Transoceanic Management and Treatment of Aneurysmal Subarachnoid Hemorrhage
A 10-Year Experience
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Background and Purpose—Because of the small number of yearly cases of ruptured cerebral aneurysms, endovascular treatment is not performed in Martinique. Therefore, patients from Martinique are sent 7000 km to Paris on commercial flights as soon as possible, where treatment is performed. Nontransportable patients are treated locally with either surgery or symptomatic care. The objective of our study was to assess patient outcomes and safety of this treatment strategy.

Methods—We retrospectively examined all cases of aneurysmal subarachnoid hemorrhage in Martinique diagnosed during 2004 to 2013. Medical case records were searched for the type and location of treatment, clinical status, and transfer duration.

Results—A total of 119 patients had an aneurysmal subarachnoid hemorrhage during the 10-year period. Of these, 91 were transferred to Paris, 12 were surgically treated locally, and 16 received symptomatic treatment. None of the transferred patients experienced any hemorrhagic recurrence, and none suffered a significant complication related to the air transportation. The median time between aneurysmal subarachnoid hemorrhage diagnosis and arrival at the referral center was 32 hours. The 30-day case fatality rate for treated cases was 14.6% (8.8% for those treated in Paris and 58.3% for those treated locally).

Conclusions—Our treatment strategy for aneurysmal subarachnoid hemorrhage resulted in a 30-day case fatality rate similar to those observed elsewhere, despite an 8-hour flight and a median treatment delay of 32 hours. This strategy therefore seems to be safe and reliable for isolated regions with small populations. (Stroke. 2018;49:127-132. DOI: 10.1161/STROKEAHA.117.017436.)

Key Words: endovascular procedures ■ intracranial aneurysm ■ medical records ■ subarachnoid hemorrhage ■ transportation

With a 30-day case fatality rate of around one third, these aneurysmal subarachnoid hemorrhage (aSAH) is the deadliest type of stroke, even though a decline in mortality rates has been seen over the past 25 years. Furthermore, approximately half of all survivors are left with some neurological deficit, cognitive impairment, or behavioral changes (some of these impairments being likely underestimated with usual assessment scales). The recurrence rate of bleeding in the first days after onset is high, and, thus, patients require treatment as soon as possible, usually within the first 24 hours after onset. Endovascular treatment has progressively become the first-line treatment in most countries since the year 2000. This treatment requires costly equipment, high medical expertise, and a sufficient patient volume to justify human and material investments. For these reasons, most parts of the world are currently not properly covered for this severe pathology. Moreover, some parts of the world will likely not be covered in the future because they are isolated or have small populations. This is the case in the Southern Caribbean islands, where the populations are small and the incidence of aneurysmal pathology is lower than in other parts of the world. In Martinique, the incidence of spontaneous SAH is 3.29 of 100,000 person-years, whereas the worldwide incidence rate is ≈9.1 of 100,000 person-years.

Faced with this situation of a low number of cases, our institution has put an original management plan into place. All patients with suspected SAH in Martinique are brought to our hospital, where an emergency computed tomography (CT) angiogram is performed. Patients with aSAH are transported, whenever possible, to Paris for endovascular treatment. Transportation of the patient occurs as soon as possible, accompanied by 2 members of medical staff (a doctor and a nurse), on a commercial air flight (duration ≈8 hours). When transfer is not possible, surgical or symptomatic treatments are performed locally.

We retrospectively reviewed all cases of ruptured cerebral aneurysms in Martinique and Paris from 2004 to 2013. The objective of this descriptive series was to assess the patient outcomes and safety of...
our treatment strategy, consisting of transferring patients with aSAH from Martinique to continental France.

**Subjects and Methods**

**Area of Investigation**

Martinique is a French island located in the south of the Caribbean basin. It is the most developed island in the Caribbean basin and is classified as high in terms of global human development at the world level. Its population (392,311 inhabitants in 2011) is composed mostly (95%) of French African Caribbeans, with the remaining 5% being French Caucasians. Medical care in Martinique is free of charge, allowing unrestricted access to high-quality medical services.

Martinique is in the northern hemisphere and is separated from continental France by the Atlantic Ocean, with a distance between the airports of Martinique and Paris of around 7000 km. There are 5 to 7 commercial air flights from Martinique to Paris each day. Planes depart from Martinique in the evening (17:00–21:00) and arrive in Paris, after a flight of around 8 hours, between 07:00 and 11:00 the following day. There is 5 or 6 hours difference between the time zones of Martinique and continental France (eg, when it is 19:00 in Paris, it is 13:00 or 14:00 in Martinique, depending on whether it is winter or summer time).

**Patient Management**

All cases of suspected stroke from the island are referred to the University Hospital of Martinique. If nontraumatic SAH is suspected, emergency CT and CT angiograms are performed. A team of 3 experienced neuroradiologists (between 12 and 25 years of experience) is in charge of the interpretation. When no aneurysm is seen, a cerebral digital subtracted angiography is performed. If an aneurysm is diagnosed, either on CT angiogram or digital subtracted angiography, the images are sent to a partner hospital center in Paris, which has a dedicated Interventional Neuroradiology team available 24/7.

In patients with obstructive hydrocephalus, an external ventricular drain is placed by a neurosurgeon. The medical transfer is then planned as soon as possible (eg, if the aneurysm is diagnosed in the morning, the patient is sent later on the same day; if the aneurysm is diagnosed after 15:00, the patient is usually sent the evening of the following day). Our hospital has a partnership with a commercial company allowing us to book 8 seats (in 2 rows near the windows) at very short notice (Figures 1 and 2). If regular passengers have already booked these seats, the company moves them to other seats or another flight. The patient is transported by ambulance to the plane 2.5 hours before the flight. The patient is accompanied by a doctor and by a nurse, both specialized in critical care.

The patient is secured to a stretcher and provided with cold and noise protection. Two wide-bore intravenous working cannulas are inserted before transfer, and pain is managed with opioid and paracetamol continuous intravenous infusion. As low humidity on planes can lead to dryness, hydration is performed with isotonic saline. Humidified oxygen is delivered nasally. Permanent monitoring (ECG, oxygen saturation, blood pressure, temperature, respiratory rate) is performed with a blood pressure target of 140/80 mm Hg and a peripheral oxygen saturation target >95%. Monitoring equipment is properly secured, and extra batteries are carried. If the patient is under mechanical ventilation, endotracheal and nasogastric tubes are properly secured. Patients are usually sedated using sufentanil and midazolam, and sometimes with curare. An intra-arterial catheter is secured for invasive blood pressure monitoring. Our institution has estimated that the mean cost of a 1-way transfer is 20,568 Euros (23,320 US$) per patient (comprising the cost of the flight, ambulance, human resources, and equipment).

On arrival in Paris, it takes ≈70 minutes to reach the hospital, where a CT scan is performed before the intervention. Endovascular treatment is performed on the day of arrival. In Paris, cerebral hemodynamics are monitored daily for 2 weeks by transcranial Doppler sonography. A vasospasm was considered present if the mean blood flow velocities in the middle cerebral artery were >100 cm/s or increased 25% in 24 hours. The treatment of vasospasm includes a medical component (oral nimodipine, hypervolemia) and, often, an endovascular component (intra-arterial injection of nimodipine and milrinone or intracerebral balloon angioplasty).

When transfer is not possible, usually in case of compressive hematoma (Figure 3) or, rarely, in case of hemodynamic instability, surgery is performed locally in Martinique. A team of 3 neurosurgeons with a modern operating facility is available 24/7; aneurysmal clipping is performed using a microsurgery technique. In patients with a very severe clinical condition, only symptomatic treatment is performed.

**Case Ascertainment**

All patients with aSAH diagnosed in Martinique between January 1, 2004, and December 31, 2013, were studied. Multiple overlapping methods of case ascertainment were used. First, the patient administration systems of our hospital were searched for all patients coded with the International Classification of Disease, Tenth Revision codes that defined nontraumatic SAH and with a discharge diagnosis consistent with SAH. Second, the operation database of our institution was searched for all patients who underwent aneurysm surgery during the study period. Third, the emergency medical department database was searched for all patients registered as having an SAH. For all recorded patients, the medical records were reviewed. Patients with arteriovenous or other malformations were excluded. Patients were only included if they presented with their first ever SAH. Patients with an intracerebral hemorrhage without SAH were included only if the origin of the bleeding was clearly identified as an intracranial aneurysm.

The following clinical data were assessed: age, sex, case fatality rate at 30 days, Glasgow Coma Score (GCS) at initial hospitalization, GCS at arrival in Paris, modified Rankin Scale score at discharge from the hospital (in Paris or Martinique), vasospasm detection and treatment (data only available in Paris), location and type of treatment, time between diagnosis and arrival at the referral center, mechanical

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**Figure 1.** Patient placement in the plane occupying 4 seats in a row: (A) stretcher alone above the seats near the window, (B) patient placement with some equipment placed under the stretcher. Four other seats are dedicated to the staff (1 doctor and 1 nurse) and the rest of the equipment. A light curtain shields the patient from view.
ventilation required in Martinique, external ventricular drain required in Martinique, significant neurological worsening (defined as GCS worsening >2), and complication(s) during transfer (drain extraction, extubation, need for intubation, hypovolemia, severe hypoxemia). This research was conducted according to the principles of the Declaration of Helsinki. The anonymized data that support the findings of this study are available from the corresponding author on reasonable request.

Statistical Analysis
A comparison of the 3 groups of patients (transferred to Paris, treated surgically in Martinique, treated symptomatically in Martinique) was performed. Comparison of qualitative data was performed with the $\chi^2$ test. Given that the Shapiro–Wilk W test demonstrated non-normality in the distribution of quantitative data, we used the median test for GCS comparison and the Kruskal–Wallis test for age comparison. Statistical significance was set at $P<0.05$. Data handling was performed using Microsoft Access V 7.0, and analysis was performed with SPSS software 22.1 for Windows (SPSS, Inc, Chicago, IL).

Results
During the 10-year study period, there were 119 patients with aSAH (mean age, 54.8 years; 68.1% women; Table). In 3 cases out of the 119, the hemorrhage was strictly parenchymatous.

Ninety-one cases (75.7%) were transferred to Paris, with a median time of 32 hours and 13 minutes (interquartile range, 20 hours 44 minutes; range, 12 hours 02 minutes–617 hours 16 minutes) between imaging diagnosis and arrival at the referral center in Paris. Endovascular treatment was performed in Paris in 89 cases, whereas 2 patients underwent surgical treatment (one because of an aortic coarctation, the other because of a blister-like aneurysm). None of the transferred patients had a bleeding recurrence or a significant complication during the flight. Six patients (6.6%) experienced a GCS worsening (because of an increase of parenchymal edema) between first assessment in Martinique and assessment on arrival in Paris (Table). Despite these 6 cases, the median GCS was still 15 on arrival at Paris. Among the 91 patients sent to Paris, a vasospasm was detected in 15 (16.5%), 13 of whom had endovascular treatment. The median modified Rankin Scale score at discharge from the Parisian hospital was 0.

Twenty-eight patients were not transferred to Paris, of whom 12 underwent aneurysmal surgical treatment and 16 received symptomatic treatment (Table). The patients who had surgical treatment in Martinique underwent surgery on the day of diagnosis ($n=10$) or after a delay of 1 day ($n=2$).

Not surprisingly, there were some significant differences in patient characteristics between the groups, as suitability for transfer was an important factor. The median GCS at diagnosis was significantly higher ($P<0.001$) among transferred patients than in the other 2 groups (Table). The mean ages of the treated groups (Paris or Martinique) were significantly lower than the group who underwent symptomatic treatment. Overall, the in-hospital case fatality rate at 30 days was 30 of 119 (25.2%). Among treated patients (Paris or Martinique), it was 15 of 103 (14.6%), whereas in the group of 16 patients who only received symptomatic treatment, 10 patients died on the same day as the first imaging was performed and 5 died between then and day 30. Only 1 patient of this last group did not die. This patient, despite an acceptable general clinical condition, refused any invasive treatment. Case fatality, mechanical ventilation, and GCS worsening rates were significantly lower among transferred patients than in the other 2 groups.

Figure 2. Stretcher installation and monitoring setting by the accompanying medical staff before the flight.

Figure 3. Example of a 46-year-old female patient who could not be transferred to Paris because of a major parenchymal hematoma caused by a middle cerebral artery aneurysm: (A) computed tomography (CT) angiogram showing the aneurysm, (B) and (C) noncontrast CT scanner showing the parenchymal hematoma with a herniation). She underwent emergency surgery and eventually survived with a modified Rankin Scale score of 5.
Discussion

In this case series, the overall 30-day case fatality rate of our patients is similar to modern population-based studies from the literature.²,⁶ This included an 8.8% case fatality for patients transferred to Paris—despite a median delay of 32 hours 13 minutes because of trans-Atlantic transfer. We know that treatment in a high-volume hospital reduces morbidity and mortality.⁷,⁸ An activity threshold of 20 cases per year used to be considered suitable,⁹,¹⁰ but a more recent study showed that the impact of caseload on outcome persists well beyond this threshold.⁸ In France, a neurointerventional center accepting patients with aneurysms for endovascular treatment is required to treat at least 80 patients per year. Regionalization policies have been put in place worldwide during the past 20 years, based on the assumption, proven first in surgery, that highly experienced teams obtain better clinical outcomes.¹⁰ This has also been proven for the endovascular treatment of SAH.⁸ Such organization is also cost-effective,¹⁰ as a significant outcome improvement because of a high-volume hospital can justify the extra transfer costs. We know that transfer is not associated with bad outcomes but it is, not surprisingly, responsible for a longer length of stay and higher cost.¹¹

This regionalization policy implicitly implies a short duration of transfer (to lower both the delay before treatment and the cost of transportation). As the number of cases in our hospital would only be ≈12 per year, it makes sense to transfer our patients to a high-volume center. As there is no center close enough for helicopter transfer, we chose airplane transportation. The closest centers with flight routes are San Juan (PR) at 687 km and Miami (FL) at 2345 km (a 3-hour, 45-minute flight), but these destinations are not served by daily flights. Chartering a dedicated plane would certainly shorten the time between diagnosis and departure time but would be very expensive. Also, transferring patients to a foreign country raises problems including language and regulatory issues (visa, payment), which do not exist between Martinique and continental France. Therefore, we send our patients to Paris, the only route with multiple daily commercial flights. Our patients are then treated at a high-volume center, which treats around 300 aneurysms per year (60 ruptured and 240 unruptured). We acknowledge that our trans-Atlantic strategy is costly, in terms of flight costs and medical resources. Currently, each territory of the Lesser Antilles deals separately with its own airline routes, hospital partnerships, health insurance system, and regulatory issues. In most parts, neurosurgical and neuroradiological facilities are lacking. If patients have a sufficient insurance or can afford the cost of treatment, they are referred to Trinidad and Tobago or to the United States. The population of the Lesser Antilles (from Saint-Martin to Grenada) comprises around 2000000 inhabitants, with an approximate potential of 80 aSAH per year (at a yearly hypothetical incidence of 4/100000). Therefore, 1 single center could handle all of the cases in this area within a maximum flight time of 2 hours. However, this would require international cooperation.

None of our transferred patients experienced any significant complications during the flight, which we attribute

### Table. Characteristics of Aneurysmal Subarachnoid Hemorrhage Patients by Type and Location of Treatment (119 Patients)

<table>
<thead>
<tr>
<th></th>
<th>Paris Treatment</th>
<th>Martinique Surgery</th>
<th>Martinique Symptomatic Treatment</th>
<th>P Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cases, n (%)</td>
<td>91 (75.7)</td>
<td>12 (10)</td>
<td>16 (14.1)</td>
<td>…</td>
</tr>
<tr>
<td>Mean age, y</td>
<td>53.0</td>
<td>53.6</td>
<td>65.8</td>
<td>0.04</td>
</tr>
<tr>
<td>Women, n (%)</td>
<td>60 (65.9)</td>
<td>9 (75.0)</td>
<td>12 (75.0)</td>
<td>0.6</td>
</tr>
<tr>
<td>Median GCS</td>
<td>15</td>
<td>6</td>
<td>3</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Mechanical ventilation, n (%)</td>
<td>17 (18.7)</td>
<td>10 (83.3)</td>
<td>12 (75.0)</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Worsening,* n (%)</td>
<td>6 (6.6)</td>
<td>8 (75.0)</td>
<td>15 (93.7)</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>External ventricular drain, n (%)</td>
<td>10 (11.0)</td>
<td>5 (42)</td>
<td>1 (6)</td>
<td>0.01</td>
</tr>
<tr>
<td>30-d case fatality rate, n (%)</td>
<td>8 (8.8)</td>
<td>7 (58.3)</td>
<td>15 (93.7)</td>
<td>&lt;0.001</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Discharge mRS,† n (%)</th>
<th></th>
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</thead>
<tbody>
<tr>
<td>0</td>
<td>43 (51.8)</td>
<td>0</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>13 (15.7)</td>
<td>0</td>
<td>1 (100)</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>12 (14.5)</td>
<td>0</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>5 (6.0)</td>
<td>2 (40.0)</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>4 (4.8)</td>
<td>0</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>5 (6.0)</td>
<td>3 (60.0)</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>Unknown</td>
<td>1 (1.2)</td>
<td>0</td>
<td>0</td>
<td></td>
</tr>
</tbody>
</table>

GCS indicates Glasgow Coma Score; and mRS, modified Rankin Scale.
*Clinical or radiological.
†Score at discharge from hospital for patients who survived >30 days.
to the experience of our dedicated accompanying medical team. Our institution transfers >100 patients each year over the Atlantic Ocean, including very complex cases such as extracorporeal membrane oxygenation patients. We observed a GCS worsening in 6.6% of transferred patients, not related to rebleeding or hydrocephalus, but we know that GCS may vary over time in patients with parenchymal edema. Rebleeding is a major complication and is the main rationale for rapid treatment, but it did not occur during the flight in any of our patients. There used to be a debate over the effect of cabin pressure on the risk of rebleeding, but this has never been proven and there is no ban on air transportation of this pathology. Also, as commercial aircraft are not pressurized to ground-level pressure, but rather to a pressure between ground-level and a maximum equivalent cabin altitude of 8000 feet, it may theoretically impact cerebral perfusion in sick patients. The partial pressure of oxygen is 149 mm Hg at sea level, but 108 mm Hg at 8000 feet, resulting in a lower fraction of inspired oxygen. This is sufficient for healthy individuals but frequently results in short events of hypoxemia (oxygen saturation <90%) in some patients, even though it remains unclear whether it may be injurious without a parenchymal brain lesion. Therefore, a continued monitoring of oxygen saturation is necessary and an oxygen supplementation is required.

We did not notice any hydrocephalus worsening after the flight, which we attribute to the fact that a decision for external drainage is taken with even early signs of hydrocephalus, as this cannot be performed during >11 hours of flight and ambulance transfer. Vasospasm is another main complication and has been reported to increase with transfer and delay to emergency department. Cooperation of the airplane staff is also required to they quickly have to liberate 8 contiguous seats on the day of departure. Cooperation with the airline companies is also crucial, as they quickly have to liberate 8 contiguous seats on the day of departure. Cooperation of the airplane staff is also required to install the patient and reduce or avoid any disagreement for other passengers during the flight.

Our overall 30-day case fatality rate of 58.3% for patients treated surgically in Martinique is high but is consistent with the initial severity of these patients. Only the most difficult cases (with major bleeds, intracranial hypertension, and brain edema) are treated surgically in Martinique. This highlights the difficult challenge faced by our neurosurgeons, who have very few cases (only 1 or 2 per year), to maintain their expertise in this demanding surgery.

As with all studies, our study has some limitations. The retrospective design of our study did not allow us to assess the long-term outcome of our patients (dependency, quality of life, etc), and we were not able to retrieve data on the rate of vasospasm among patients treated in Martinique. Also, we were not able to determine the exact time of treatment in Paris, but it is usually performed on the day of arrival. Finally, the small sample of our population (especially for the Martinique surgery and symptomatic treatment groups) limits the generalization of our results.

**Conclusions**

Our study is the first to describe a long-term (>10 years) and routine (around 12 per year) transoceanic management and transportation of patients with aSAH. We showed that this management strategy is safe and generates a delay of around 1 day before endovascular treatment. This management of patients with severe pathologies in an emergency setting could be duplicated elsewhere. However, it requires international cooperation as, in some parts of the world, one dedicated and specialized center could treat all patients (after airplane transportation) to reach a critical threshold required to have suitable expertise and be economically sustainable.

**Acknowledgments**

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**Disclosures**

None.

**References**


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