genotypes are associated with aneurysm formation, there is evidence to believe they have effect on clinical manifestations and progress of intracranial aneurysms. There is common association of eNOS gene polymorphisms in clinical course and poor prognosis in both malignancies and aneurysmal SAH.

It is well known that tumor can embolize and get seeded in parts of brain and vessel wall that can lead to formation of pseudoaneurysms. But usually, such thromboembolic phenomenon involves distal circulation and low caliber vessels. All the patients presented here have aneurysms in proximal large caliber vessels and one even at bifurcation of ICA. Most thromboembolic phenomenon due to tumor metastasis should cause Intracerebral hemorrhage as compared with SAH. Thus, it is difficult to predict whether the SAH is due to tumor emboli or berry aneurysmal bleed. One more thing to note here is most of our patients had only one aneurysm, whereas multiple aneurysms are usually seen in thromboembolic tumor metastasis. We agree that there is still no study available to properly predict the time lag between brain parenchymal metastasis versus tumor emboli in cerebral blood vessels, but none of the patients presented here showed any possible brain metastasis in CT/MRI at the time of diagnosis of aneurysms or prior. This reiterates our assumption that the aneurysmal bleed in our patients is most likely due to de novo aneurysmal rupture unrelated to thromboembolic phenomenon. Also, out of seven patients, five had undergone clipping; there was no intraoperative impression of tumor emboli aneurysmal bleeding in these

### Table 3 SAH association with various cancers and outcome

| SAH        | Cancer and conclusions/Outcome                                                                 | Studies |
|------------|-----------------------------------------------------------------------------------------------|---------|
| (22%) had SAH | 42 different cancers ICH in these patients often occurs from unique mechanisms                 | 25      |
| ICH with various cancers | Patients with systemic cancer have higher mortality and less favorable discharge outcomes after ICH than patients without cancer. Cancer subtype may influence outcomes after ICH | 24      |
| ICH with various cancers | ICH in these patients often occurs from unique mechanisms                                          | 33      |
| Ischemic and hemorrhagic | Lung cancer, pancreatic cancer, colorectal cancer, breast cancer, prostate cancer Incident cancer is associated with an increased short-term risk of stroke. This risk appears highest with lung, pancreatic, and colorectal cancers | 26      |

Abbreviations: ICH, intracranial hemorrhage; SAH, subarachnoid hemorrhage.

### Table 4 Tumors with various eNOS expressions

| Cancer diagnosis              | eNOS 4a/4b | eNOS -786T > C | eNOS-894G > T |
|-------------------------------|------------|----------------|--------------|
| 1. Carcinoma cervix           | 4bb        | TT             | GG           |
| 2. Carcinoma cervix           | 4bb        | TC             | GT           |
| 3. Carcinoma breast           | 4bb        | CC             | GG           |
| 4. Bladder carcinoma          | 4ab        | TT             | GG           |
| 5. Renal carcinoma            | 4bb        | TT             | GT           |
| 6. Atypical pituitary macroadenoma | 4bb       | TT             | GG           |
| 7. Carcinoma cervix           | 4ab        | TT             | GG           |
patients. We assume that the SAH caused in our patients is most likely due to berry aneurysmal rupture than due to pseudoaneurysm. However, further histopathological analysis of these aneurysmal specimens needs to be done to arrive at a conclusion.

Also, after reviewing the last 10 years database from PubMed and NCBI sites, we have formed concise tabular formats relating to cancers, SAH and eNOS gene polymorphisms. As per our analysis, we think a clear association of eNOS with SAH and metastatic cancers is possible. Also, a notable conclusion speculates that most of our observational cases had SAH within few months of diagnosis of cancer following the completion of full course of chemoradiotherapy. It is noteworthy that in spite of complete treatment the occurrence of SAH was seen quite early in the course of disease post-complete treatment. None of these patients were diagnosed with aneurysms while receiving chemotherapeutic full course of treatment. Additionally, none of these had any neurological manifestations before they presented for SAH.

Our study reports conclusively that aneurysms and aneurysmal SAH in invasive systemic cancers have a definite correlation with eNOS gene polymorphisms and more so of 4bb. Polymorphisms associated with 4bb were associated with early occurrence of SAH with relatively poorer prognosis.

**Limitations**

A larger sample size is needed to confirm the strength of the above association. Also, histopathological analysis post-surgery may add to and help in further strengthening the evidence of this association.

**Conclusion**

If patients with malignancy present with SAH due to either berry aneurysm or pseudoaneurysm, the clinical course and prognosis may be poor. The cause and effect of eNOS gene polymorphism specially on the higher stage malignancy are not fully understood. The course of the patients with higher stage malignancies may be associated with higher incidence of complications, especially if they present with SAH. Early recognition of these complications and treatment may decrease the morbidity and mortality in these patients. Also, the variable presence of 4ab and 4bb polymorphisms in certain patients can be helpful in predicting the poor outcome in association with SAH. To our knowledge, there is no literature associating presence of malignancies and poor prognosis in SAH associated with eNOS gene polymorphisms. A further study with a larger sample may be required to determine the strength of this association.

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**Conflict of Interest**

None declared.

**References**

1. Lee T-H, Huang S-C, Su T-M, Yang K-Y, Rau C-S. Multiple cerebral aneurysms and brain metastasis from primary cardiac myxosarcoma: a case report and literature review. Chang Gung Med J 2011;34(03):315–319
2. Nomura R, Yoshida D, Kim K, Kobayashi S, Teramoto A. Intracerebral hemorrhage caused by a neoplastic aneurysm from pleomorphic lung carcinoma. Neurol Med Chir (Tokyo) 2009;49(01):33–36
3. Cheng WY, Shen CC. Minimally invasive approaches to treat simultaneous occurrence of glioblastoma multiforme and intracranial aneurysm – case report. Minim Invasive Neurosurg 2004;47(03):181–185
4. Cheon KT, Choi KH, Lee HB, Park SK, Rhee YK, Lee YC. Gene polymorphisms of endothelial nitric oxide synthase and angiotensin-converting enzyme in patients with lung cancer. Lung 2000;178(06):351–360
5. Ivanovic BA, Tadic M, Vranes M, Orbovic B. Cerebral aneurysm associated with cardiac myxoma: case report. Bosn J Basic Med Sci 2011;11(01):65–68
6. Spetzger U, Mull M, Sure U, Gilshbach J. Subarachnoid and intraventricular hemorrhage caused by hypernephroma metastasis, accompanied by innocent bilateral posterior communicating artery aneurysms. Surg Neurol 1995;44(03):275–278
7. Yamamoto F, Maruwa M, Kanetani K, Matsuho H, Shigemori M, Kuramoto S. [Coexistence of multiple metastatic brain tumors from thyroid carcinoma and cerebral aneurysms]. No Shinkei Geka 1990;18(04):361–365
8. Matsko DE, Bapaiteev AV, Glukhovets BI, Litvak EA. [Intracranial oncogenic aneurysm]. Arkh Patol 1989;51(02):72–75
9. Honda M, Kamada K, Nakata Y, Harada T, Ivanaga H, Tsukamoto M. [The association of cerebral aneurysm with malignant brain tumor–report of a case (author’s transl)]. No Shinkei Geka 1980;8(11):1065–1070
10. Pant B, Arita K, Kurisu K, Tominaga A, Eguchi K, Uozumi T. Incidence of intracranial aneurysm associated with pituitary adenoma. Neurosurg Rev 1997;20(01):13–17
11. Javalkar V, Guthikonda B, Vammenreddy P, Nanda A. Association of meningioma and intracranial aneurysm: report of five cases and review of literature. Neurol India 2009;57(06):772–776
12. Shibahara I, Watanabe T, Ezura M, et al. Clinical features of subarachnoid hemorrhage in patients with positive cancer history. J Neurooncol 2016;128(01):129–136
13. Maheshwari A, Gupta S, Wanstkal R, Kulkarni Y, Tongoankar HM. Brain metastasis from cervical carcinoma–a case report. J Medscape Gen Med 2005
14. Duarte FHG, Machado MC, Lima JR, Salgado LR. Severe hyperprolactinemia associated with internal carotid artery aneurysm: differential diagnosis between prolactinoma and hypothalamic-pituitary disconnection. Arq Bras Endocrinol Metabol 2008;52(07):1189–1193
15. Wadasadawala T, Gupta S, Bagul V, Patil N. Brain metastases from breast cancer: management approach. J Cancer Res Ther 2007;3(02):157–165
16. Koppelmans V, Schagen SB, Poels MMF, et al. Incidental findings on brain magnetic resonance imaging in long-term survivors of breast cancer treated with adjuvant chemotherapy. Eur J Cancer 2011;47(17):2531–2536
17. Alexander S, Poloyac S, Hoffman L, et al. Endothelial nitric oxide synthase tagging single nucleotide polymorphisms and recovery from aneurysmal subarachnoid hemorrhage. Biol Res Nurs 2009;11(01):42–52
18. Gao X, Wang J, Wang W, Wang M, Zhang J. eNOS genetic polymorphisms and cancer risk: a meta-analysis and a case-control study of breast cancer. Medicine (Baltimore) 2015;94(26):e972
19. Khurana VG, Solhi YR, Mangrum WI, et al. Endothelial nitric oxide synthase gene polymorphisms predict susceptibility to
aneurysmal subarachnoid hemorrhage and cerebral vasospasm. J Cereb Blood Flow Metab 2004;24(03):291–297
20 Ko NU, Rajendran P, Kim H, et al. Endothelial nitric oxide synthase polymorphism (-786T>C) and increased risk of angiographic vasospasm after aneurysmal subarachnoid hemorrhage. Stroke 2008;39(04):1103–1108
21 Krischek B, Kasuya H, Akagawa H, et al. Using endothelial nitric oxide synthase gene polymorphisms to identify intracranial aneurysms more prone to rupture in Japanese patients. J Neurosurg 2006;105(05):717–722
22 Li P, Ma LT, Zhang XZ, Gong J, Mo XH. [Risk of cerebral vasospasm following subarachnoid hemorrhage is associated with endothelial nitric oxide synthase gene polymorphism]. Nan Fang Yi Ke Da Xue Xue Bao 2009;29(02):280–283
23 McColgan P, Thant KZ, Sharma P. The genetics of sporadic ruptured and unruptured intracranial aneurysms: a genetic meta-analysis of 8 genes and 13 polymorphisms in approximately 20,000 individuals. J Neurosurg 2010;112(04):714–721
24 Murthy SB, Shastri A, Merkler AE, et al. Intracerebral hemorrhage outcomes in patients with systemic cancer. J Stroke Cerebrovasc Dis 2016;25(12):2918–2924
25 Navi BB, Reichman JS, Berlin D, et al. Intracerebral and subarachnoid hemorrhage in patients with cancer. Neurology 2010;74(06):494–501
26 Navi BB, Reiner AS, Kamel H, et al. Association between incident cancer and subsequent stroke. Ann Neurol 2015;77(02):291–300
27 Ozüm U, Bolat N, Gül E, Özdemir O. Endothelial nitric oxide synthase gene [G894T] polymorphism as a possible risk factor in aneurysmal subarachnoid haemorrhage. Acta Neurochir (Wien) 2008;150(01):57–61, discussion 62
28 Paschoal EHA, Yamaki VN, Teixeira RKC, et al. Relationship between endothelial nitric oxide synthase (eNOS) and natural history of intracranial aneurysms: meta-analysis. Neurosurg Rev 2018;41(01):87–94
29 Polat F, Diler SB, Azazi İ, Öden A. T-786C, G894T, and intron 4 VNTR (4a/b) polymorphisms of the endothelial nitric oxide synthase gene in bladder cancer cases. Asian Pac J Cancer Prev 2015;16(06):2199–2202
30 Rosalind Lai PM, Du R. Role of genetic polymorphisms in predicting delayed cerebral ischemia and radiographic vasospasm after aneurysmal subarachnoid hemorrhage: a meta-analysis. World Neurosurg 2015;84(04):933–41.e2
31 Staalsø JM, Edsen T, Kotinis A, Romner B, Springborg JB, Olsen NV. Association of the NOS3 intron-4 VNTR polymorphism with aneurysmal subarachnoid hemorrhage. J Neurosurg 2014;121(03):587–592
32 Starke RM, Kim GH, Komotar RJ, et al. Endothelial nitric oxide synthase gene single-nucleotide polymorphism predicts cerebral vasospasm after aneurysmal subarachnoid hemorrhage. J Cereb Blood Flow Metab 2008;28(06):1204–1211
33 Velander AJ, DeAngelis LM, Navi BB. Intracranial hemorrhage in patients with cancer. Curr Atheroscler Rep 2012;14(04):373–381
34 Verim I, Toptas B, Ozkan NE, et al. Possible relation between the NOS3 gene GLU298ASP polymorphism and bladder cancer in Turkey. Asian Pac J Cancer Prev 2013;14(02):665–668
35 Wu X, Wang Z-F, Xu Y, Ren R, Heng B-L, Su Z-X. Association between three eNOS polymorphisms and cancer risk: a meta-analysis. Asian Pac J Cancer Prev 2014;15(13):5317–5324
36 Zhang L, Chen LM, Wang MN, et al. The G894t, T-786c and 4b/a polymorphisms in Enos gene and cancer risk: a meta-analysis. J Evid Based Med 2014;7(04):263–269
37 Khalkhali-Ellis Z, Hendrix MJC. Nitric oxide regulation of Maspin expression in normal mammary epithelial and breast cancer cells. Am J Pathol 2003;162(05):1411–1417
38 Schneider BP, Radovich M, Sledge GW, et al. Association of polymorphisms of angiogenesis genes with breast cancer. Breast Cancer Res Treat 2008;111(01):157–163
39 Yeh C-C, Santella RM, Hsieh L-L, Sung F-C, Tang R. An intron 4 VNTR polymorphism of the endothelial nitric oxide synthase gene is associated with early-onset colorectal cancer. Int J Cancer 2009;124(07):1565–1571
40 Khurana VG, Meissner I, Sohni YR, et al. The presence of tandem endothelial nitric oxide gene polymorphisms identifying brain aneurysms more prone to rupture. J Neurosurg 2005;102(03):526–531