Cerebral Hyperperfusion Syndrome: an urgent complication with imaging-based diagnosis.

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Learning objectives

Describe the clinical and radiological findings of hyperperfusion syndrome secondary to cerebral arterial revascularization procedures.

Present typical cases of patients diagnosed and treated in our hospital.
Background

Introduction:

Cerebral hyperperfusion syndrome (CHS) was first described by Sundt et al. (1981) as a clinical syndrome following carotid endarterectomy.

Carotid endarterectomy (CEA) is still regarded as the gold standard therapy for prevention of primary and secondary stroke in patients with significant carotid artery disease while carotid artery stenting (we include angioplasty without stent placement in the term CAS) has been emerged as a potential alternative to carotid endarterectomy under certain indications. Cerebral hyperperfusion syndrome (CHS) is a relatively rare but potentially devastating event that can complicate both techniques. Hyperperfusion syndrome can also occur after revascularization of other arteries, such as the vertebral arteries, the subclavian arteries, or even those located within the brain, mainly the middle cerebral artery (MCA), and extracranial-intracranial bypass.

There is a critical distinction between hyperperfusion and hyperperfusion syndrome.

Hyperperfusion is usually defined as a >100% increase in CBF compared to the preoperative baseline. Hyperperfusion following CEA occurs in 0.2% to 18.9% of patients. Some patients, after carotid revascularization, demonstrate only a modest increase in CBF, less than 100%. CHS is most common in patients with CBF increases of more than 100% compared with baseline values after carotid revascularization and is rare in patients with increases in perfusion less than 100% compared with baseline values. The key event in the expression of syndrome seems to be a combination of increased cerebral blood flow (compared with preoperative levels) with individualized disturbed cerebro-vascular autoregulation.

Clinical presentation:

CHS can develop at any time from immediately after surgery to up to a month later, but most patients develop symptoms within the first few days (mean 5 days). It consist in a clinical triad of ipsilateral headache, seizure and focal neurological symptoms occurring in the absence of cerebral ischemia. It is accompanied by post-operative hypertension in almost all patients.

Headache is common after CEA, occurring in around 62% of patients, but in most patients with well-controlled blood pressure, it is mild to moderate in severity. In CHS, headaches are typically severe, ipsilateral, pounding and migrainous in type, although in some patients they may be mild, intermittent, or even absent. The neurological deficit is usually cortical (e.g. hemiplegia, neglect, hemianopia, aphasia). Seizures may be focal or generalized. Features of increased intracranial tension such as vomiting and altered
sensorium are common. Intracranial hemorrhage (ICH) is the most extreme form of presentation, with high morbidity and mortality

**Pathophysiology:**

Two interlinked and synergistic mechanisms may lead to increased CBF.

First, impaired cerebral autoregulation seems to play a significant role. The normal brain has the ability to maintain constant intracranial pressure by its autoregulatory mechanisms, when a change in blood flow occurs. The main autoregulatory mechanism is the cerebrovascular reactivity, the ability of the arterioles to constrict or dilate in response to the alterations of blood flow or to other stimuli (ie, hypocapnia). Patients with extracranial carotid stenosis often present exhausted cerebrovascular reactivity. This situation represents a status of maximal vasodilatation of cerebral arterioles, in order to maintain sufficient cerebral blood supply, counterbalancing the reduced perfusion caused by a hemodynamically significant carotid lesion.

The second significant mechanism is postoperatively elevated systemic blood pressure. Both hypertensive and hypotensive alterations of blood pressure after carotid endarterectomy have been reported in up to 66% of patients following carotid endarterectomy. Although transient hypotension and bradycardia can occasionally be observed due to stimulation of the carotid body nerve, baroreceptor reflex failure after receptor denervation during CEA may contribute to hypertension after endarterectomy. Both cerebral hyperperfusion associated with cerebral edema and elevated intracranial pressure may lead to an increase of central and peripheral norepinephrine levels and a subsequent further elevation of the systemic blood pressure.

Increased CBF, which can not be controlled by autoregulatory mechanisms, leads to transudation of fluid into the pericapillary astrocytes and interstitium. This results in vasogenic white matter edema, especially in the vertebrobasilar circulation territory of the posterior parietal and occipital regions.

**Risk factors and prediction:**

Cerebral haemodynamics and cerebral autoregulation are individualized in each patient. CBF changes after revascularization vary, while there is no evidence directly linking the CBF modifications and the degree of stenosis. This could be explained by the different extent of collateral circulation available in each patient and by the autoregulatory mechanisms of the cerebral circulation stimulated after the detection of the hyperperfusion.

Definitive prediction of subgroups of patients as those at increased risk of developing CHS after CEA or CAS, is not feasible because of the complexity and the multifactorial contribution in the pathogenesis of the syndrome.
**Diagnosis:**

The diagnosis of CHS is based on the initial suspicion arising from the characteristic triad of headache, focal neurological deficit, and seizure after arterial revascularization. The differential diagnosis should include stroke and TIA. Seizures and altered consciousness favor the diagnosis of CHS.

**Prognosis:**

The prognosis of CHS depends on timely recognition of hyperperfusion and adequate treatment of hypertension before cerebral edema or ICH develops. The prognosis following ICH is very poor, with mortality of 36-63% and significant morbidity (80%) in the survivors. The prognosis of CHS in patients without ICH is more difficult to estimate, because symptom severity varies widely, but the outlook is clearly better, with very low mortality. Recent studies suggest lesser incidence of ICH and better prognosis when patients are identified and treated early.

**Hyperperfusion or reperfusion syndrome?**

Hyperperfusion is common in symptomatic patients, but it is not invariably present. With complex pathophysiology, and some patients showing only a modest increase in CBF (20-44% above baseline). Based on this finding, some authors have suggested that this syndrome should also be called "reperfusion syndrome" rather than hyperperfusion syndrome, to reflect the reperfusion injury effects.
Clinical presentation of hyperperfusion syndrome in the reviewed series

<table>
<thead>
<tr>
<th>Type of symptom</th>
<th>Incidence</th>
</tr>
</thead>
<tbody>
<tr>
<td>Deterioration of consciousness, confusion</td>
<td>37.1 %</td>
</tr>
<tr>
<td>Headache</td>
<td>30.6 %</td>
</tr>
<tr>
<td>Epileptic disturbances, focal seizures</td>
<td>25.8 %</td>
</tr>
<tr>
<td>Motor disturbances (hemiparesis, hemiplegia)</td>
<td>17.7 %</td>
</tr>
<tr>
<td>Abnormal speech, aphasia</td>
<td>6.4 %</td>
</tr>
<tr>
<td>Nausea</td>
<td>4.8 %</td>
</tr>
<tr>
<td>Intracranial hemorrhage</td>
<td>4.8 %</td>
</tr>
<tr>
<td>Psychotic disorders</td>
<td>3.2 %</td>
</tr>
<tr>
<td>Visual disturbances (hemianopsia)</td>
<td>3.2 %</td>
</tr>
<tr>
<td>Ataxia</td>
<td>1.6 %</td>
</tr>
</tbody>
</table>

Fig. 1

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Risk factors of hyperperfusion and cerebral hyperperfusion syndrome

Preoperative:
- Long standing increased BP with hypertensive microangiopathy
- Diabetes mellitus
- Increased age
- Recent contralateral CEA (<3 months)
- High grade ipsilateral carotid stenosis with poor collateral flow
- Contralateral carotid occlusion
- Incomplete circle of Willis
- Attenuated cerebrovascular reactivity after acetazolamide challenge

Perioperative:
- Intraoperative distal carotid pressure of <40 mmHg
- High doses of volatile halogenated hydrocarbon anesthetics
- Periprocedural cerebral infarction
- Intraoperative ischemia
- Refractory postoperative cerebral hyperperfusion

Postoperative:
- Postoperative hypertension
- Administration of anticoagulants or antiplatelet agents
- BP, Blood pressure; CEA, carotid endarterectomy.

Fig. 2

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Findings and procedure details

We present cases, diagnosed and treated in our center.

After the initial clinical suspicion, neuroimaging plays a crucial role because in addition to ruling out ischemic and hemorrhagic lesions it can reveal characteristic signs of hyperperfusion.

Given the widespread availability of CT, any acute neurological event after revascularization is usually studied with this technique. CT is most useful for ruling out hemorrhagic processes. Given that the initial symptoms of CHS can mimic stroke or TIA, CT can give us clues that argue against an ischemic stroke, because CT findings are usually normal after a TIA and are often normal within hours after a stroke. Diffusion MRI is the technique of choice to rule out acute ischemic stroke; MRI has shown that there are a greater number of embolic lesions up to 48 hours after CAS, although nearly all are asymptomatic.

Cerebral hyperperfusion

The imaging techniques that can demonstrate hyperperfusion are single-photon emission computed tomography (SPECT), positron emission tomography (PET), transcranial Doppler (TCD), CT and MRI.

CT in CHS typically reveals ipsilateral sulcal effacement and cerebral edema immediately following the onset of symptoms; these findings are considered indirect signs of hyperperfusion. CT findings early after the onset of symptoms can be completely normal, even when SPECT shows hyperperfusion.

Without doubt, T2-weighted and FLAIR MRI sequences are more precise in demonstrating areas of cerebral edema, and diffusion-weighted MRI makes it possible to rule out hyperacute ischemic lesions. However, normal findings on MRI do not exclude the presence of CHS. Both MRI and CT enable angiographic maps to be constructed to rule out arterial occlusions and perfusion maps can show local hyperemia.

Hypoperfusion before revascularization and especially hyperperfusion after revascularization are conditions that are closely related with CHS. TCD is the method most often used to detect these conditions because it enables variations in CBF to be calculated in real time. TCD has many advantages and multiple indications in cerebral vascular disease. TCD monitoring can provide direct and real-time information on MCA flow indicative of preoperative cerebral hypoperfusion, CVR, postoperative hyperperfusion, and emboli after CEA and CAS. Moreover, TCD is widely available,
noninvasive, and reproducible. It is important to do a baseline study to enable flow velocities before and after revascularization to be compared.

Perfusion CT has also contributed to our understanding of CHS. Findings of decreased CBF together with MTT prolongation and a slight increase in CBV indicate that blood vessels are dilated, thus confirming that the autoregulation mechanism is impaired.

Multislice dynamic susceptibility contrast MRI or perfusion-weighted MRI can also be used in the preoperative assessment of CBF. Perfusion sequences, however, are not quantitative and can only help in the absence of contralateral ICA stenosis.

PET has also provided valuable information about CHS: Cerebral oxygen saturation can serve as an indirect measure of CBF.
Fig. 3: Man, 64 years old. Hypertension, smoking. DL. ITA 18 months before. Remitted from another hospital for treatment of left ICA stenosis > 70%, symptomatic. Carotid left endarterectomy is performed with Dacron patch closure and suction drain. In the immediate postoperative period, presents a left neurological deficit. CT: normal (no hemorrhage). CTA: Postsurgical changes secondary to right CEA, with permeability of extra-and intracranial arteries. PCT: minimal increase of CBF in the anterior left circulation, with increased CBV in the sylvian region, compatible with hemispheric reperfusion. Clinic imaging findings are attributable to hyperperfusion syndrome. Full recovery after steroid therapy in the next hours.

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**Fig. 4:** Man. 83 yo, hypertension, smoking, severe COPD (high surgical risk). Previous stenting in right ICA by 90% symptomatic stenosis. Now: Left hemispheric ITA. CTA: 90% left ICA stenosis. Aplasia ACoP and A1 (isolated MCA territory).

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Fig. 5: DSA: Severe stenosis. PTA and Stent placement in left ICA without complications and good morphologic result.

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**Fig. 6:** In the postoperative period the patient presents mild left neurological symptoms. CT normal.

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**Fig. 7:** PCT and CTA show permeability of the ICA stent and increased flow in the territory of the left MCA, with prominence of the distal cortical branches of this artery. Diagnosed of hyperperfusion syndrome, is transferred to the stroke unit. The neurological outcome was favorable.

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Fig. 8: 75 year old woman, who was referred from another hospital for treatment of critical stenosis of ICA with episodes of amaurosis fugax. DSA shows pre-occlusive stenosis of right ICA, by densely calcified atheromatous plaque.

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Fig. 9: Placement of carotid stent without post-dilation because of high risk of hyper-perfusion syndrome. Good angiographic result, and 50% residual stenosis, with diameter recovery of the cervical ICA.

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Fig. 11: Four days later, she suffered repetitive episodes of loss of strength in the left side of the body. Doppler ultrasound shows ICA stent patency, and the flow acceleration at the origin of the right MCA. FLAIR and T2WI MR sequences show signal increased in right fronto-parietal region consistent with edema, which resolved almost completely in the control after one week. DWI MR: focal parietal microlesion with restricted diffusion that corresponds to microinfarction. The remaining areas of hyperintensity on FLAIR, and isointensity on diffusion are consistent with reperfusion.

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Fig. 10: Patient is asymptomatic and MRI shows almost resolution of lesions one week later (without new ischemic areas), which corroborates the diagnosis.

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**Fig. 12:** 79 years old woman. AHT, DM2, DL, Hyperuricemia. Antecedent of atherothrombotic right hemispheric stroke 12 years ago. NSTEMI. Hospitalized by repeated ITA of left brain hemisphere. US and CTA showed atheromatous plaques in both carotid bifurcations, being significative the right side. Right A1 hypoplasia. DSA shows severe stenosis >90%. Endovascular treatment was performed (PTA and Stent placement), successfully and without complications.

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Fig. 13: After the procedure the patient present uncontrolable blood pressure values, with confusional syndrome and right hemispheric symptoms. Urgent CT excluded hemorrhage and shows a hypodense lesion in the right parietal posterior region, compatible with edema. DWI rules out cerebral infarction, and Perfusion MR sequence suggests hyperperfusion. These findings were confirmed by FLAIR and T2WI MR (hyperintensity in the location described previously), with small cortical microbleeds.

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**Fig. 14:** Diagnosis is hyper perfusion syndrome again. MRI (FLAIR and T2WI) two weeks later is almost normal and patient is discharged without neurological symptoms.

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Conclusion

Patients with symptomatic arterial stenosis benefits from revascularization procedures, but also face a high risk of complications such as hyperperfusion syndrome (rare, but serious).

Unifying diagnostic criteria suggested include: headache, neurological deficit, and seizure due to ipsilateral haemorrhage after cerebral revascularization, with evidence of hyperperfusion measured by TCD, MRI or SPECT. TCD should be made available in all centres to identify patients with hyperperfusion who may benefit from aggressive post-operative blood pressure control. So, imaging plays a key role in the diagnosis and to establish the urgent treatment.
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