Intracerebral hemorrhage secondary to intravenous and endovascular intraarterial revascularization therapies in acute ischemic stroke: an update on risk factors, predictors, and management

MAXIM MOKIN, M.D., PH.D., 1,2 PETER KAN, M.D., M.P.H., 3,4 TAREQ KASS-HOUT, M.D., 1,2 ADIB A. ABLA, M.D., 3,4 TRAVIS M. DUMONT, M.D., 3,4 KENNETH V. SNYDER, M.D., PH.D., 3,4–6 L. NELSON HOPKINS, M.D., 3,4–6 ADNAN H. SIDDIQUI, M.D., PH.D., 3,4–6 AND ELAD I. LEVY, M.D. 3,4–6

Departments of 1Neurology, 2Neurosurgery, and 3Radiology, and 4Toshiba Stroke Research Center, School of Medicine and Biomedical Sciences, University at Buffalo, State University of New York; and Departments of 2Neurology and 4Neurosurgery, Millard Fillmore Gates Circle Hospital, Kaleida Health, Buffalo, New York

Intracerebral hemorrhage (ICH) secondary to intravenous and intraarterial revascularization strategies for emergent treatment of acute ischemic stroke is associated with high mortality. ICH from systemic thrombolysis typically occurs within the first 24–36 hours of treatment initiation and is characterized by rapid hematoma development and growth. Pathophysiological mechanisms of revascularization therapy-induced ICH are complex and involve a combination of several distinct processes, including the direct effect of thrombolytic agents, disruption of the blood-brain barrier secondary to ischemia, and direct vessel damage from wire and microcatheter manipulations during endovascular procedures. Several definitions of ICH secondary to thrombolysis currently exist, depending on clinical or radiological characteristics used. Multiple studies have investigated clinical and laboratory risk factors associated with higher rates of ICH in this setting. Early ischemic changes seen on noncontrast CT scanning are strongly associated with higher rates of hemorrhage. Modern imaging techniques, particularly CT perfusion, provide rapid assessment of hemodynamic parameters of the brain. Specific patterns of CT perfusion maps can help identify patients who are likely to benefit from revascularization or to develop hemorrhagic complications. There are no established guidelines that describe management of revascularization therapy–induced ICH, and great variability in treatment protocols currently exist. General principles that apply to the management of spontaneous ICH might not be as effective for revascularization therapy–induced ICH. In this article, the authors review current knowledge of risk factors and radiological predictors of ICH secondary to stroke revascularization techniques and analyze medical and surgical management strategies for ICH in this setting.

(key Words • acute ischemic stroke • intracerebral hemorrhage • intravenous thrombolysis • endovascular intervention • computed tomography • blood pressure

According to the most recent report from the American Heart Association, 795,000 people in the US experience a new or recurrent stroke each year, and 87% of these strokes are ischemic. Despite advances in treatment and rehabilitation strategies, stroke remains the leading cause of long-term disability in adults. A short time window for treatment (within the first 4.5 hours of stroke onset) and late arrival to the hospital are major barriers preventing many patients from receiving IV thrombolysis. Careful analysis of acute stroke care provided at multiple hospitals in the US shows that even some patients with no absolute contraindications for thrombolysis who present to the emergency department with the “therapeutic window” do not receive recommended thrombolytic therapy. Intracerebral hemorrhage secondary to thrombolysis is associated with high mortality and remains the most feared complication of acute stroke treatment. In fact, it is often cited as a primary reason preventing patients from receiving fibrinolytic agents to restore blood flow to the brain. Endovascular interventions with IA thrombolytic
agents or by means of mechanical revascularization strategies demonstrate high recanalization rates in strokes with large artery occlusion and can be performed with an extended time window or when contraindications for IV thrombolysis are present. Theoretical models have projected that IA therapies for acute stroke secondary to large-vessel occlusion will be used in up to 10,400–41,500 cases per year in the US. However, similar to IV thrombolysis, endovascular interventions carry a risk of ICH. Recent advances in stroke imaging allow selection of patients who can benefit the most from revascularization and prediction of which patients are at higher risk for hemorrhagic complications.

In this article, we review the current literature on clinical and laboratory risk factors and radiological predictors of ICH secondary to IV and IA revascularization therapies in patients presenting with acute ischemic stroke, as well as analyzing strategies for managing this iatrogenic complication.

**Frequency and Definition**

Intracerebral hemorrhage after systemic thrombolysis typically occurs within the first 24–36 hours after initiation of treatment. In the landmark NINDS tPA Stroke Trial, most hemorrhages occurred within the first 6 hours from tPA infusion. Several definitions of thrombolysis-induced symptomatic ICH (sICH) currently exist, depending on the clinical or radiological characteristics considered. According to the NINDS definition, a hemorrhage is considered symptomatic if it is associated with any decline in neurological status. An alternative definition of sICH frequently used in many clinical trials is deterioration of 4 or more points in the NIHSS score. When comparing the frequency of sICH among trials evaluating different revascularization strategies, it should be taken into account that the rates can vary significantly, depending on the definition chosen. For example, in a recent study of 985 ischemic strokes, the frequency of sICH ranged from 2.1% to 9.4% when different definitions of sICH were applied. Likewise, the ECASS III trial, which tested IV tPA administered between 3 and 4.5 hours after stroke onset, demonstrated a wide range of sICH rates (2.4%–7.9%), depending on specific criteria used to define sICH.

Table 1 summarizes the rates of sICH and sICH-related mortality in major international stroke trials conducted during the last 2 decades. The rate of sICH following administration of IV tPA within the first 3 hours of acute stroke was 6.4% in the original NINDS tPA trial. The SITS-MOST provided valuable information about the safety of administering IV tPA within 0–3 hours in routine clinical practice. In this large observational study, a total of 6483 patients were enrolled from 285 centers in the European Union (of which half had little previous experience with stroke thrombolysis).

**TABLE 1: Rate and definition of sICH in major international stroke trials**

<table>
<thead>
<tr>
<th>Authors &amp; Year</th>
<th>Study</th>
<th>Protocol</th>
<th>Rate of sICH</th>
<th>Definition of sICH</th>
<th>Mortality Due to sICH</th>
</tr>
</thead>
<tbody>
<tr>
<td>NINDS rt-PA Stroke Study Group, 1995</td>
<td>NINDS tPA</td>
<td>IV tPA (0.9 mg/kg) w/in 3 hrs of stroke on set</td>
<td>6.4%</td>
<td>any decline in neuror status</td>
<td>47%</td>
</tr>
<tr>
<td>Hacke et al., 1995</td>
<td>ECASS I</td>
<td>IV tPA (1.1 mg/kg) w/in 6 hrs of stroke on set</td>
<td>10.7%</td>
<td>24-hr deterioration</td>
<td>53%</td>
</tr>
<tr>
<td>Hacke et al., 1998</td>
<td>ECASS II</td>
<td>IV tPA (0.9 mg/kg) w/in 6 hrs of stroke on set</td>
<td>8.8%</td>
<td>clinical worsening (e.g., drowsiness) or worsening in NIHSS score by ≥4 points</td>
<td>44% “at 7 days”</td>
</tr>
<tr>
<td>Hacke et al., 2008</td>
<td>ECASS III</td>
<td>IV tPA (0.9 mg/kg) btwn 3 &amp; 4.5 hrs after stroke on set</td>
<td>2.4%</td>
<td>worsening in NIHSS score by ≥4 points</td>
<td>9.4%</td>
</tr>
<tr>
<td>del Zoppo et al., 1998</td>
<td>PROACT I</td>
<td>IA pro-UK (6 mg) w/in 6 hrs of stroke on set in pts w/ MCA occlusion</td>
<td>15.4%</td>
<td>neurodeterioration w/in 24 hrs of treatment</td>
<td>25%</td>
</tr>
<tr>
<td>Furlan et al., 1999</td>
<td>PROACT II</td>
<td>IA pro-UK (9 mg) w/in 6 hrs of stroke on set in pts w/ MCA occlusion</td>
<td>10.2%</td>
<td>neurodeterioration w/in 24 hrs of treatment</td>
<td>NR</td>
</tr>
<tr>
<td>Smith et al., 2005</td>
<td>MERCI</td>
<td>mechanical embolectomy w/in 8 hrs of stroke on set in pts ineligible for IV tPA</td>
<td>7.8%</td>
<td>worsening in NIHSS score by ≥4 points or any subarachnoid blood on CT scan</td>
<td>NR</td>
</tr>
<tr>
<td>Smith et al., 2008</td>
<td>Multi MERCI</td>
<td>mechanical embolectomy w/in 8 hrs of stroke on set in pts w/ persistent large-vessel occlusion after IV tPA</td>
<td>9.8%</td>
<td>worsening in NIHSS score by ≥4 points</td>
<td>NR</td>
</tr>
<tr>
<td>IMS Study Investigators, 2004</td>
<td>IMS I</td>
<td>0.6 mg/kg IV tPA started w/in 3 hrs of stroke on set followed by IA tPA</td>
<td>6.3%</td>
<td>any decline in neuro status w/in 36 hours of treatment</td>
<td>28% “at 7 days”</td>
</tr>
<tr>
<td>IMS II Trial Investigators, 2007</td>
<td>IMS II</td>
<td>0.6 mg/kg IV tPA started w/in 3 hrs of stroke on set followed by IA tPA using small-vessel US infusion system</td>
<td>9.9%</td>
<td>any decline in neuro status w/in 36 hrs of treatment</td>
<td>NR</td>
</tr>
</tbody>
</table>

* neuro = neurological; NR = not reported; pro-UK = pro-urokinase; pts = patients; US = ultrasound.
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The rate of sICH (according to the NINDS definition) was 7.3%, indicating that systemic thrombolysis administered outside a clinical trial was associated with a similar complication rate.

Accurate comparison of sICH rates for different IA revascularization approaches is complicated because often more than one treatment modality is used to achieve successful revascularization. In many large prospective studies, the trial design allows patient enrollment after “failure” of systemic thrombolysis, whereas other patients can be taken directly for intervention because of eligibility for systemic IV tPA administration. Trials of IA pharmacological thrombolysis (PROACT I and II and IMS I and II) demonstrated a rate of sICH in the range of 6.3%–15.4%.8,14,23,24 When mechanical thrombectomy with the Merci retriever device (Concentric Medical) was tested for acute stroke treatment in the MERCI44 and Multi-MERCI43 trials, sICH occurred in 7.8% and 9.8% of patients, respectively. Aspiration thrombectomy with the Penumbra system (Penumbra, Inc.) utilizes continuous aspiration together with mechanical fragmentation of the clot. In the Penumbra Pivotal Stroke trial,41 which was designed to assess safety of the Penumbra system for treatment of acute stroke due to large-vessel occlusion within the first 8 hours of symptom onset, sICH occurred in 11.2% of patients. Although the overall rates of sICH following pharmacological and mechanical endovascular approaches to acute stroke treatment are higher compared with IV thrombolysis with tPA alone, these results should be interpreted with caution. Endovascular therapy is typically reserved for strokes in patients with higher NIHSS scores (scores of 8–10 and above, depending on the trial design) and within a more extended time window (up to 6–8 hours of stroke onset). Both severity of baseline NIHSS score and extended treatment window are well-known risk factors for sICH (which we discuss in further detail later in this article), raising an argument that patients eligible for endovascular treatment are more prone to develop sICH due to the natural history of these strokes.

Intracerebral hemorrhage as a result of acute stroke treatment (either with IV or IA approaches) should be distinguished from ICH that can occur from a hyperfusion syndrome following endarterectomy or carotid artery stenting in patients with carotid artery stenosis. This syndrome is thought to be caused by impaired cerebral autoregulatory mechanisms and usually occurs a few days after the surgery, although delayed presentations for up to several weeks have been described.39,48 The most catastrophic presentation associated with this syndrome—ICH—occurs in up to 1%–2% of patients who undergo carotid artery interventions, according to previously published retrospective studies of case series summarized in a review article by Moulakakis et al.34 Radiographically, ICH can be classified on the basis of size of hemorrhage, as well as extent of ischemic infarct. This principle is applied in the ECASS classification scheme, in which hemorrhagic transformation after IV thrombolysis can be divided into 4 categories.13 Examples of these categories are shown in Fig. 1. Hemorrhagic infarction types 1 and 2 (HI-1 and HI-2) are defined as small petechiae along the margins of the infarct and larger more confluent petechiae without a space-occupying effect, respectively. Parenchymal hematoma Type 1 (PH-1) is defined as hemorrhage in less than 30% of the infarcted area, with some mild space-occupying effect representing parenchymal hematoma Type 1 (PH-1) hemorrhage. D: A large hematoma with significant space-occupying effect is characteristic of PH-2 hemorrhage.

**Fig. 1.** Noncontrast CT scans showing examples of radiographic types of revascularization-induced ICH, according to the ECASS classification. A: Right MCA stroke with small petechial hemorrhage representing hemorrhagic infarction Type 1 (HI-1). B: Right internal capsule stroke with larger confluent petechial hemorraghes within the infarct core representing HI-2. C: Left parietooccipital stroke with hemorrhage in less than 30% of the infarcted area and some mild space-occupying effect representing parenchymal hematoma Type 1 (PH-1) hemorrhage. D: A large hematoma with significant space-occupying effect is characteristic of PH-2 hemorrhage.

**Mechanisms**

Pathophysiological mechanisms of revascularization therapy–induced ICH are complex and include a combination of several distinct processes. Direct thrombolytic effects of pharmacological agents can occur parallel to
blood-brain-barrier alteration, which is triggered by ischemia. Spontaneous hemorrhagic transformation and edema formation are frequently observed in large strokes due to major artery occlusion. When occurring at the same time, these processes potentiate hematoma formation, causing rapid growth of intraparenchymal hematomas. Recanalization strategies introduce the risk of reperfusion hemorrhage, and wire and catheter manipulation in cases of IA interventions can cause direct damage to the endothelial wall. A combined analysis of the IMS I and II trials, as well as local registries of IA cases, showed that microcatheter contrast injections during IA thrombolysis also increase hemorrhagic risk, potentially due to degradation of the basal lamina.

Clinical and Laboratory Predictors

Many studies have addressed various clinical and laboratory risk factors associated with higher rates of ICH, predominantly in patients who received IV thrombolysis with tPA. In general, these factors can be divided into modifiable types (such as baseline blood pressure, serum glucose level, or lytic dose) and nonmodifiable types (such as admission NIHSS score, age, and comorbid conditions). Here, we will review only those factors that are of greatest importance in clinical practice when evaluating potential candidates for revascularization approaches.

Severity of NIHSS score and its correlation with higher rates of ICH has been a subject of multiple study analyses since the NINDS tPA trial investigators showed that patients with higher admission NIHSS scores were at greater risk for development of sICH. In patients with NIHSS scores lower than 10, the rate of sICH was 3%, compared with 17% in patients with an NIHSS scores of 20 or greater. This relationship between severity of stroke symptoms and increased risk of hemorrhage was later confirmed by studying a large number of patients receiving IV tPA for acute ischemic stroke treatment in routine clinical practice. The higher baseline NIHSS scores of patients enrolled in IA revascularization trials is one potential explanation for the higher rates of ICH in these trials than in IV thrombolysis trials.

Elevated systemic blood pressure is frequently observed in patients who present with acute ischemic stroke. This is thought to represent a physiological response to brain ischemia, causing an increase in cerebral blood perfusion to maintain adequate oxygenation of brain “penumbra” (that is, brain tissue at risk). For patients to be eligible for IV thrombolysis with tPA, blood pressure should not exceed 185/110 mm Hg, according to the acute stroke management guidelines of the American Heart Association’s Stroke Council. During and within the first 24 hours following IV thrombolysis, blood pressure should be maintained at a level below 180/105 mm Hg. The guidelines indicate that similar blood pressure parameters should be applied to stroke patients treated with other acute reperfusion interventions, but no data currently exist to support this principle. In clinical practice, however, more conservative blood pressure parameters are often used for endovascular interventions, on the basis of evidence that higher NIHSS scores (an endovascular approach is typically reserved for patients with an NIHSS score ≥ 8) and frequent concurrent use of systemic anticoagulation further increase the risk for ICH.

Another important modifiable risk factor is glucose control. Hyperglycemia is responsible for blood-brain barrier damage through increased production of lactic acid and free radicals, as well as direct damage to the lipid-rich neuronal membrane. The desired range of blood glucose values is 80–140 mg/dl. To avoid causing hypoglycemia, treatment is often not recommended unless glucose values exceed 200 mg/dl.

Radiographic Predictors

When evaluating patients with suspected acute stroke, a noncontrast cranial CT scan is always part of the initial diagnostic algorithm, allowing rapid and accurate differentiation between ischemic and hemorrhagic strokes. Patients who are candidates for an endovascular approach often undergo a CT angiogram. This study allows direct visualization of vascular anatomy and identification of potential sites of vessel occlusion. Although CT perfusion imaging is not (yet) a component of clinical trials or standard evaluation protocols, its utilization has markedly increased at stroke centers. For example, in the ongoing IMS III trial, the investigators noticed more frequent use of CT angiograms and perfusion studies for assessment of patients with acute stroke during the past 5 years, both at academic centers and at community hospitals. With rapid advancement in imaging technologies, radiographic findings are becoming a promising tool in predicting risk of hemorrhagic complications due to stroke revascularization therapies.

Noncontrast CT Scanning. Multiple studies have demonstrated that early ischemic changes, especially hypodensity on a noncontrast CT scan, are strongly associated with higher rates of thrombolysis-induced hemorrhage. Unfortunately, during the first few hours of stroke symptom onset, these findings can be rather subtle and thus are interpreted with great variability, even by experienced clinicians. Current recommendations for imaging of acute ischemic stroke state that frank hypodensity on noncontrast CT scans, particularly if occupying more than one-third of the MCA territory, is a strong contraindication to treatment with IV thrombolitics owing to a high chance of hemorrhagic complication.

Several scoring scales have been proposed in an attempt to simplify evaluation of noncontrast images when estimating risk of hemorrhagic transformation. The most commonly used scale, the ASPECTS, is a 10-point grading system that divides the MCA territory into 10 regions of interest. Subcortical structures are allotted 3 points; MCA cortex is allotted 7 points; and 1 point is subtracted for each area displaying early ischemic change. Patients with ASPECTS below 8 are at substantially higher risk of thrombolysis-related ICH.

Intracerebral hematomas in the setting of endovascular interventions can sometimes be mistaken for contrast medium. Hyperdense lesions of various degrees of intensity can be found in up to 50% of interventional cases, and some of these do not represent hemorrhage and are

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benign. Early differentiation is clinically important when deciding whether to continue systemic anticoagulation therapy or treatment with antiplatelet agents. Yoon et al.52 described 2 distinct imaging features of contrast medium in an attempt to differentiate it from hemorrhage. First is contrast enhancement, which shows rapid clearance of a hyperdense lesion on follow-up CT scans and does not produce any mass effect. Second is contrast extravasation, which is characterized by a mixture of blood and contrast material. It typically exhibits extremely high density on CT studies and, unlike contrast enhancement, is associated with poor neurological outcomes. Two illustrative cases of hyperdense signal due to contrast medium and ICH following interventional procedures are shown in Fig. 2. Disruption of the blood-brain barrier, especially at the core of the cerebral infarct, is believed to be the underlying mechanism of extensive contrast extravasation. An iodine-induced signal can be subtracted from the brain CT scan using dual-energy CT technology and virtual imaging, allowing accurate differentiation between ICH and iodinated contrast medium staining.17 Although this technique does not require extra doses of radiation and appears to have great potential for clinical practice, its use at the present time is limited to major clinical research centers.

Computed Tomography Perfusion Imaging. The use of CT perfusion provides rapid assessment of hemodynamic parameters of the brain. With the introduction of 320–detector row CT perfusion scanners, perfusion maps of the whole brain (including posterior fossa structures) can now be rapidly obtained in minutes.40 Two illustrative cases of CT perfusion findings in patients with ischemic stroke who received emergent endovascular interventions are shown in Figs. 3 and 4. Matched areas of decreased CBV, CBF, and MTT represent areas of the brain with irreversible ischemic damage.31 When only CBF or MTT is compromised but CBV is preserved, indicating salvageable tissue known as “penumbra,” recanalization techniques can reverse ischemic damage to the brain tissue. Identification of brain regions with decreased CBV, especially when combined with the ASPECTS grading system, can help identify patients who are at higher risk for hemorrhagic complications from both IV and IA therapies.15 Larger infarct core size, which is characterized by significant loss of CBV, is a strong predictor of hemorrhage and poor outcomes. Given the wide availability of CT perfusion scanners and short imaging protocol times, CT perfusion is becoming more commonly used in evaluating patients with acute stroke.

The endovascular approach to acute stroke allows
extension of the treatment window compared with IV thrombolysis. A real-world experience with patient selection for endovascular therapy on the basis of CT perfusion findings shows a similar rate of ICH in those who had favorable CT perfusion findings irrespective of time constraints and those who had time-guided selection (0–6 hours from symptom onset to endovascular procedure). This suggests that in properly selected patients, ischemic stroke can be safely treated beyond the current recommended time intervals without significantly increasing the rate of hemorrhagic complications.

Management

In contrast to several existing reports of well-defined clinical, laboratory, and radiographic risk factors and predictors, few studies have addressed efficacy of management strategies in ICH secondary to revascularization therapies in acute ischemic stroke. Therefore, general principles that apply to management of spontaneous ICH might not be as effective for thrombolysis-induced ICH.

Medical Management

According to the American Heart Association guidelines, infusion of platelets and cryoprecipitate is recommended to reverse coagulopathy secondary to systemic administration of tPA. Intraarterial stroke interventions often include use of heparin infusion; in these cases, protamine sulfate can be used to reverse the systemic effect of heparin. However, the guidelines do not address the optimal range of blood pressure parameters. Large parenchymal hemorrhages (PH-2 according to the ECASS classification) strongly correlate with poor neurologic outcome and high mortality rate, whereas petechial hemorrhages do not seem to affect long-term outcomes. Therefore, more aggressive blood pressure management might be justified in cases of thrombolysis complicated by large parenchymal hematomas. On the other hand, patients with strokes with smaller petechial hemorrhages might benefit from a less aggressive approach allowing higher blood pressure to preserve blood perfusion to the “penumbra.” A quantitative analysis of hematoma volumes and blood pressure measurements during and immediately after IV tPA administration showed that early blood pressure reduction can have a significant effect on hematoma expansion. The majority of patients included in this study had at least one blood pressure reading above the American Heart Association’s recommended 180/105 mm Hg parameters, demonstrating that deviations from treatment protocols are associated with higher rates of ICH. Blood pressure variability—not just an increase in absolute blood pressure parameters—might also contribute to hemorrhagic transformation. Patients with higher variability of both systolic and diastolic blood pressure measurements showed increased rates of hemorrhagic transformation, possibly due to rupture of vessels within the ischemic core as a result of sudden rises in blood pressure. In a retrospective analysis of data from patients with ICH secondary to IV and IA thrombolysis, Goldstein et al. found great variability in treatment protocols, including use of fresh frozen plasma, platelets, cryoprecipitate, phytonadione, and aminocaproic acid. Analysis of treatment records showed that very few patients received the same treatment regimen. The small number of patients with data available for analysis and the wide range of treatment strategies precluded the determination of whether any specific therapy was associated with improved clinical outcomes. Forty percent of patients showed a significant increase in hematoma size, despite

Fig. 3. A: Noncontrast CT scan and perfusion maps obtained in a patient with acute stroke from a left internal carotid artery occlusion (NIHSS score 12). The perfusion maps demonstrate markedly increased time-to-peak (upper right) in the left hemisphere but preserved CBV (upper middle), indicating a significant amount of brain tissue at risk (penumbra). The patient subsequently underwent mechanical thrombectomy. B: Follow-up CT scan showing no postintervention hemorrhage.
reversal of coagulopathy. Rapid hematoma expansion due
to IV thrombolysis with tPA was confirmed by another
recent study that reported an even more dramatic 74% in-
crease in the size of the ICH, as demonstrated by 2 serial
CT scans performed only 9 hours apart. These 2 studies
clearly show that more effective treatment strategies are
needed to achieve better control of hematoma expansion.

Surgical Management

To date, the effect of decompressive surgery in pa-
tients with revascularization therapy–induced ICH has
not been studied in a randomized trial. In patients with
malignant MCA strokes, 3 randomized clinical trials [De-
compressive Craniectomy in Malignant Middle Cerebral
Artery Infarcts [DECIMAL], Decompressive Surgery for
the Treatment of Malignant Infarction of the Middle Cer-
rebral Artery [DESTINY], and Hemicraniectomy After
Middle Cerebral Artery Infarction with Life-threatening
Edema Trial [HAMLET]] showed that hemicraniectomy
performed within the first 48 hours of stroke onset leads
to reduction of mortality and improvement of functional
outcomes compared with medical therapy alone. However, patients who received IV thrombolysis or had
hemorrhagic transformation resulting in a large paren-
chymal hematoma were excluded from enrollment in all
three trials.

Williams et al. reported 2 cases of patients who un-
derwent decompressive hemicraniectomy postthrombol-
sis. No significant intra procedural complications related
to thrombolysis were noted, and both patients had favor-
able outcomes. In neither case was there any hemorrhagic
component to the initial stroke. Opposite results were
demonstrated in a study investigating in-hospital mortal-
ity in a large cohort of patients from multiple hospitals in
the US who underwent hemicraniectomy for large isch-
emic strokes. Mortality rates were significantly higher
in patients who were treated with thrombolysis and sub-
sequently underwent hemicraniectomy for life-threaten-
ing brain edema than in patients who were treated with
thrombolysis and did not undergo hemicraniectomy. No
information was provided whether any patients in the
hemicraniectomy group had thrombolysis-related ICH.

In one case report, a young patient with a left MCA
stroke who was treated with a combination of IV throm-
bolysis and IA thromboaspiration developed a large in-
sular hematoma immediate after the intervention and
underwent emergent craniectomy and hematoma evacu-
ation. Despite a high initial NIHSS score of 24, the pa-
tient made a significant recovery. In the study by Mokin
et al., cited above, 3 patients with thrombolysis-induced
ICH were treated surgically. One patient had PH-1; 2 pa-
tients had PH-2. Details of the surgical procedures were
not provided.

The limited number of publications suggests that sur-
gical evacuation of ICH after tPA or endovascular stroke
intervention is uncommon. More research is required to
determine which patients with ICH secondary to IV or
IA revascularization therapy can benefit from a surgical
approach. Given the relatively low number of such cases,
however, it is unlikely that a randomized trial addressing
this subject will be conducted in the near future.

Conclusions

A review of the literature demonstrates that the oc-
currence of ICH after IV tPA thrombolysis or endovas-
cular stroke intervention is multifactorial. Variability in
the definition of ICH associated with either treatment ap-
proach provides some limitations in the ability to draw
definitive conclusions from pooling the several large
studies described in this report. Prevention of ICH in
this setting involves careful patient selection using pre-

Fig. 4. A: Noncontrast CT scan and perfusion maps obtained in a patient with a left M, superior trunk occlusion (NIHSS score
12), showing a large area of increased MTT and time-to-peak penumbra, indicating potentially salvageable brain (upper middle
and bottom middle, respectively). However, the perfusion mapping shows significant signal loss in the left basal ganglia (upper
middle). B: Noncontrast CT scan obtained following mechanical thrombectomy and angioplasty, showing a parenchymal he-
matoma in the left basal ganglia.
viously described clinical and radiographic predictors of ICH and conscientious management of blood pressure and glucose values during and following IV thrombolysis and IA interventions. Management of revascularization therapy—induced ICH (by comparison with hemorrhage outside the ischemic realm) focuses on reversal of anticoagulation and/or antiplatelet effects of medications while instituting a tempered antihypertensive strategy without inducing hypotension. Surgical evacuation of ICH after tPA or endovascular stroke intervention is uncommon, and further studies are needed to determine which patients can benefit from such an approach.

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Address correspondence to: Elad I. Levy, M.D., University at Buffalo Neurosurgery, 100 High Street, Suite B4, Buffalo, New York 14203. email: e Levy@ubns.com.