Patterns of Enhancement

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Contrast Enhancement

- **Vascularity**
  - Arteries & veins > capillary
  - Perfusion MTT
  - Blood Volume (rCBV)
  - Blood Flow (rCBF)
- **Permeability**
  - **Capillary (leakage)**

When Endothelium Goes Bad!

Mechanisms of Enhancement

**Contrast Enhancement**

- **VASCULAR** (intravascular) PHASE
  - Inc. Blood Flow/Hypervascular neoplasm
  - AVM, Meningioma, GBM
  - **TRUE “Luxury” Perfusion**
    - Hyperemic Swelling (“malignant brain edema”)
- **INTERSTITIAL** (extravascular) PHASE
  - Blood-brain-barrier breakdown
  - Acute inflammation (MS)
  - Neoplasm, Abscess, “granulation” tissue
  - Ischemia, “luxury” perfusion, contusion
  - Gliosis?

Time Density Curves

*Figure 1*

The bolus creates a high intravascular concentration gradient that pushes contrast across a permeable membrane into the tissue interstitial space.

Ultrastructure of BBB

*Figure 2*

Schematic of Ultrastructure of blood-brain-barrier.
CNS: Normal Tissues without BBB
- DURA (falx and tentorium)
- ARACHNOID ? (it’s avascular)
- CHOROID PLEXUS
- PINEAL GLAND (epiphysis)
- PITUITARY GLAND (hypophysis)
- CTZ (area postrema of medulla oblongata)
  - One of the “Circumventricular Organs”

Survival Strategy …
- Tastes Bitter
  - Alkaloids, most medicines
- Absorbed in Stomach
- Carried via bloodstream to brain

Medulla Oblongata
- Area Postrema (floor of 4th ventricle)
- CTZ – Chemoreceptor trigger zone
- Vomiting Control Center of Autonomic System

Normal Enhancement
- Choroid Plexus (blood CSF barrier)
- Pineal Gland
- Pituitary Stalk
- Pituitary Gland
  - Anterior - Adenohypophysis
  - Posterior Hypophyseal Portal System
- Cavernous sinus and dural reflections
- Nasal turbinates
- Sinonasal mucosa
- Extracranial muscles and mucosa

Nasal Cycle
- Vasocongestion ~/~ Vasoconstriction
  - 6 to 8 hour cycle alternation
- Humidify and warm the air
- Secrete mucus (1 – 2 liters/day)
- Chronic vasocongestion would cause submucosal edema
- Breathe mostly through the vasoconstricted side (~ 75-85%)
- Yogi’s can control which nostril
  - So can Tom Cruise (Minority Report)

Fat -Suppressed T1W - Gd  [Figure 3]

Cranial Nerve Enhancement
- Optic Nerve – Never normal
  - * Seventh Nerve:
    - Inside facial canal – Yes, asymmetric ~70%
    - Geniculate ganglion – 98%
    - Tympanic > labyrinthine > mastoid
    - May represent perineural vessels
- Eighth Nerve – Never normal

Contrast Enhancement - Phases
- VASCULAR  BBBB
  - ANGIO(I-) ++++                   -
  - R-N (Tc+) + (flow) + (static)
  - C.T. (I-) +                     +++
  - MRI (Gd+) +/-                   +++

Enhancement vs. Vasogenic Edema  [Figure 4]

ABNORMAL PERMEABILITY
(ABBB)

EDEMA  ENHANCEMENT

INCREASED VASCULARITY

Patterns of Enhancement L->R: Normal patchy, Dura-arachnoid (pachymeningeal), Pia-Arachnoid, dural-based extraaxial, intraaxial subcortical, cortical.

Abnormal optic nerve enhancement – optic neuritis.
Contrast Morphologic Patterns
- Homogeneous (Solid)
- Heterogeneous (Non-uniform)
- Ring Lesions
  - Unilocular or multilocular
  - Smooth Thin Ring
  - Thick Irregular Ring
  - Incomplete Ring
  - “Cyst” with Mural Nodule
- Serpentine (“Gyriform”)
  - Serpiginous?

Contrast Location Patterns
- Superficial (Serpentine or Gyral)
  - Pachymeningeal
    - Dura-arachnoid
  - Leptomeningeal
    - Pia-arachnoid (subarachnoid space)
- Cortical-gyral
- Grey-white junction
- Deep white matter
- Periventricular
  - Ependymal

Patterns of Enhancement  

Intracranial Hypotension

Spontaneous Intracranial Hypotension
- Orthostatic headache, worse upright
- Mr is relatively sensitive and specific
- Thick linear dural enhancement
- No enhancement of sulci or brain surface
- Enhancement above and below tentorium
- Enlargement of the pituitary gland
- Descent of brain
  - Low cerebellar tonsils
  - 3Rd ventricle iter below the tentorium incisural line
- Some patients have 2nd subdural effusions and/or hemorrhage

Dural Enhancement - Meningioma
- Globose Nodular Enhancement + Linear “Dural Tail”
Linear Dural Enhancement Meningioma
- Curvilinear enhancement
  - Dural Tail AKA “dural flair”
- First reported with meningioma
- First reported to be neoplastic invasion
- **What is it REALLY?**
  - Thickening of the dura
  - Vasocongestion of the dura
  - Edema of the dura

Pia-Arachnoid Enhancement
- Infectious Meningitis
  - Bacterial
  - Viral
- Chemical Meningitis
  - Subarachnoid Hemorrhage
  - Ruptured Dermoid, Epidermoid, Teratoma, Cranio
- Neoplastic Meningitis
  - CSF Dissemination

**Enhancement?**
- Leptomeningeal Enhancement - Pneumococcal Meningitis
- Bacterial glycopeptides cause Breakdown in the BBB

**Figure 9**
*Multiple symmetric areas of abnormal leptomeningeal enhancement from meningitis. Notice the abnormal enhancement of the entire suprasellar cistern.*

Zulmarie Roig, MD and Gil Gonzalez, MD, MGH.

**CNS Bacterial Infections**
- Birth to Four Weeks
  - 2-10 cases / 10k births
  - Group B streptococcus
  - E. coli
  - Listeria monocytogenes
- 3 mo. to 3 yrs
  - *Haemophilus influenzae* (Type B)
  - Strep pneumoniae
  - Meningococcus (Neisseria meningitidis)
- Over 3 yrs to Adult
  - Strep pneumoniae
  - N. meningitidis

**CSF Spread - Zuckerguss**
- Carcinomatous Meningitis

**Figure 10**
*Diffuse leptomeningeal (pia-arachnoid) enhancement from disseminated CSF seeding of a medulloblastoma.*

**Serpentine - Cortical Gyral**

**Contrast Enhancement**
- Cortical/Gyiform
  - Cerebral Ischemia / Infarction
    - Ischemia
    - Infarction
    - Hyperemia
  - PRES, Seizure, Migraine
  - Meningo-encephalitis
  - Herpes virus: HSV1, HSV2
  - Creutzfeldt-Jakob
- CSF or sub-pial spread
- S.A.H. (rarely seen)
- Leptomeningeal Malformation (SW)
- Meningoangiomatosis (NF2)

**Ischemic Enhancement**
- Acute and/or Reperfusion enhancement
  - True “luxury perfusion” 2° to acidosis
  - BBBB after 4-6 hours of ischemia
- Subacute to Chronic enhancement
  - Capillaries grown in from surface
  - Primarily in GM (cortex and deep)
  - Peak intensity at 2-3 weeks
  - Fades away over weeks to months
- Atrophy replaces Enhancement

**Reperfusion Injury**
- Hemorrhagic Infarction

**Figure 11**
*Hemorrhagic infarction shows early and dense enhancement due to reperfusion.*
**Subacute Stroke vs. SWS**  
[Figure 12]
- Enhancement with Atrophy (left image)
- Enhancement w/o Atrophy (right image)

**Herpes Encephalitis**  
[Figure 13]
- Serpentine - Cortical Gyral
- Periventricular or Ependymal
  - CMV
    - Thin smooth linear enhancement
    - Herpes virus family
    - Ependymitis
  - Lymphoma
    - Thick irregular enhancement
    - Primary CNS Lymphoma
- Cytomegalovirus Ependymitis

**RIM PHOMA**  
[Figures 14 and 15]

**Ring Enhancing Lesions**
- Ring Lesion
  - Circumferential or peripheral/marginal enhancement, surrounding a central non-enhancing region.
  - In turn, this is often surrounded by a large area of “edema”.
  - May be unilocular or multilocular.

**Figure 12**
Re-perfusion of ischemic brain (left) vs. Sturge-Weber disease (right).

**Figure 13**
Herpes encephalitis. Abnormal cortical signal in multiple vessel territories.

**Figure 14**
Ependymitis
Diffuse enhancement of the lining (ependyma) of both lateral ventricles from CMV ependymitis.  
(Courtesy Vince Mathews, M.D.)

**Figure 15**
Rimphoma
A thick rind of abnormal enhancing tissue surrounds both lateral ventricles – significantly more on the right.

**Ring Lesion Causes**
- Necrotic Neoplasm
- Fluid-secreting Neoplasm
- Advancing Infection-Cerebritis
- Organized Abscess with Pus & Necrosis
- Subacute Hematoma
- Advancing Inflammation (e.g. MS)
Abscess [Figure 16]

Two different patients with cerebellar abscess. The CT on the right shows the formation of a daughter abscess.

Rules for Ring Enhancing Masses [Figure 17]

- Benign
  - Round and convex
  - Smooth, uniform
  - Thin (< 10mm)
- Malignant
  - Undulating
  - Irregular, variable
  - Thick

Abscess [Figure 20]

- Round
- Smooth
- Regular
- Convex all around
- Rim of Edema
- Restricted Diffusion
- MRS shows
  - AA peaks
  - Acetate
  - Succinate

WHO 1 vs. WHO 4 [Figure 19]

One of these patients has a WHO Grade 4 tumor (Glioblastoma Multiforme – GBM) and the other has a WHO Grade 2 tumor (Pilocytic astrocytoma). Which is which? COME TO CLASS.......
Abscess

Cerebral abscess – corresponding CT, T2-Gd, T2, and DWI image. The ring is thin and smooth, hypointense on T2. Centrally, there is restricted diffusion.

Abscess

- Viscous pus and coagulation necrosis

Glioblastoma Multiforme vs. Abscess (toxoplasmosis).

The viscous pus and white cell infiltrate in the abscess causes restricted diffusion – bright on DWI.

Glioblastoma Multiforme

Glioblastoma multiforme (WHO Gr3): Portions of this ring-enhancing lesion are smooth and thin. However, there are multiple linear enhancing strands extending into the center. This is inconsistent with an abscess or cerebritis. This represents residual islands of enhancing living tumor surrounding vessels.

DWI: Necrosis vs. PUS

- “We conclude that viable cell density is the main biological parameter responsible for restricted diffusion in brain abscess, and it is not influenced by the etiological agents responsible for its causation.” Magn. reson. med. 2005, vol. 54, no4, pp. 878-85.
**Tumefactive Demyelination**

(Figure 26)
- Absent vasogenic edema ... signal abnormality ends at edge of enhancement

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**Open (Incomplete) Ring Sign**
- **Demyelinating Disease**
- Fluid-secreting "Cystic" Neoplasms


**Contrast Enhancement: Hematoma**
- EARLY: Hyperdense, round/oval
  Homogeneous mass of RBC’s with proportional mass effect for volume
  Edema “Halo”, not spreading
- LATER: Iso-/Hypodense, smaller.
  Reactive capillaries form outside. Uniform rim of enhancement. May see “vasogenic” edema spreading.

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**Hematoma – Halo of Serum**

(Figure 27)
- Acute Hematoma - halo of edema
  Subacute to chronic may have vasogenic edema.

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**Reactive Ring Enhancement**

(Figure 28)
- Acute Hematoma - halo of edema
  Subacute to chronic may have vasogenic edema.

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**Post-Operative Enhancement**
- RESIDUAL TUMOR
  ➢ Left behind
- RECURRENT TUMOR
  ➢ It grew back
- Infection
- Normal Postoperative Change
  ➢ Surgical “trauma”, healing, gliosis
- Radiation Necrosis

**Surgical Change and/or Residual Neoplasm?**
- Surgical Enhancement typically begins after 24-48 hrs.
  ➢ Scan early (24 hours) or scan late (4-6 wks)
  ➢ May fade after a few weeks but may last for months
  ➢ Gd+ enhancement may begin in 4-6 hours
• In the Operative Bed
  • Mixed w/ residual tumor?
  • Along the Margins of Resection
  • Thin and uniform in brain (CT/MR)
• LINEAR meningeal/dural enhancement on MR
  • NOT lumpy-bumpy
• Small amts. of air, blood are normal
  • No instruments or sponges, etc.!!

References
