WATERSHED STROKES

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• I have no disclosures

"Under disclosure rules, I'm required to tell you I own stock in the company whose drug I'm prescribing."
BORDER ZONE OR WATERSHED INFARCTS ARE ISCHEMIC LESIONS THAT OCCUR IN CHARACTERISTIC LOCATIONS AT THE JUNCTION BETWEEN TWO MAIN ARTERIAL TERRITORIES. THEY COMPRISEx APPROXIMATELY 10% OF ALL ISCHEMIC STROKES

Internal Border Zone Infarcts
• The internal or subcortical border zones are located at the junctions of the anterior, middle and posterior cerebral artery territories with the Recurrent Artery of Heubner, lenticulostriate and anterior choroidal artery territories

External Border Zone Infarcts
• The external or cortical border zones are located at the junctions of the anterior, middle and posterior cerebral artery territories
External border zones—light blue
Internal border zones—red
INTERNAL BORDER ZONE INFARCTS

• Often manifests as a series of 3 or more lesions, each with a diameter of 3 mm or more, arranged in a linear fashion parallel to the lateral ventricle in the centrum semiovale or corona radiata (rosary/bead)

• Can be confluent or partial; perhaps a briefer episode of hemodynamic compromise leads to a partial infarct, while a confluent infarct may be manifested by step-wise hemiplegia related to a longer period of hemodynamic compromise

• Caused mainly by arterial stenosis or occlusion, usually paired with hemodynamic compromise

• Thought to be much less likely than external border zone infarcts to be secondary to emboli

• Often associated with a more poor prognosis and clinical deterioration when compared with external border zone infarcts
EXTERNAL BORDER ZONE INFARCT

- Typically wedge shaped or ovoid shaped, size is variable because of anatomic variation and minimal/maximal distribution of each of the large vessel territories (MCA, ACA, PCA) from person to person
- Also may vary secondary to the development of leptomeningeal collateral vessels
- Often caused by hemodynamic compromise and may pair with moderate or severe narrowing of the carotid or proximal cerebral arteries
- As opposed to internal border zone infarcts, microemboli from the heart or atheroembolic events can propagate to the cortical border zones; these areas have a lower perfusion than more proximal regions, so less ability to “wash out” the microemboli
  - Recent intraplaque hemorrhage/plaque rupture may play a role
- Patients often have a more benign clinical course and better prognosis than those with internal border zone infarcts, especially if unilateral or only in one border zone
<table>
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<th>Pattern</th>
<th>Type of Lesion</th>
<th>Borderzone Location</th>
<th>Example</th>
<th>Example on MRI</th>
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<td>4</td>
<td>***Cortical borderzone infarcts</td>
<td>Junctions between the cortical frontal, *ACA and MCA (A) or cortical occipital, MCA and **PCA</td>
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<td>(B) Paramedian borderzone infarct located between the MCA and the *ACA</td>
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<td>***Internal borderzone infarct</td>
<td>Infarct at the junction between the deep and the superficial arterial system of the MCA, a confluent pattern</td>
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<td>Infarct at the junction between the arterial system of the *ACA and MCA, a typical rosary-like pattern</td>
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**BORDER ZONE INFARCTS IN THE CEREBELLUM**

- These are usually < 2 cm in size and are seen at the borders of the AICA, SCA and PICA (and their branches)
- Due to stenosis or embolism. Embolic events can come from the heart or atherosclerotic disease
- May be seen with vertebral dissections
- Typically not disabling in and of themselves, but often coexist with large territorial lesions
- They can be silent if small, or similar in presentation to larger cerebellar infarcts, with vertigo and ataxia
Red is AICA
Dark Green is lateral SCA
Light Green is medial SCA
Dark Blue is lateral PICA
Light Blue is medial PICA
STAGES OF HEMODYNAMIC IMPAIRMENT

- In stage I impairment, a decline in cerebral perfusion pressure leads to autoregulatory vasodilatation of resistive vessels of the brain.
- This can be measured with various methods, including xenon-enhanced CT, CT perfusion, MR perfusion, SPECT and PET.
- Mainly, the modalities measure cerebral blood flow, cerebral blood volume and mean transit time.
- To measure cerebrovascular reactivity, cerebral blood flow measurements can be repeated after a vasodilatory challenge.
- Normally, an increase in CBF is expected; however, with hemodynamic compromise, the CBF is often not increased because autoregulation has already caused maximum vasodilatation in response to decreased CPP.
STAGES OF HEMODYNAMIC IMPAIRMENT

• In stage II, further reduction in CPP causes inadequate autoregulatory vasodilation, and CBF decreases
• As blood flow decrease, the oxygen extraction fraction in the brain may increase, and can be measure with PET
• The increased oxygen extraction fraction in the ischemic region has been described as misery perfusion, where the metabolic demand of tissue is greater than its blood supply
• Patients with misery perfusion, which is a significant disturbance of cerebral autoregulation, have a significantly higher stroke recurrence ratio than patients without misery perfusion
STAGES OF HEMODYNAMIC IMPAIRMENT

Stage I: CPP ↓ → Autoregulation → CBF ↓, CBV ↑, MTT ↑ → Imaged with perfusion CT/MRI, PET, or SPECT

Stage II: CPP ↓↓ → Autoregulation exceeded → CBF ↓↓, OEF ↑ → Evaluated with PET
Border Zone Infarcts: Pathophysiologic and Imaging Characteristics

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Border zone or watershed infarcts are ischemic lesions that occur in characteristic locations at the junction between two main arterial territories. These lesions constitute approximately 10% of all brain infarcts and are well described by imaging. Their pathophysiology has not yet been fully elucidated, but a commonly accepted hypothesis holds that decreased perfusion to the distal regions of the vascular territories leaves them vulnerable to infarction. Two zones of risk of zone infarcts are recognized: external (cortical) and internal (subcortical). To select the most appropriate methods for managing these infarcts, it is important to understand the underlying causal mechanisms. Internal border zone infarcts are caused mainly by hemodynamic compromise, whereas external border zone infarcts are believed to result from embolism but not always with associated hyperperfusion. Various imaging modalities have been used to determine the presence and extent of hemodynamic compromise or myxoid perfusion in association with border zone infarcts, and some findings (eg, multiple small internal infarcts) have proved to be independent predictors of subsequent ischemic events. A combination of subcortical edemas (eg, diffusion and perfusion magnetic resonance imaging and computed tomography), positron emission tomography, transcranial Doppler ultrasonography (TCD) monitoring, and pathophysiologic processes, making an early clinical diagnosis, guiding management, and predicting the outcome.

The Pathogenesis of Watershed Infarcts in the Brain

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Watershed infarcts are ischemic lesions which are situated along the border zones between the territories of two major arteries, for example the anterior and middle or middle and posterior cerebral arteries (Fig. 1). They may also be located between the territories of the major cerebral arteries and veins and have even been described between the territories of the small arteries in the basal ganglia. However, the exact nature of the latter lesions is more uncertain. The infarct may be of hemorrhagic or mixed but generally the hemorrhagic component is not prominent. Altogether, approximately 10% of all brain infarcts are watershed infarcts. Similar infarcts are also found in other organs, such as the heart and the kidneys, but they are more easily recognized in the brain because of the well defined course and extent of the cerebral arteries. The mechanisms whereby watershed infarcts develop have been debated for many years and they have been variously ascribed to embolic thrombosis.1,7,8,22 episodes of syncope hypotension,3,4,22,23 cardioembolism3,22,24 and microembolism.4,22,25,26 It has now been convincingly shown that both hypotension and microembolization can cause such lesions. However, in some cases, particularly those with a progressive or superimposed clinical course, the mechanism still remains uncertain. Watershed Infarcts Caused by Hypotension

A sharp drop in the systemic blood pressure is the most frequent cause of watershed infarcts.1,3,4,22,29,30,31,32,33 Particularly, the reduction in the blood flow becomes severe in the terminal arteries of the cerebral vascular system. Therefore, this is the whole explanation for the distinctive combination of partial units and bilateral infarcts that may occur. The most striking and most frequent occurrence is the territory between the blood pressure falls in the brain, and therefore the distance may be a diffuse nerve cell loss that is not uncommon in addition to a superficial cutaneous ulcer, but to a remarkable extent. The watershed infarcts caused by hypotension are

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Microemboli versus hypoperfusion as an etiology of acute ischemic stroke in Egyptian patients with watershed zone infarction

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Abstract
Background: Brain perfusion is most likely to be impaired in the border zone regions, and clearance of emboli will be much affected in these regions due to low blood flow. Severe occlusive closure of the internal carotid artery causes both embolism and decreased perfusion as well as some cardiac diseases that cause microembolization. Objectives: To differentiate between hyperperfusion and microembolism as etiology of acute ischemic stroke in watershed zone infarction.

Subject and methods: Fifty patients of acute ischemic stroke in watershed zones were recruited within 7 days, their stroke was assessed using transcranial Doppler TCD monitoring for the intracranial vessels to detect microembolic signals and magnetic resonance imaging (MRI) perfusion imaging to detect hypoperfusion signs.

Results: We detected embolic cause of watershed infarction (50%) by using TCD with 41% sensitivity and 14% specificity and hypoperfusion cause of stroke by using MRI perfusion studies with 66% sensitivity and 14% specificity.

Conclusion: We noticed the etiology of stroke, either embolic by using TCD or hyperperfusion by using MRI. The embolic cause of stroke usually cause external or mixed and hypoperfusion of stroke cause internal MRI.

Keywords: Microemboli, Hemiparesis, Wasted Zone ischemic

Introduction

Watershed strokes are named because they affect the distal watershed areas of the brain. The term “watershed” refers to those areas of the brain that receive blood supply from the branching ends of two large arteries. They are situated between the territories of the anterior cerebral artery (ACA), middle cerebral arterial territory (MCA), and posterior cerebral arterial territory (PCA). Internal watershed strokes (IWS), or sub-cortical brain infarcts, are located in the white matter along and slightly above the lateral ventricles, between the superficial arteries of the MCA and ACA, or between the deep and the superficial arterial systems of the MCA. These ischemic areas are considered homogeneous disease produced by region-specific ischemia or occlusion. The lower pressure positions found within the border zone areas in this setting contain an increased susceptibility to ischemia, which can lead to infarction [1]. Radiologic studies also suggest the hypothesis that border zone infarcts distal internal carotid arterial disease are more likely to occur in the presence of a non-coronary circle of Willis (EAC). Hypoperfusion, or decreased blood flow, is likely to impede the clearance (resorption) of embolus. Because perfusion is most likely to be impaired in border zone regions, clearance of emboli will be most impaired in these regions due to low blood flow. Severe occlusive diseases of the internal carotid artery causes...
WATERSHED STROKES AFTER CARDIAC SURGERY

- Watershed distribution strokes are seen more frequently in patients with postcardiac surgery stroke than in the general population (> 40% vs 2-5%)
- These patients are more likely to require long-term care than other postcardiac surgery stroke patients
- Probably involves a combination of hypoperfusion and embolization
- In cardiac surgery, global systemic hypoperfusion caused by severe intraoperative hypotension is known to be associated with poor outcomes
- One randomized trial showed improved neurological and cardiac outcome in patients with MAP maintained at 80 to 100 mm Hg vs 50 to 60 mm Hg
One study done at John Hopkins followed patients who underwent cardiac surgery between 1998 and 2003 and developed a focal neurologic deficit post operatively. Data was reviewed for patients with watershed infarctions.

Intraoperative blood pressure was defined as blood pressure while on CPB, so patients who underwent off-pump CABG were excluded from the part of the study involving BP measurements.

Only those patients who had MRI/DWI imaging were included, although patients also underwent CT.

Standard MAP goal during CPB at John Hopkins is (was) 60 to 80 mm Hg.

91 patients were included, with 5 patients excluded that underwent off-pump CABG and 2 that developed symptoms over 10 days post-operatively.
WATERSHED STROKES AFTER CARDIAC SURGERY

• Patients with bilateral watershed infarctions were more likely to have undergone an aortic procedure and less likely to have undergone a simple or redo CABG

• Patients with bilateral watershed infarcts were 6.23 times as likely to be discharged to an ARF, 12.46 times more likely to be discharged to subacute rehab or to SNF, and 17.28 times more likely to die in the hospital than be discharged home

• Patients with a length of stay > 14 days were more likely to have bilateral watershed infarcts than other stroke patterns

• Patients with a drop in MAP or at least 10 mm Hg were 4.06 times (adjusted OR: 95% CI: 1.05, 15.98) as likely to develop bilateral watershed strokes as those patients who had a smaller drop or no drop in bp

• Data showed that bilateral watershed strokes were more readily detected by DWI MRI (than CT) and were associated with poor short-term outcomes, and MAY have been related to a decrease in intraoperative blood pressure from a preoperative baseline
DEFICITS/FINDINGS RELATED TO LOCATION(S)

• Deficits are relative to stroke burden and locations
• Internal border zone infarcts, especially if more “cigar” shaped or multiple “beads on a string”, tend to do worse then isolated cortical border zone infarcts
• Bilateral infarcts also tend to do worse
• “Man in a Barrel” syndrome can occur if bilateral MCA/ACA cortical infarcts are extensive: proximal > distal UE weakness, inability to abduct arms; bilateral brachial weakness, can spare face, legs
• Balint’s syndrome can be caused by bilateral posterior MCA/PCA border zone infarcts
  • 3 classic findings are simultanagnosia, optic ataxia and oculomotor apraxia—severe visual-spatial abnormalities
CASE STUDY

- 69 yo male presenting with chest pain radiating to left jaw, down left arm and increasing SOA x 1 week
  - Chest pain not relieved with nitro; also, nitro caused N/V
  - Further history revealed he had been sleeping in a recliner for 2 weeks
  - Wife reported confusion, which was very unusual, as well as increasing fatigue and easy bruising
- PMH significant for ischemic cardiomyopathy, CAD, s/p STEMI, PAD, PVD, OSA/CSA, CKD, DM, hxtn, bilateral carotid artery disease, s/p stents bilaterally at OSH
- Initial labs revealed glucose 124, remainder of CMP normal, troponin 0.03, Hgb 6.9, hct 21, WBC 1.7, Plt 37—significant thrombocytopenia
CASE STUDY

- Troponins elevated to 2, No ST elevation/depression
- Hgb worsened, pt transfused, nephrology, GI medicine, cardiology and Heme/onc all consulted
- Day 5, pt noted to be more somnolent, slurred speech, neurology consulted
- On exam, he was somnolent, clearly encephalopathic, no definite vision change, but right facial droop and subtle right sided weakness (superimposed on notable generalized weakness)
- Review of BPs over the previous 24 hours with SBP as low as 71, transiently, but often in the 90s
- MRI obtained. Pt continued to be markedly pancytopenic. Also ordered carotid Doppler/US
MRI slices showing watershed infarcts

Carotid Doppler/US indicated 70% to near total occlusion of LICA.
CASE STUDY

• The patient was recommended to transfuse to Hgb 9 or greater—both for neurologic and cardiologic reasons
• Recommend keep SBP > 110
• He underwent bone marrow biopsy prior to neuro consult—preliminary findings of myelodysplastic syndrome, 6-7% blasts
• He was improved significantly in regards to his encephalopathy and his right sided weakness within 2 days, but does continue to wax and wane in regards to his mental status. BP has mostly been > 110, and HGB > 8 with repeated transfusions
CONCLUSIONS

• Watershed or border zone infarcts are much more common than initially thought
• In addition to hemodynamic compromise, micro emboli likely play a role, especially in external or cortical border zone infarcts
• Internal border zone infarcts may be difficult to distinguish from other entities; chronically, WM lesions from demyelination, and when minimal, often thought to be “lacunar” infarcts
• Cerebellar border zone infarcts are also possible, and probably more common than initially recognized
• Hence, large vessel imaging is extremely important in ALL ischemic stroke work ups
• Longer times of hemodynamic compromise often leads to more severe stroke deficits
• Neurologic exams and, if focal deficits are found, MRI imaging are important post cardiac surgery, or any prolonged surgery with drop in MAP from baseline
• Quick hemodynamic support is imperative for good outcomes in cases where this is a problem
REFERENCES

• Google images


• Gottesman, MD, Rebecca F., et al. “Watershed Strokes After Cardiac Surgery: Diagnosis, Etiology and Outcomes.” STROKE. DOI: 10.1161/01.STR.00002360424.68020.3a. 2306-2311.
Thank You!