

周生期脳低血流障害

横地健治

1

Konstantin-Alexander Hossmann, Wolf-Dieter Heiss. History of the Letzte Wiese/Last Meadow Concept of Brain Ischemia. Stroke 2016;47:e46-50.

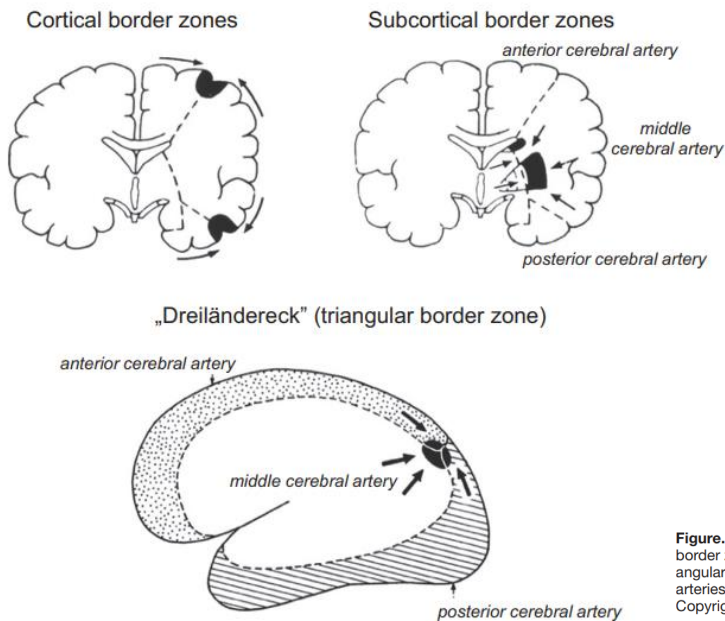
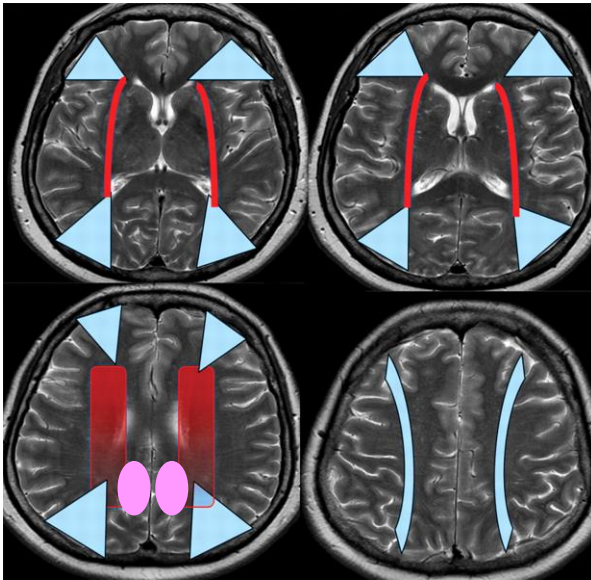


Figure. Localization of cortical (external) and subcortical (internal) border zones (letzte Wiesen). The parietal Dreiländereck is the triangular border zone between the cortical branches of all 3 brain arteries. Reprinted from Zülch¹⁰ with permission of the publisher. Copyright © 1985, Springer.

2



The external or cortical border zones

- the **anterior** external border zones と paramedian white matter は、ACAとMCAの境界域
- the **posterior** external border zones (the parieto-occipital areas) は、MCAとPCAの境界域

● 大脳内側後方のACAとPCAの境界域は？

The internal or subcortical border zones

- the Heubner artery (長中心動脈(反回動脈)、ACA) 、the lenticulostriate artery (MCA)、the anterior choroidal artery (内頸動脈) との境界域
- the lenticulostriate artery とMCA
- the lenticulostriate artery とACA
- the Heubner arteryとACA
- the anterior choroidal arteryとMCA
- the anterior choroidal arteryとPCA

Color overlays on axial T2-weighted magnetic resonance (MR) images of normal cerebrum show probable locations of external (blue) and internal (red) border zone infarcts.

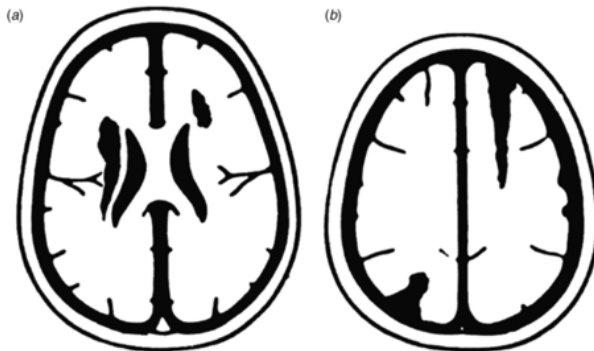
脳低血流となれば、この二型以外の三大脳動脈領域内の終末枝梗塞も起こるはず

Rajiv Mangla , Balasubramanya Kolar, Jeevak Almast, Sven E. Ekholm. Border Zone Infarcts: Pathophysiologic and Imaging Characteristics.

RadioGraphics 2011

3

Caplan LR, van Gijn J. Stroke syndromes. 3rd edi. 2012.



*cortical borderzone infarctions*の独立性に否定的

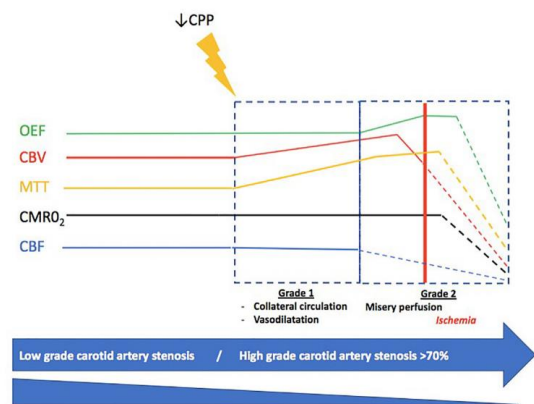
Borderzone infarcts

- a: subcortical low-flow infarctions (terminal supply area infarctions)
- * internal borderzone territory infarct
- internal watershed infarctions はmisleading
- b: borderzone infarctions (watershed infarcts)

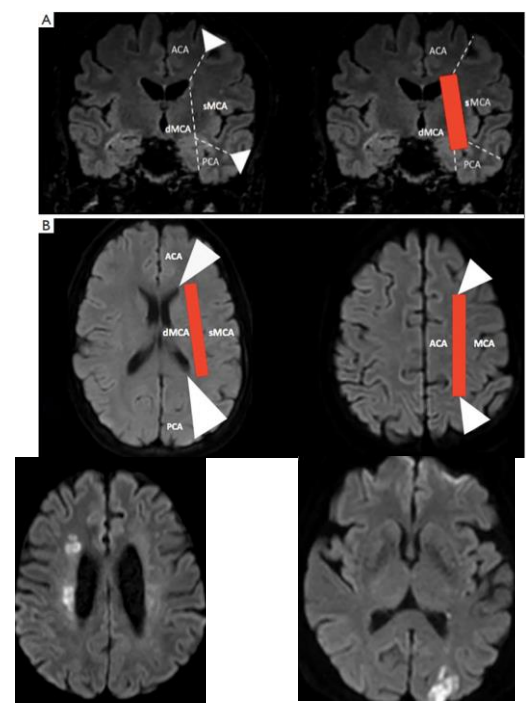
- Low-flow infarctions ↔ thromboembolically caused infarcts
- 灌流圧の低下と微小血栓の生成は対応する
- 重症血流障害では半卵円中心が侵されやすい (皮質分水嶺領域より)
→ chain-like or rosary-like arrangement
- Isolated cortical watershed infarctsはa combined embolic-hemodynamic pathogenesis
- 前頭側頭境界部と頭頂後頭境界部の楔状の皮質梗塞はthromboembolic strokesをlow-flow infarctionsと誤認しやすい *両者の鑑別はdifficult
- * 前頭葉のACA・MCA境界域の長細い梗塞は真のcortical watershed infarcts

4

Mechtouff L et al. A narrative review of the pathophysiology of ischemic stroke in carotid plaques: a distinction versus a compromise between hemodynamic and embolic mechanism. Ann Transl Med 2021;9:1208.



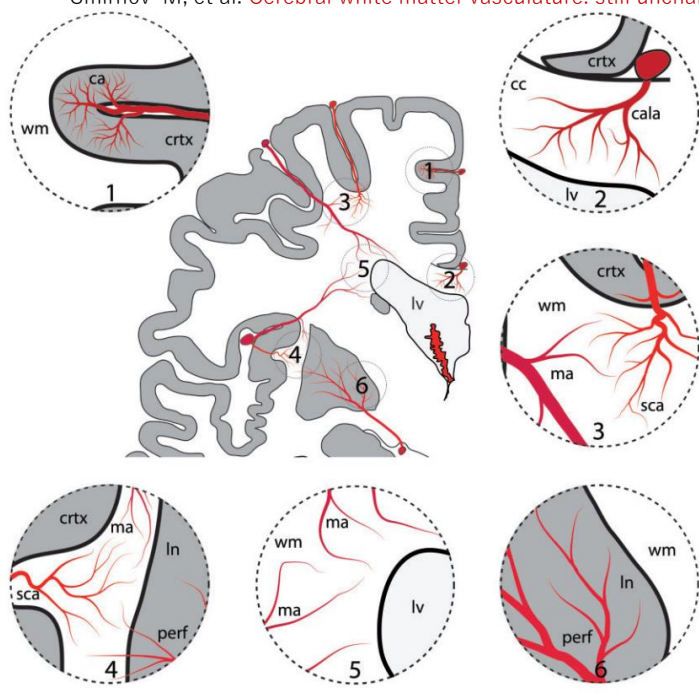
CPP, cerebral perfusion pressure;
CBF, cerebral blood flow;
CBV, cerebral blood volume;
CMRO₂, cerebral metabolic rate of O₂;
MTT, mean transit time;
OEF, oxygen extraction fraction.



Internal watershed infarcts Posterior cortical watershed infarcts

5

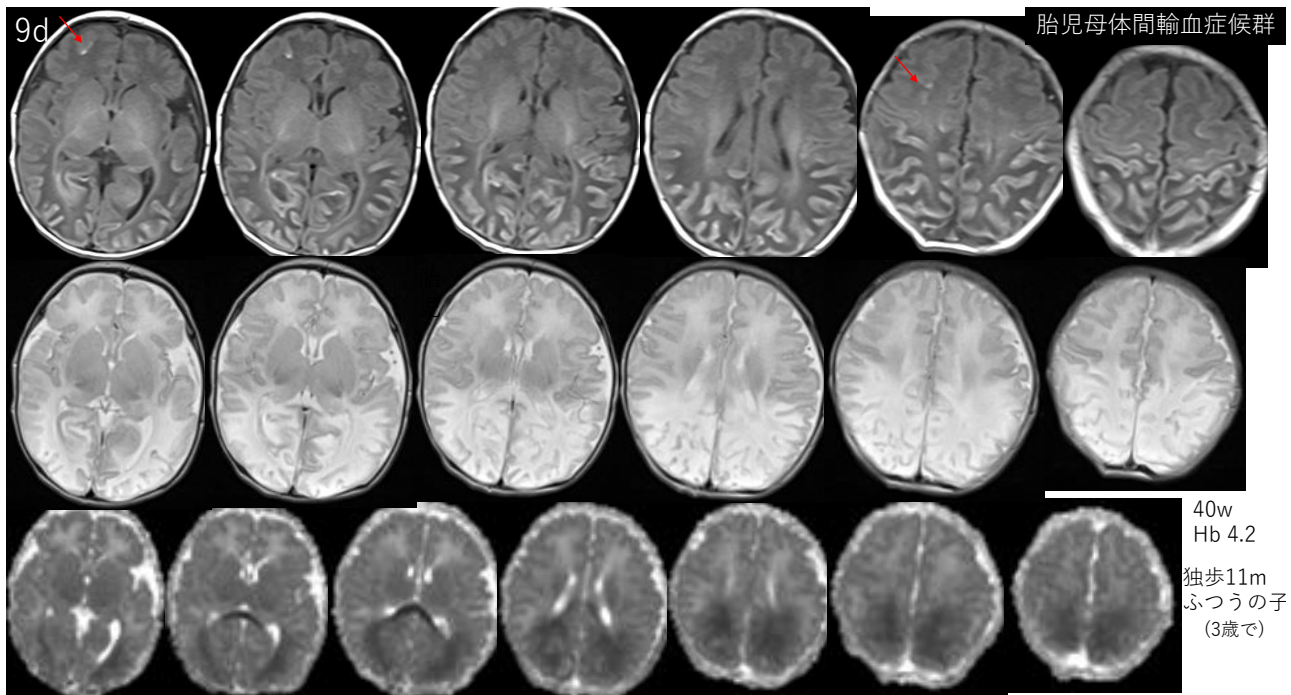
Smirnov M, et al. Cerebral white matter vasculature: still uncharted? Brain 2021;144:3561–75.



Type 1: Arterial vascularization of the cortex depends on short arterioles originating from the same pial vessels (single source juxtaposed (並列) supply).
Type 2: The corpus callosum is supplied by short arterioles originating from the pial network (single source juxtaposed supply).
Type 3: Short association U-fibers are supplied by subcortical arteries and earliest branches of medullary arteries (dual source interdigitated supply).
Type 4: The external capsule, claustrum and extreme capsule take up subcortical arteries, earliest branches of medullary arteries, and terminals of perforating arteries of the base of the brain (triple source interdigitated supply).
Type 5: The centrum semiovale is supplied by terminals of deep white matter arteries (single source juxtaposed supply).
Type 6: Vessels supplying the basal ganglia and the thalamus are long, perforating arterioles and arteries originating from the base of the brain (single source juxtaposed supply).
cc = corpus callosum; crt看 = cortex; lv = lentiform nucleus; lv = lateral ventricle; ma = medullary artery; perf = perforating artery; sca = subcortical artery; wm = white matter.

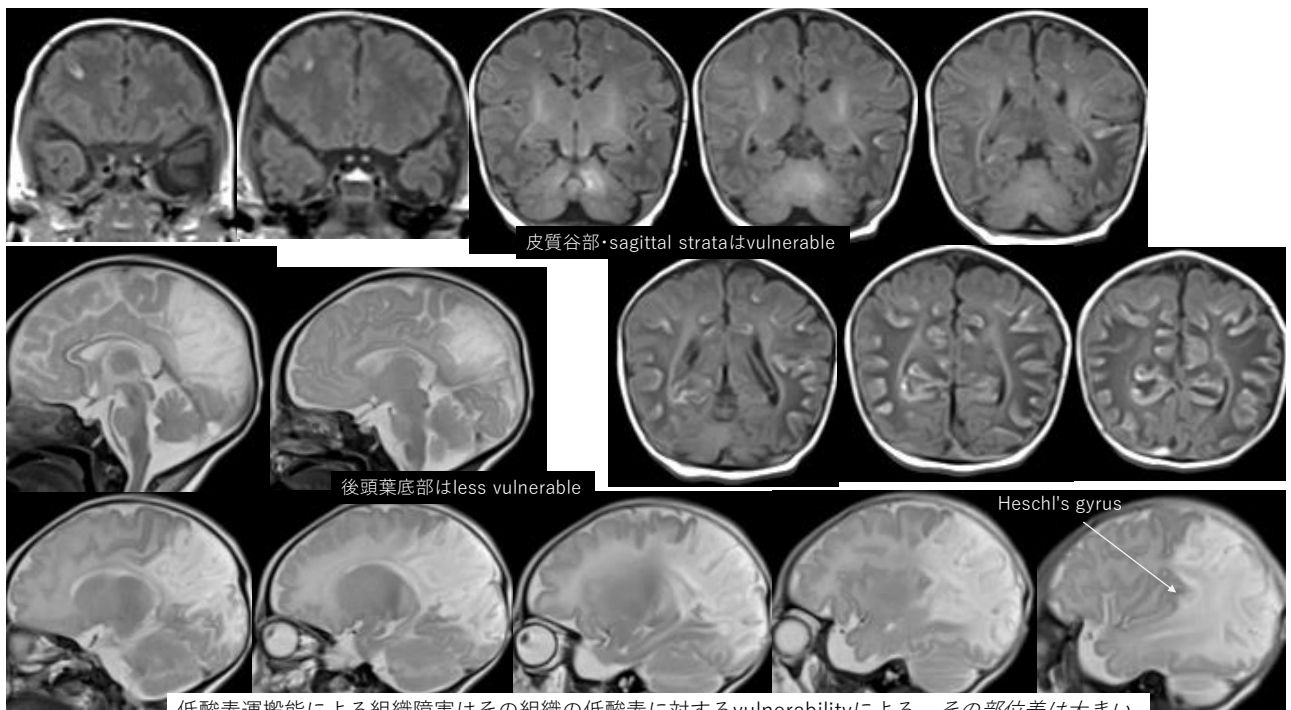
Type 1~4 : 外部型脳低血流障害
Type 5~6 : 内部型脳低血流障害
Type 1~6 : 全脳型脳低血流障害

6



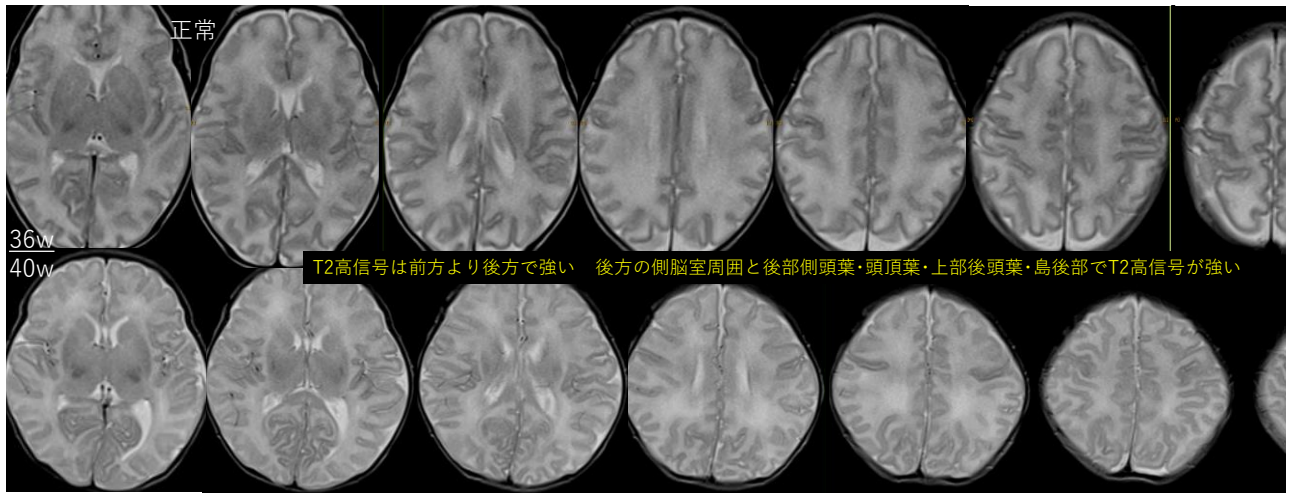
・ 右前頭部皮質谷部・sagittal strataがT1高信号・T2高信号 ・ PCA領域・ PCA・MCA境界域・ MCA領域後方・ ACA・PCA境界域が低血流 ・ 視床病変あり

7

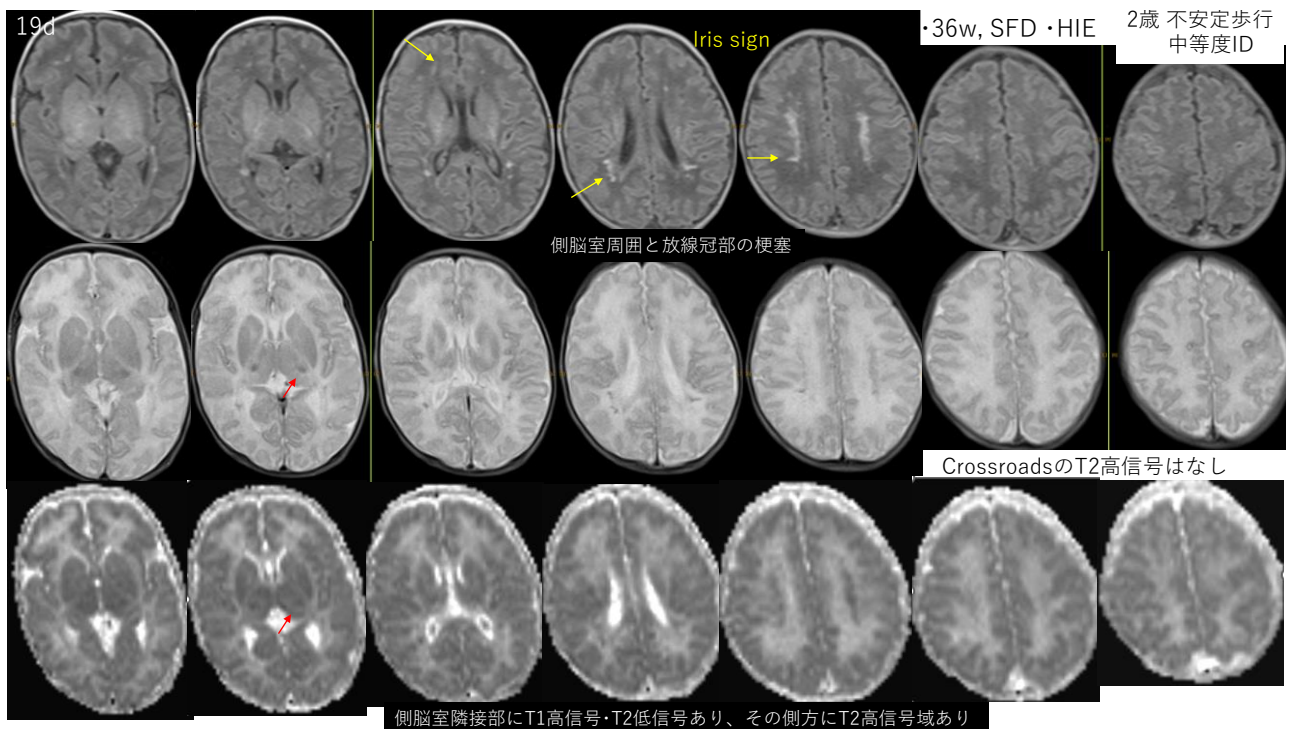


低酸素運搬能による組織障害はその組織の低酸素に対するvulnerabilityによる その部位差は大きい

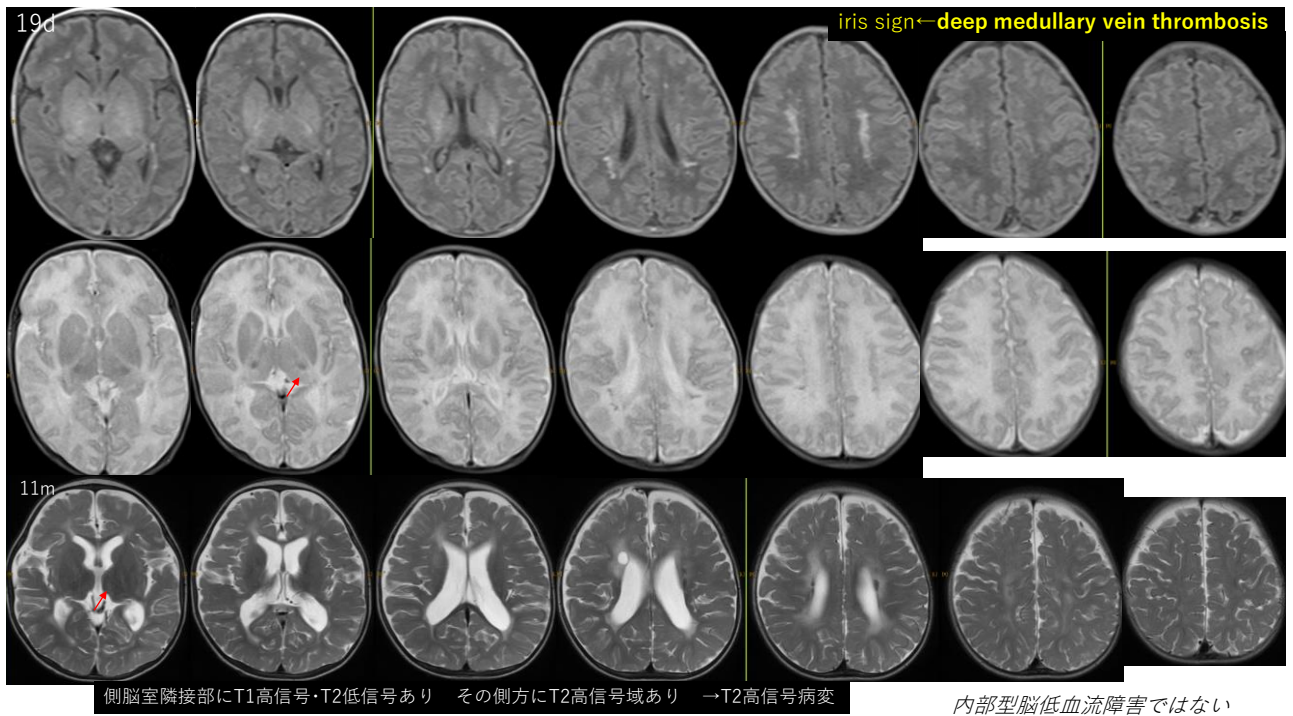
8



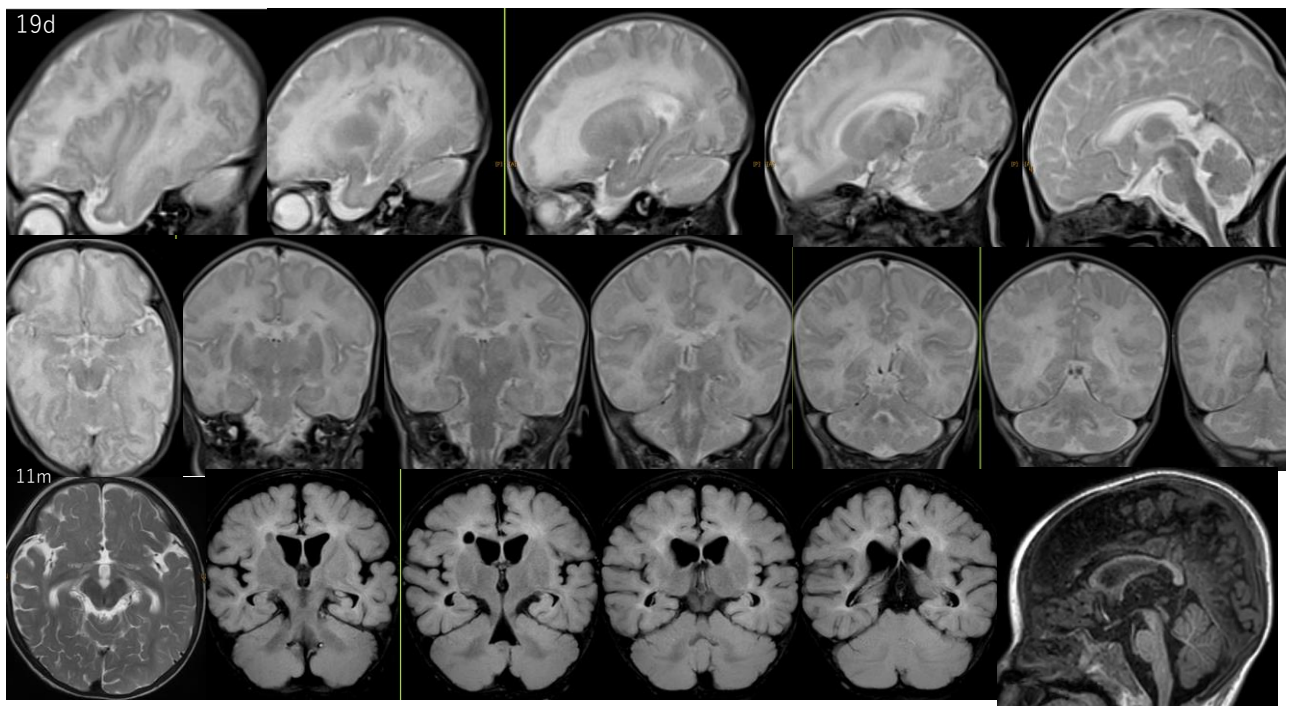
9



10



11



12

周生期脳低血流障害

- 満期時は多血で易血栓形成性 *微小血栓はあるかも
- 貧血による酸素運搬能低下もこの病態に含む

*終末部血液流量の減少はないが

- 灌流圧の低下は静脈うっ滞(engorgement)・静脈梗塞を来す
- 組織障害の決定因子

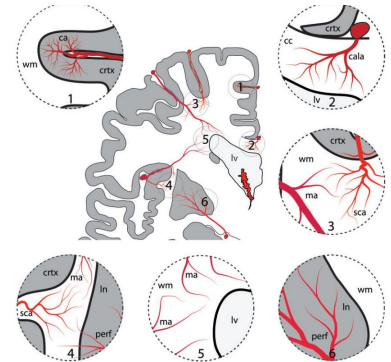
- ・終末部のhemoglobin流量
 - ・灌流圧 ・ hemoglobin量 ・ 隣接血管との吻合
- ・当該組織の易侵襲性

✓ 満期時T2高信号白質域は高分化状態であり、低灌流にvulnerable 前方後方二分

・ 頭頂葉深部 ・ 頭頂葉内側部 ・ 後頭葉内側部 ・ 島後部

この頭頂葉部をPCA-MCA境界域と誤認していた

→周生期には *cortical borderzone or watershed infarctions* は存在しないか 極めて稀



Type 1~4：外部型脳低血流障害

・ 後方型 ・ 前方型

Type 5~6：内部型脳低血流障害

Type 1~6：全脳型脳低血流障害

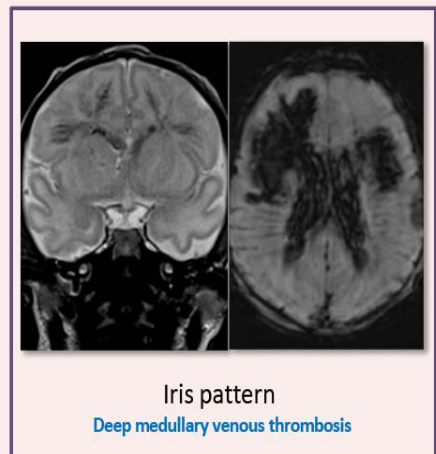
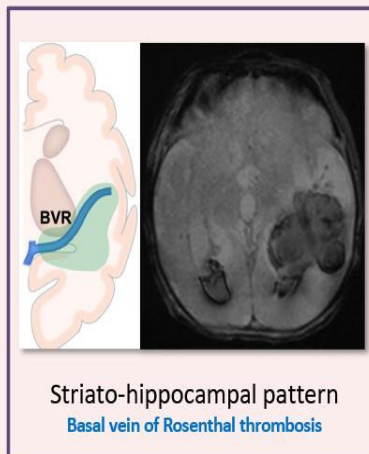
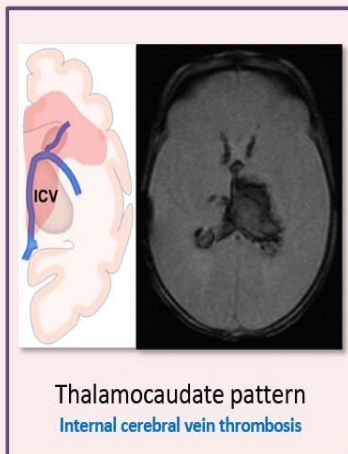
13

Lai LM, et al. Neuroimaging of Neonatal Stroke: Venous Focus. Radiographics 2024;44:e230117.

RadioGraphics

Neuroimaging of Neonatal Stroke: Venous Focus

Imaging patterns of infarcts caused by deep venous thrombosis



14

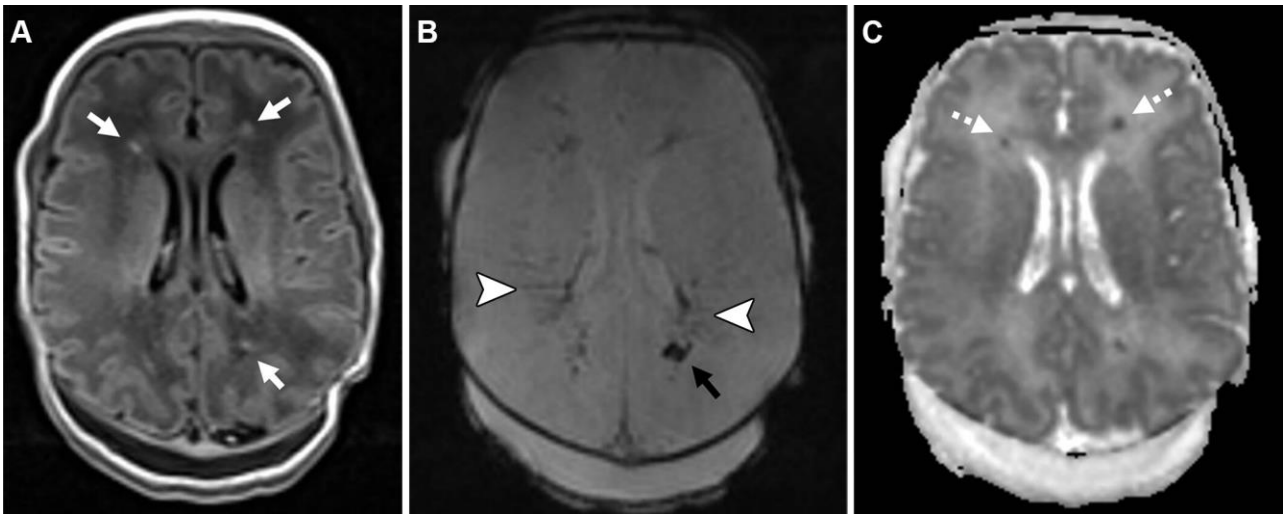
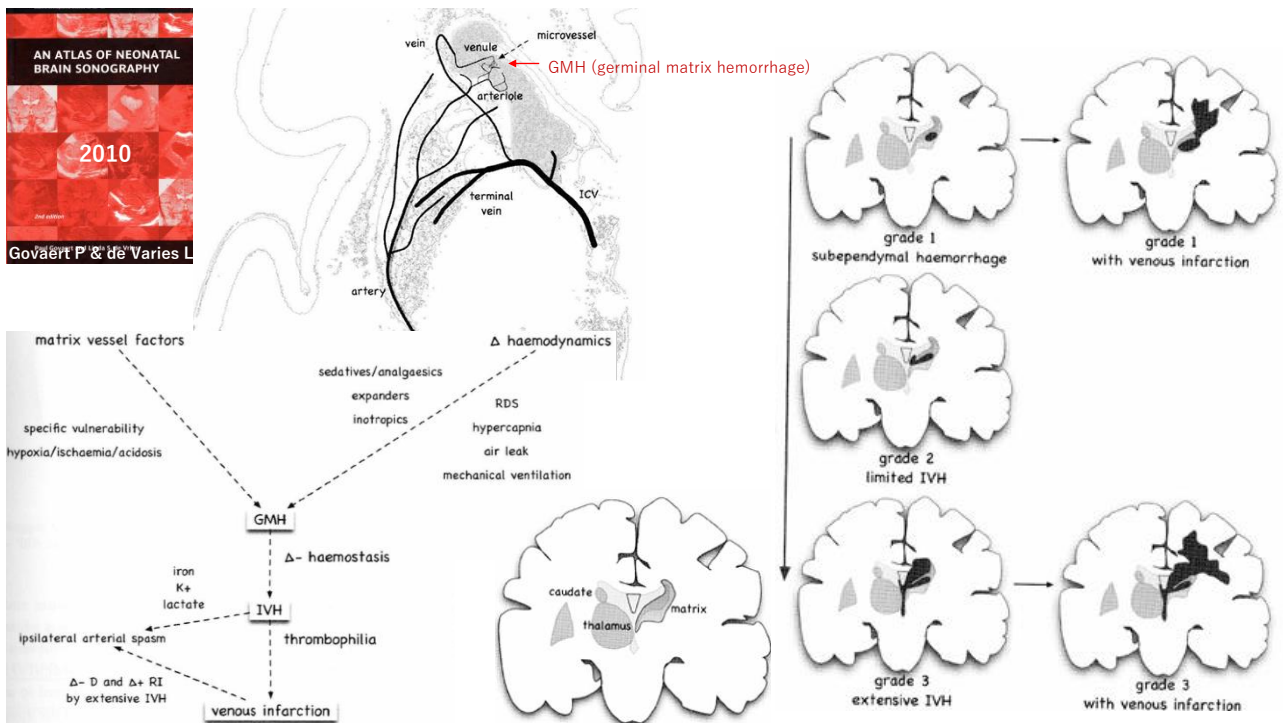


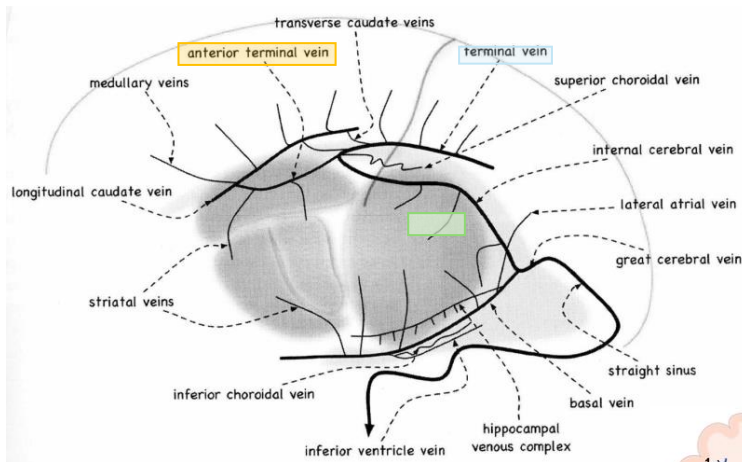
Figure 16. PMWLs and deep medullary venous congestion in a 4-day-old term male neonate with HIE and pulmonary hypertension. **(A)** Axial T1-weighted MR image shows hyperintense punctate T1 foci in the deep white matter (arrows). **(B)** Axial GRE MR image shows medullary venous congestion in the periventricular region (arrowheads). The punctate lesion in the left parietal lobe shows blooming (arrow) suggestive of venous hemorrhagic origin. **(C)** Axial apparent coefficient diffusion map demonstrates restricted diffusion (arrows) in the frontal lobe PMWLs, suggestive of an ischemic origin.

開花

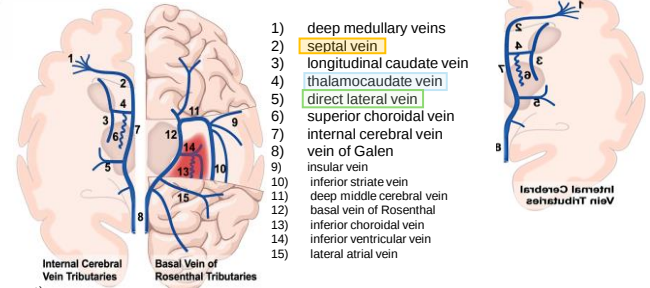
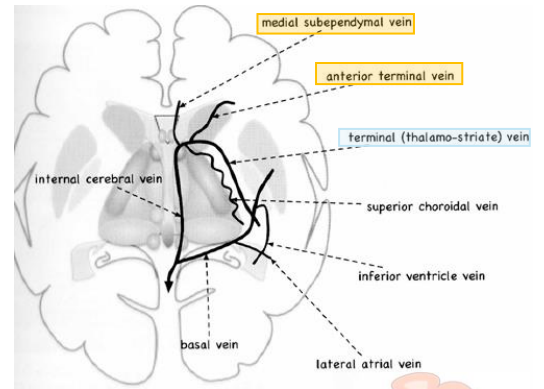
15



16

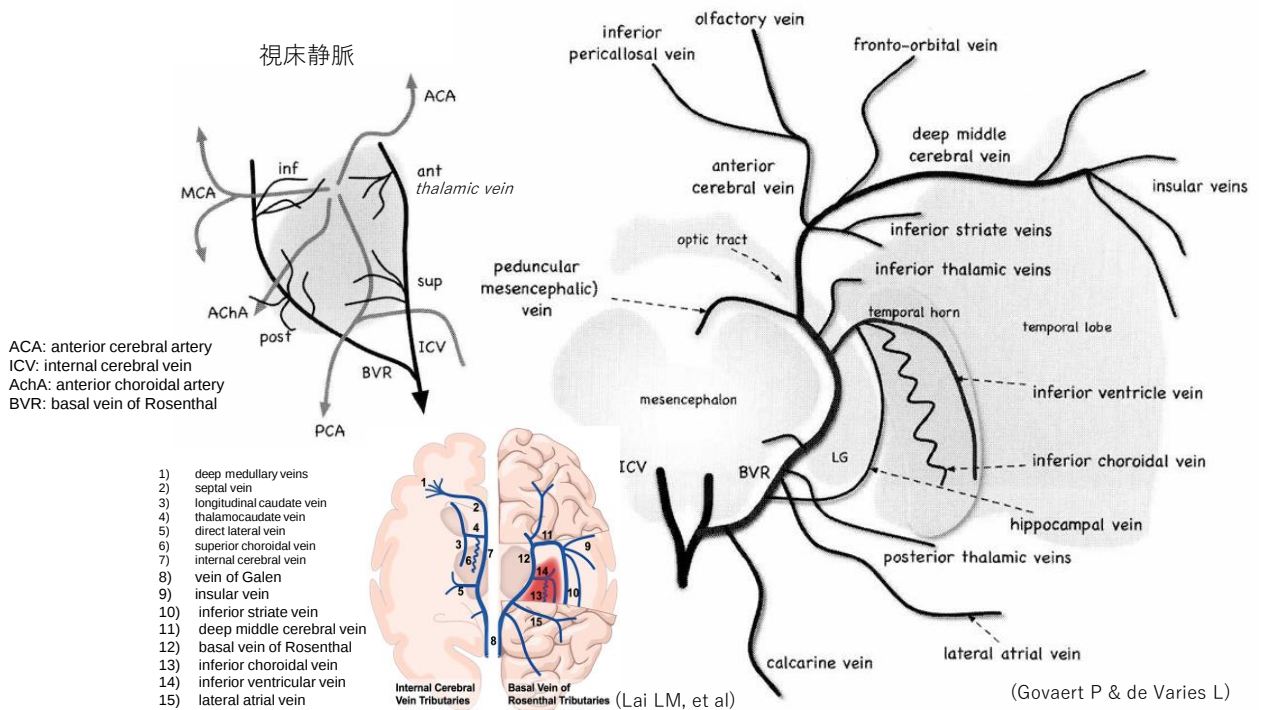


(Govaert P & de Varies L)

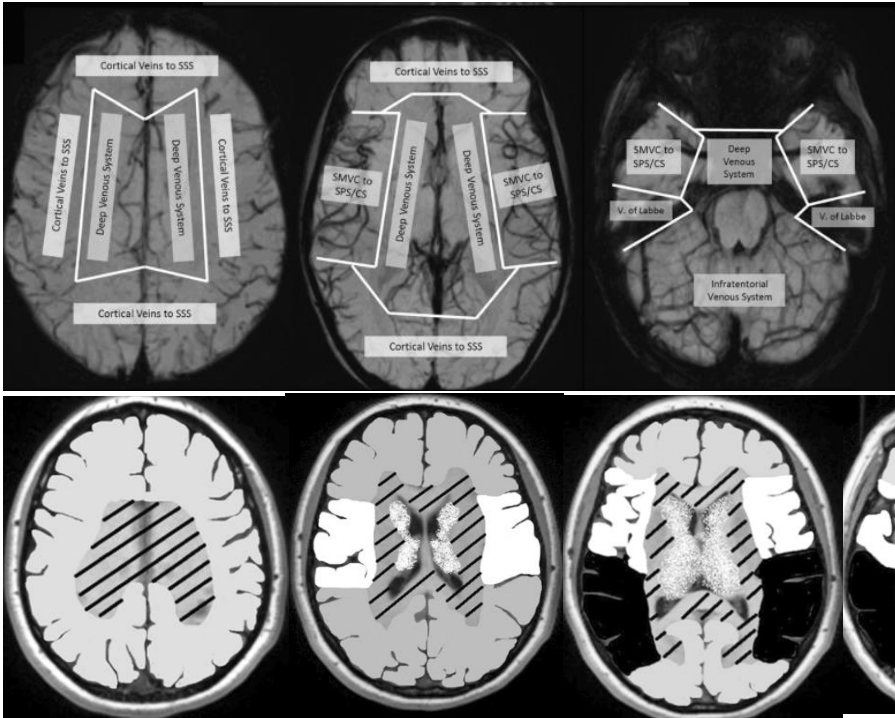


(Lai LM, et al)

17



18



Mankad K, et al. Venous pathologies in paediatric neuroradiology: from foetal to adolescent life. *Neuroradiology* 2020;62(1):15-37.

superficial middle cerebral vein (SMCV or Sylvian vein) to sphenoparietal sinus (SPS) or cavernous sinus (CS).

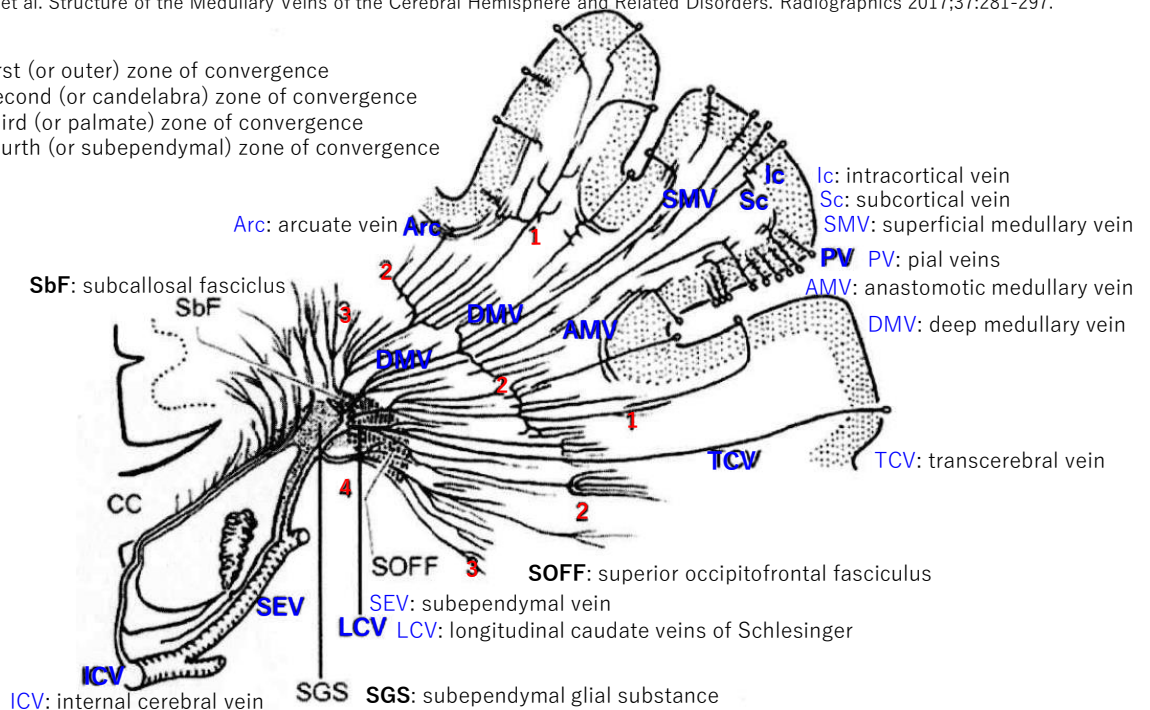
Gray superior sagittal sinus drainage territory, **white** sylvian veins, **black** transverse sinus territory (vein of Labbe'), **speckled white** thalamostriate veins (drain to internal cerebral veins), **black stripes** septal veins (drain to internal cerebral veins) and inferior sagittal sinus

Linscott LL, et al. Imaging patterns of venous-related brain injury in children. *Pediatr Radiol* 2017;47:1828-1838.

19

Taoka T, et al. Structure of the Medullary Veins of the Cerebral Hemisphere and Related Disorders. *Radiographics* 2017;37:281-297.

- 1: first (or outer) zone of convergence
- 2: second (or candelabra) zone of convergence
- 3: third (or palmate) zone of convergence
- 4: fourth (or subependymal) zone of convergence



20

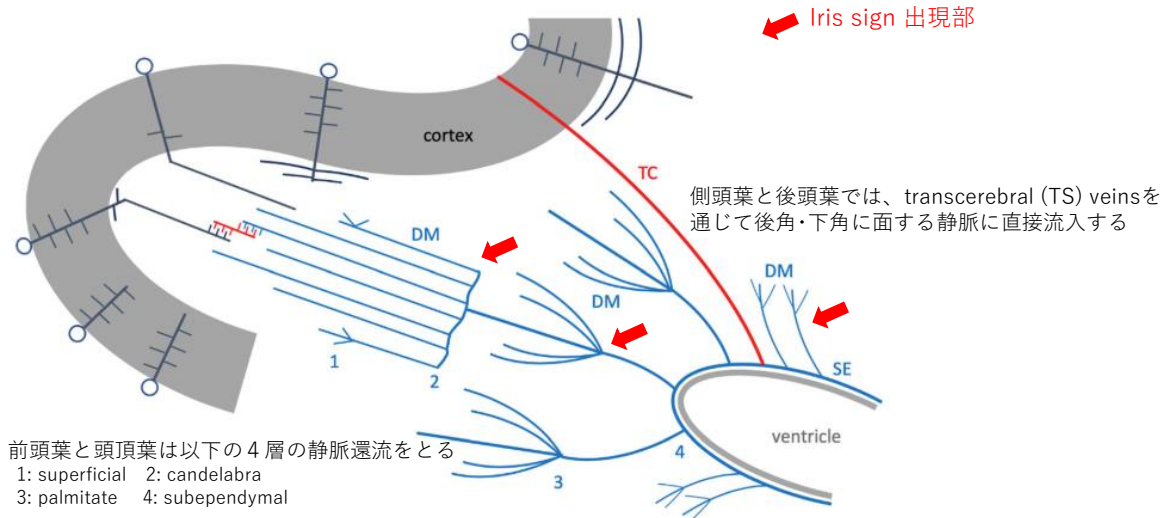
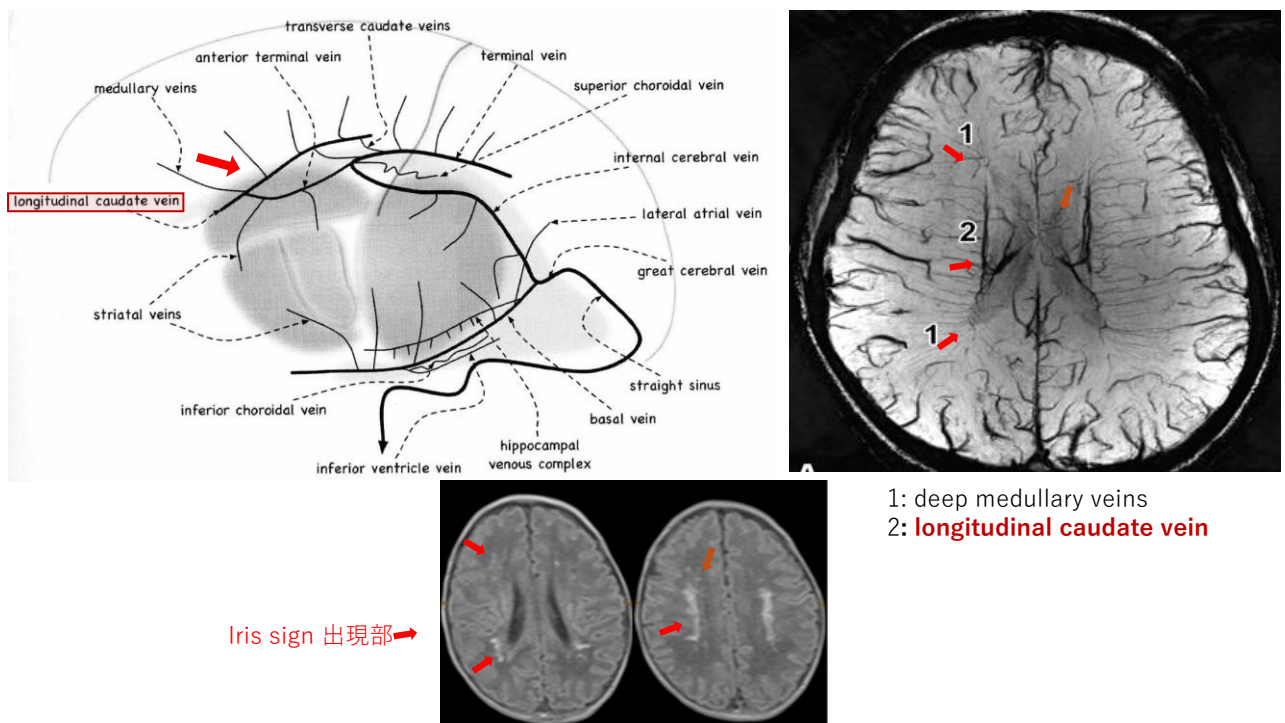
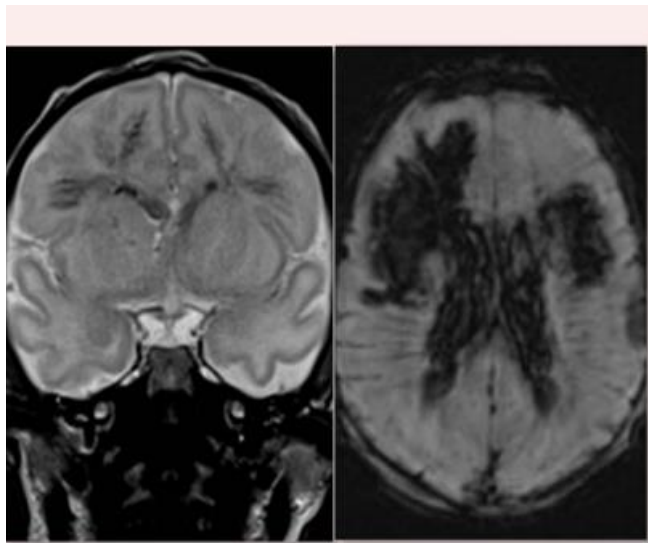


Fig. 2 The four zones of convergence of the deep medullary veins, the subependymal veins and the transcerebral veins. The deep medullary veins (DM) course centripetally to drain into the subependymal veins. Okudera et al. [13] demonstrated four zones of convergence in the frontal and parietal lobes by injecting barium into the internal jugular veins and obtaining radiographs of brain slices in cadavers. The zones of convergence from superficial to deep are **the superficial (1), candelabra (2), palmitate (3) and subependymal (4) zones**. In Zones 2 and 3 the medullary veins converge in characteristic configurations that resemble candelabras and palms, respectively. **Transcerebral (TC) veins** extend from the cortical surface to the subependymal veins. SE subependymal vein.

21



22



(Lai LM, et al)

Iris pattern

Deep medullary venous thrombosis

Khalatbari H, et al. Deep medullary vein engorgement and superficial medullary vein engorgement: two patterns of perinatal venous stroke. *Pediatr Radiol* 2021;51:675-685.

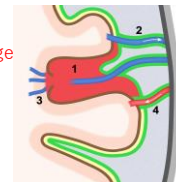
Deep medullary vein engorgement

SWI: brush sign or hypointense vessel sign
vasogenic edema, cytotoxic edema or hemorrhage
fan-shaped branching pattern → iris sign
intraventricular hemorrhage

Superficial medullary vein engorgement

SWI: engorged superficial medullary veins
vasogenic edema, cytotoxic edema or hemorrhage
subpial hemorrhage

1: subpial hemorrhage



23

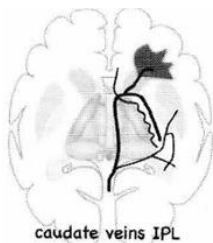
(Govaert P & de Varies L)

静脈梗塞類型

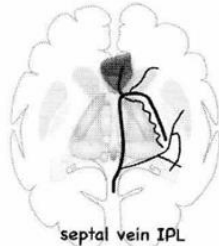
Venous infarction
with GMH/IVH



Caudate collector
vein infarction
(anterior frontal)

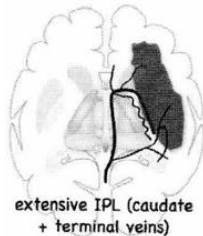


Medial subependymal
(septal and callosal)
venous infarction



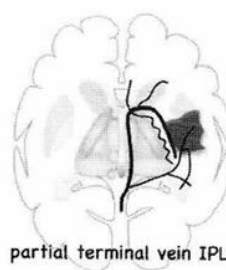
septal vein IPL

Extensive frontoparietal
venous infarction
(terminal and caudate veins)



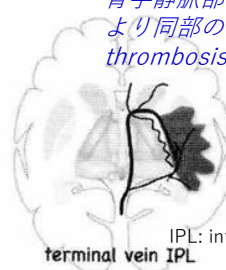
extensive IPL (caudate
+ terminal veins)

Terminal vein venous infarction
(posterior frontal to parietal)



partial terminal vein IPL

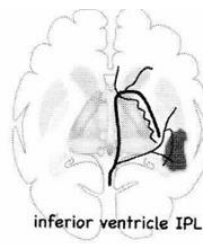
青字静脈部のうっ滞(非梗塞)により同部の Deep medullary thrombosisをきたしうる



terminal vein IPL

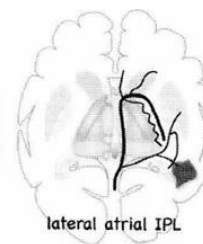
IPL: intraparenchymal lesion

Temporal and lateral atrial
venous infarction

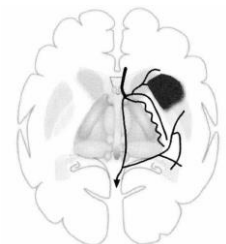


inferior ventricle IPL

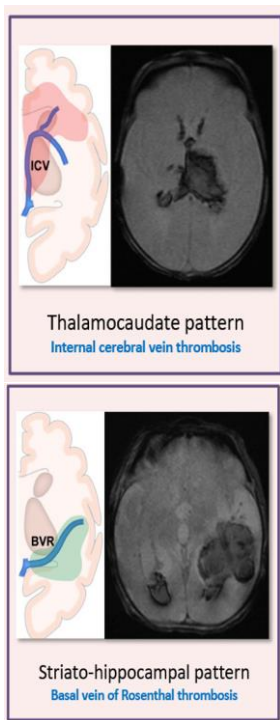
Striatal venous infarction
(internal cerebral vein area)



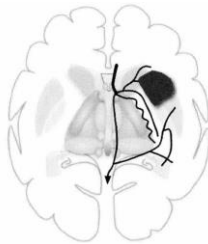
lateral atrial IPL



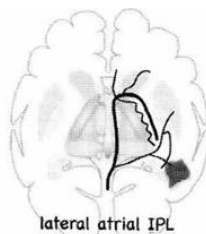
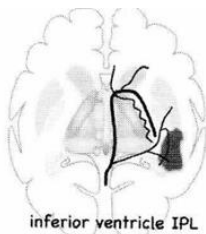
24



Striatal venous infarction (internal cerebral vein area)

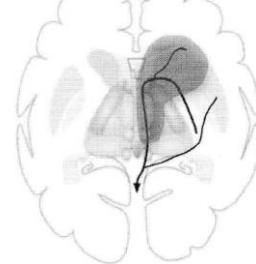


Temporal and lateral atrial venous infarction

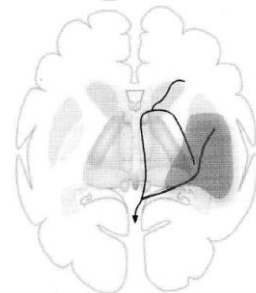


Two patterns of deep venous thrombosis

(hemorrhage into the thalamus,
basal ganglia and ventricle)



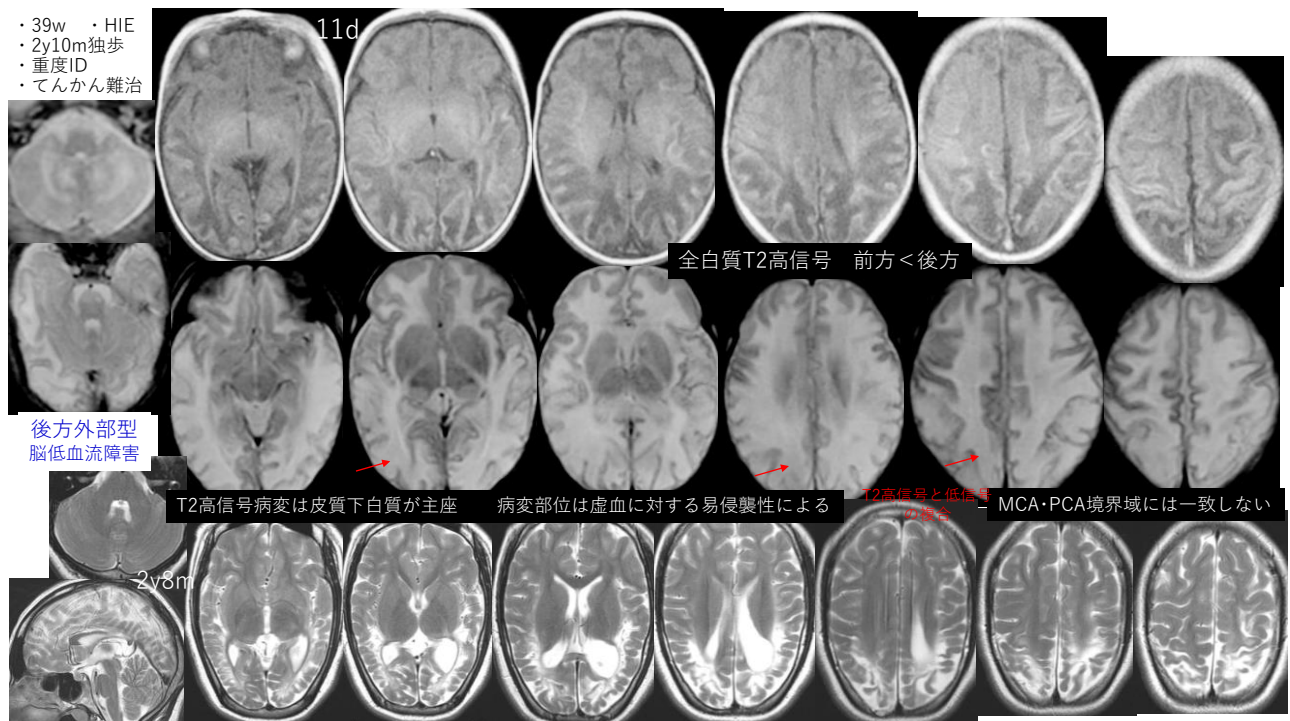
the internal
cerebral vein
drainage area
thalamo-caudate
bleeding



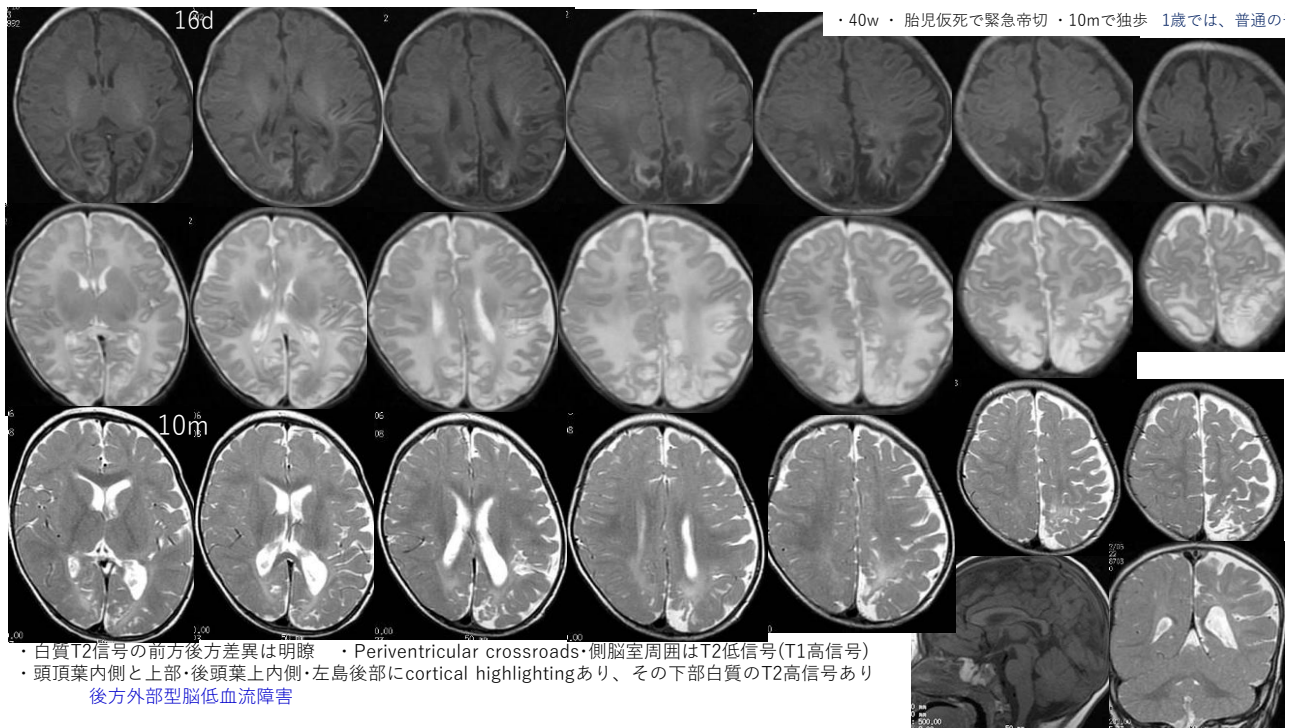
the basal vein
drainage area
basal striatal
bleeding

25

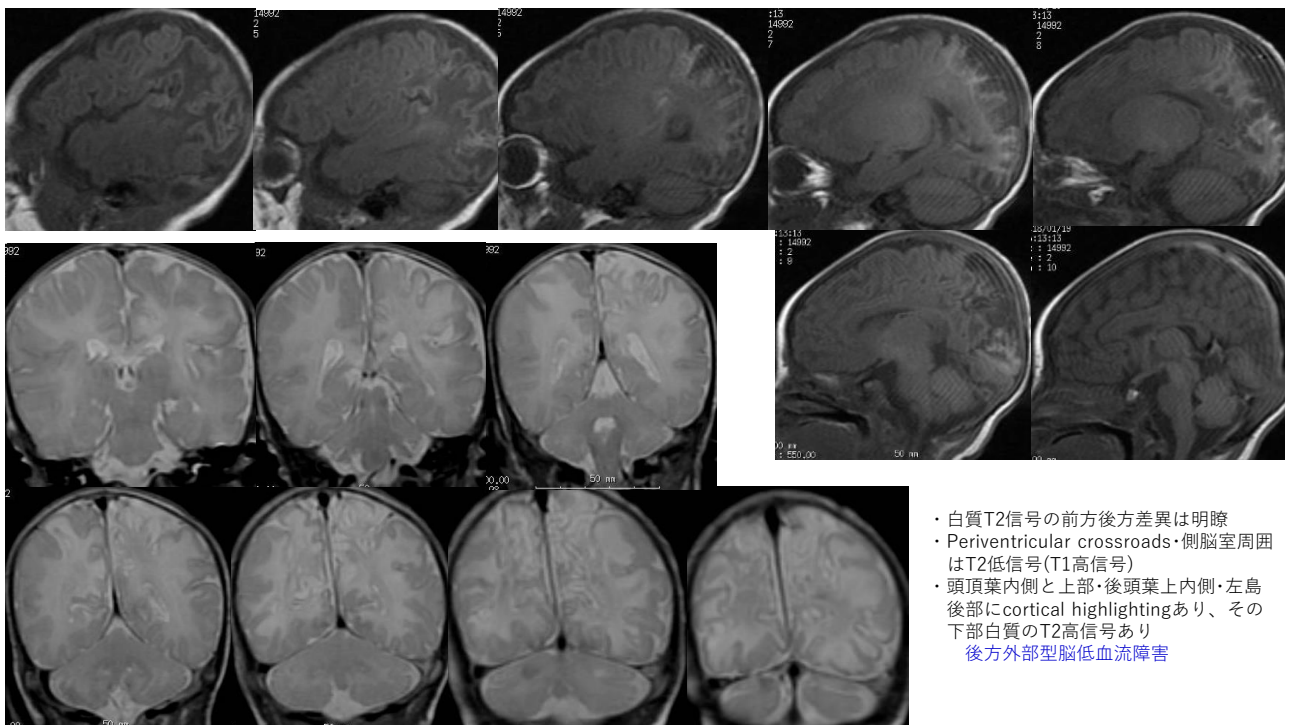
- ・39w ・HIE
- ・2y10m独歩
- ・重度ID
- ・てんかん難治



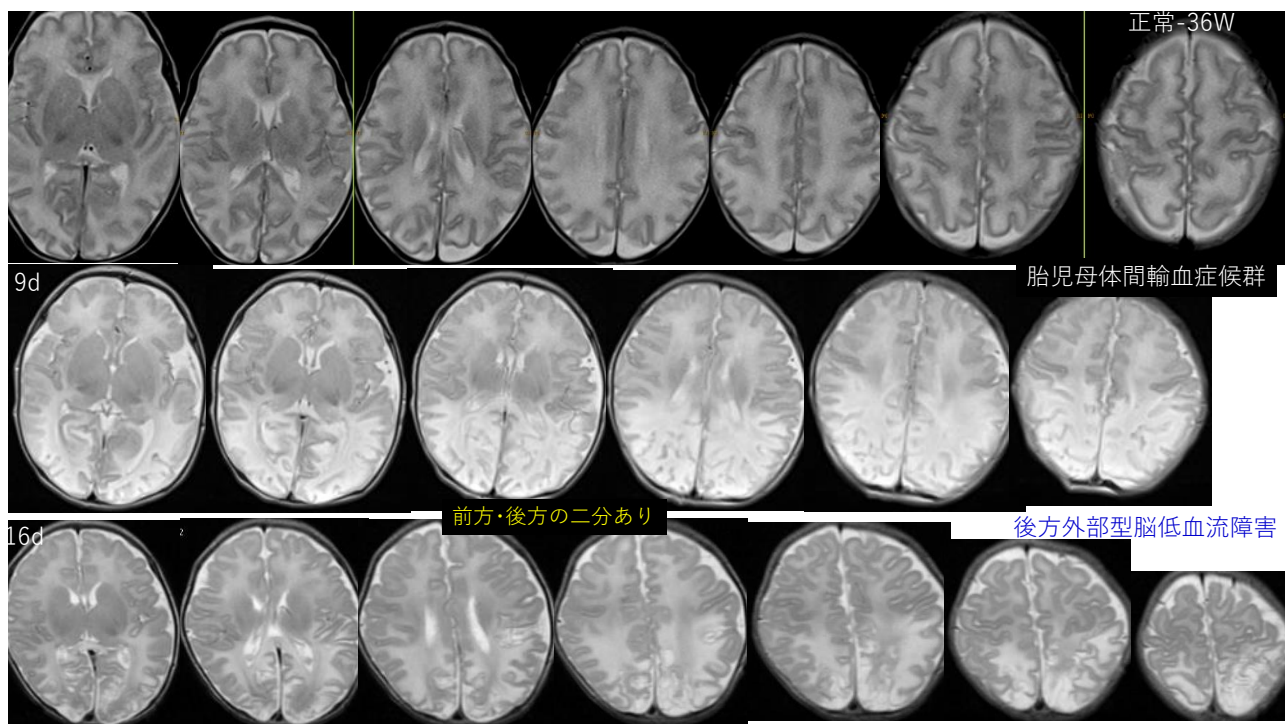
26



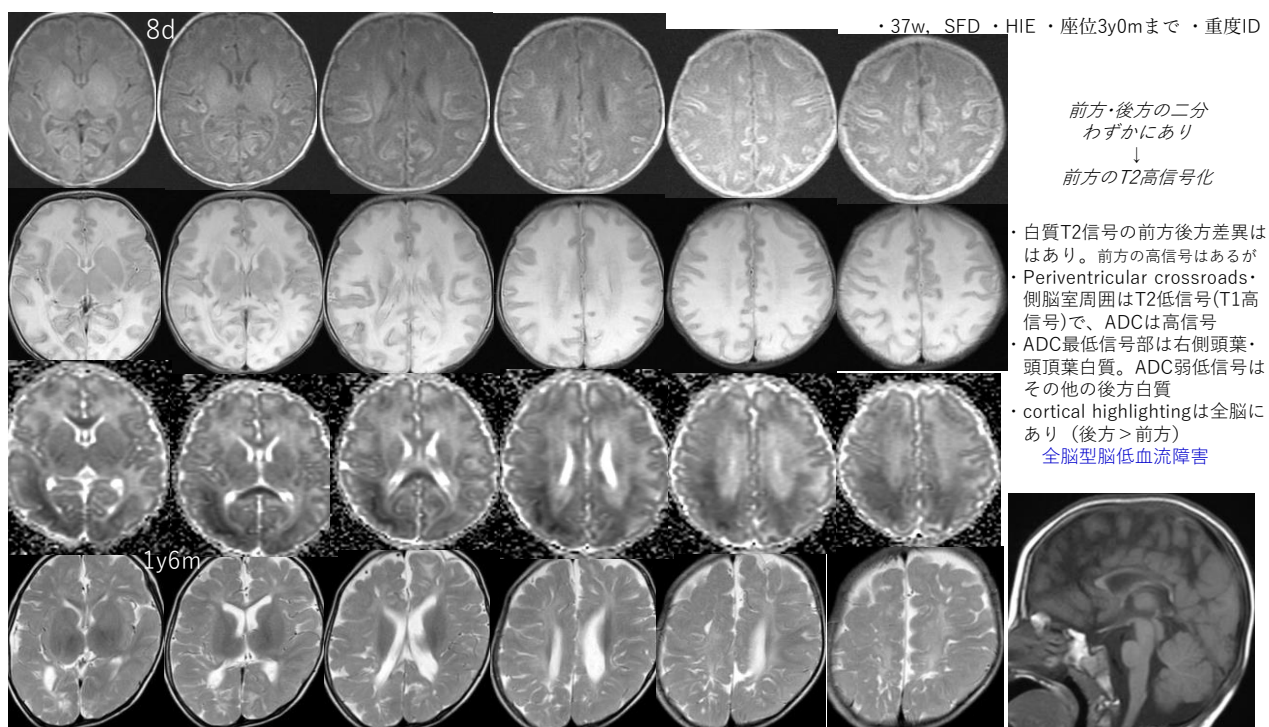
27



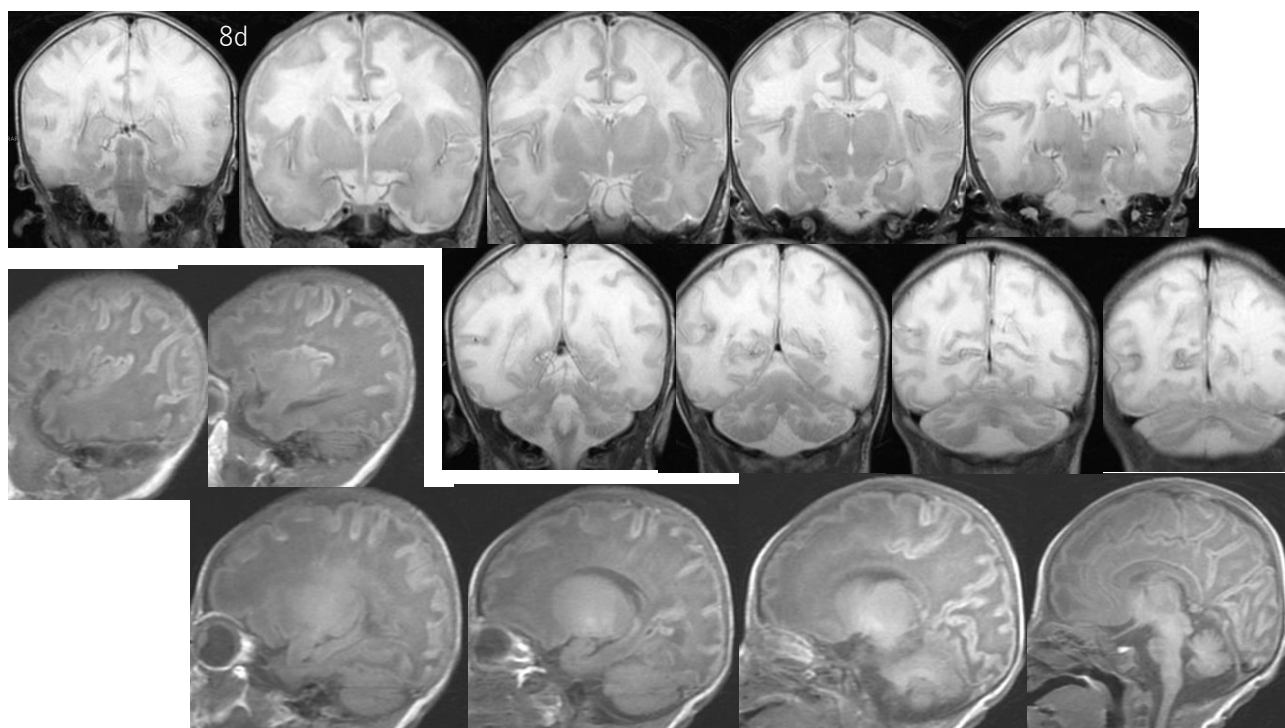
28



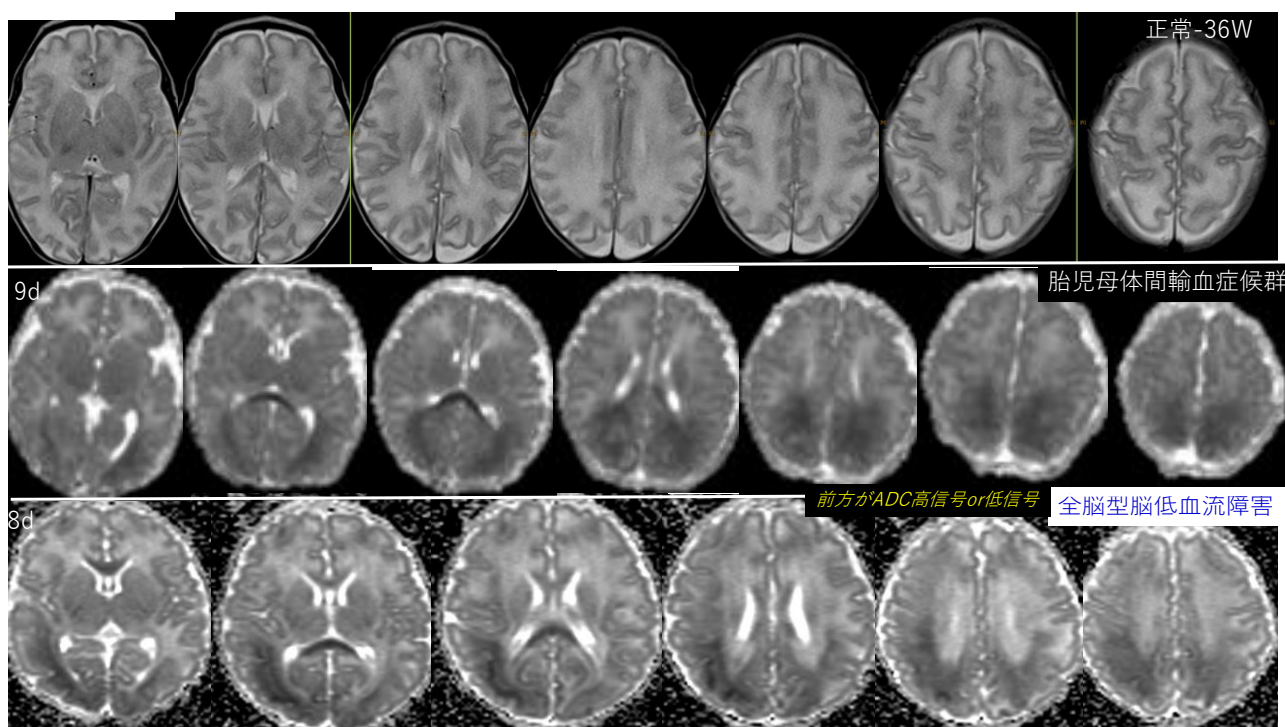
29



30

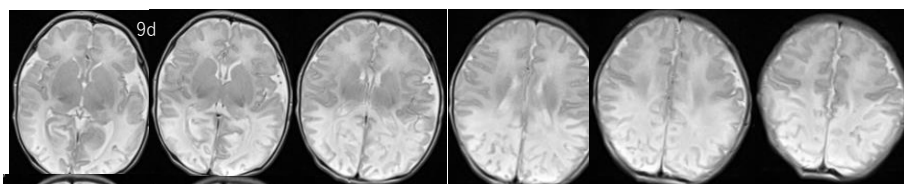


31

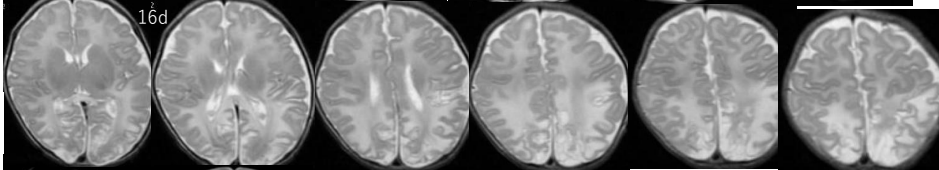


32

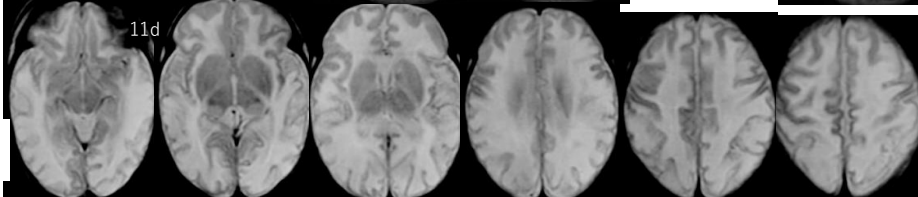
ふつうの子
胎児母体間
輸血症候群



ふつうの子
後方外部型
脳低血流障害

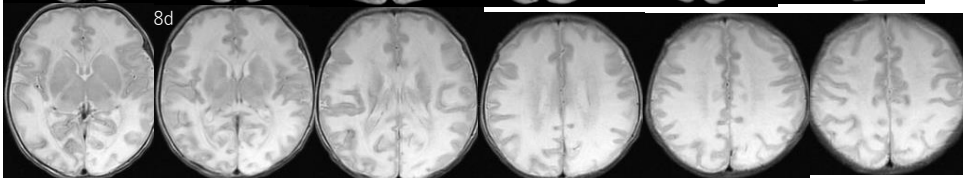


歩く
重度ID
後方外部型
脳低血流障害

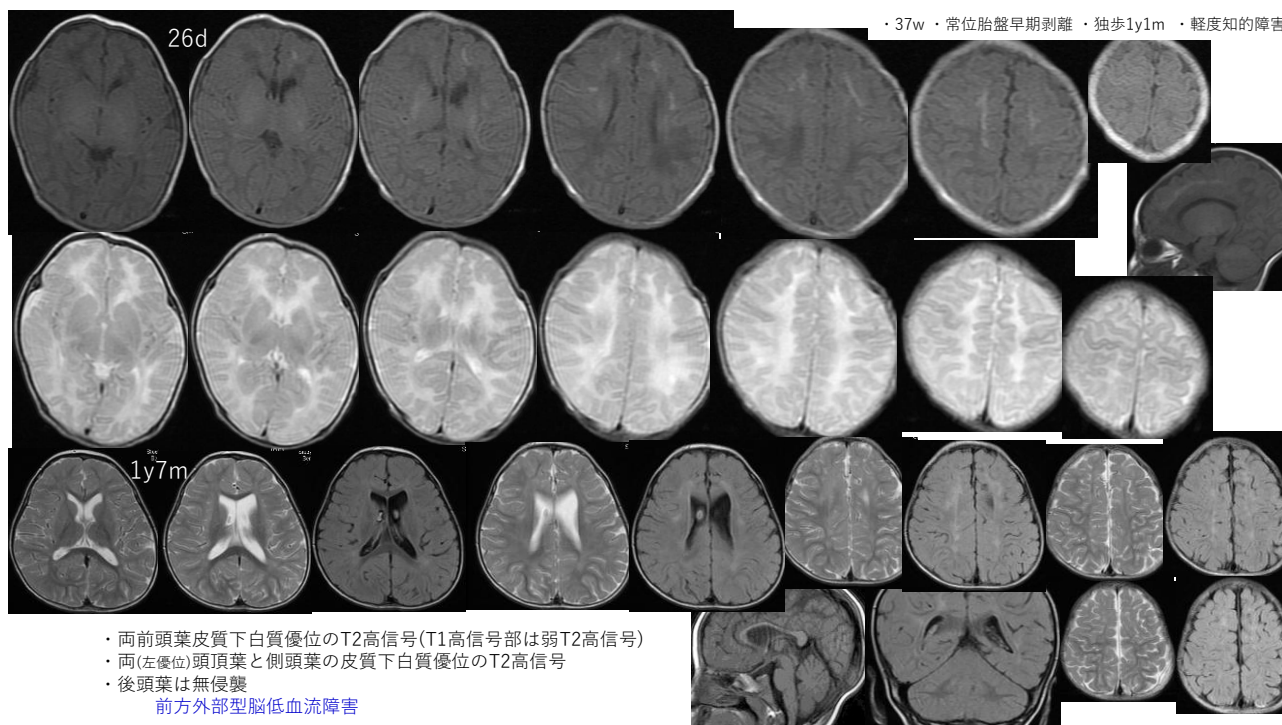


前頭葉病変
強い

歩けない
重度ID
全脳型
脳低血流障害



33

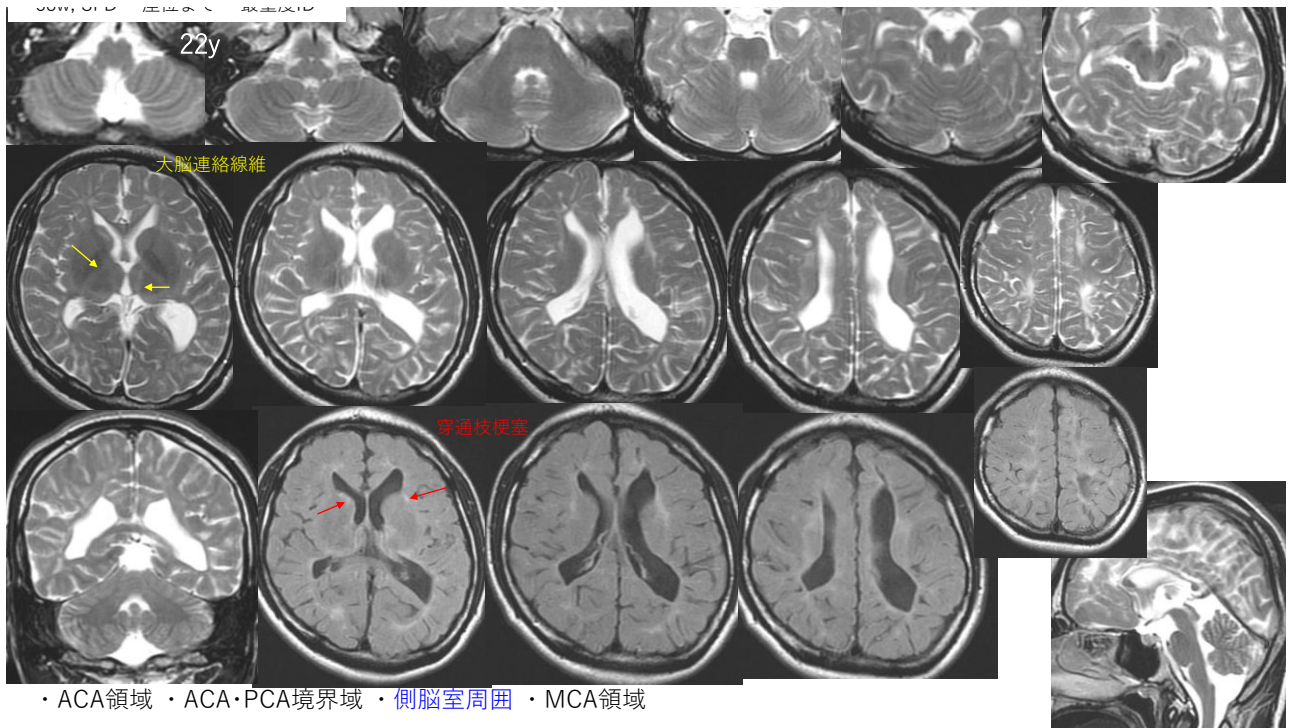


・ 37w ・ 常位胎盤早期剥離 ・ 独歩1y1m ・ 軽度知的障害

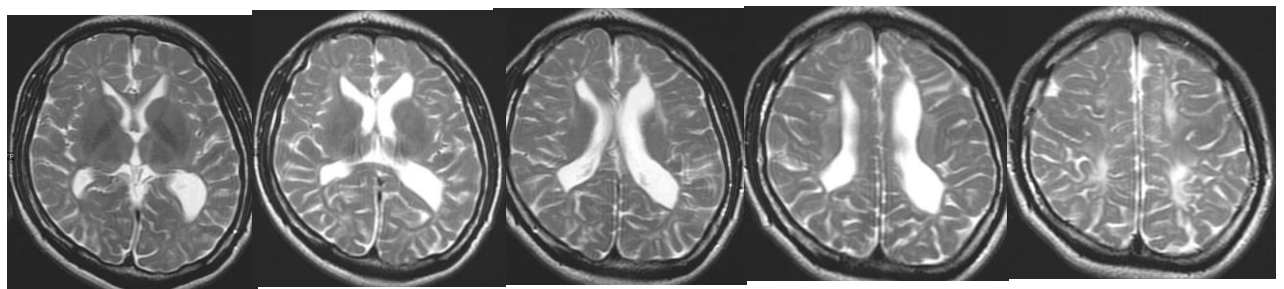
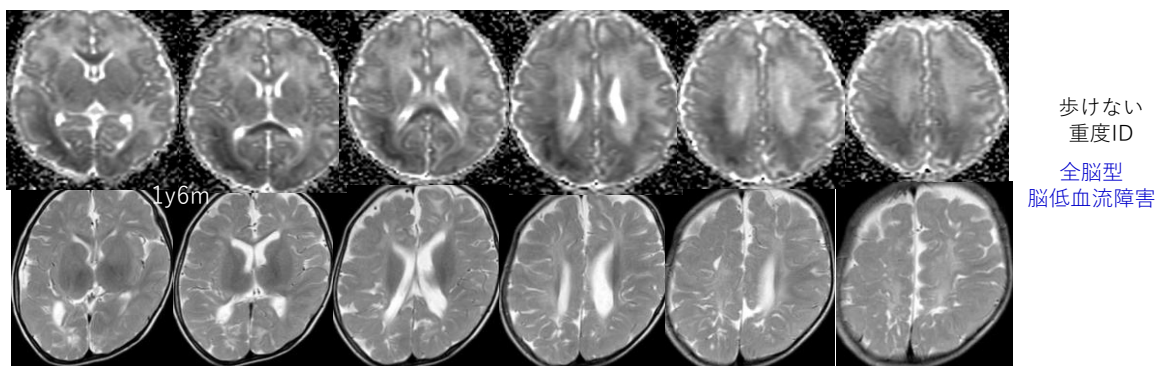
- ・ 両前頭葉皮質下白質優位のT2高信号(T1高信号部は弱T2高信号)
- ・ 両(左優位)頭頂葉と側頭葉の皮質下白質優位のT2高信号
- ・ 後頭葉は無侵襲

前方外部型脳低血流障害

34

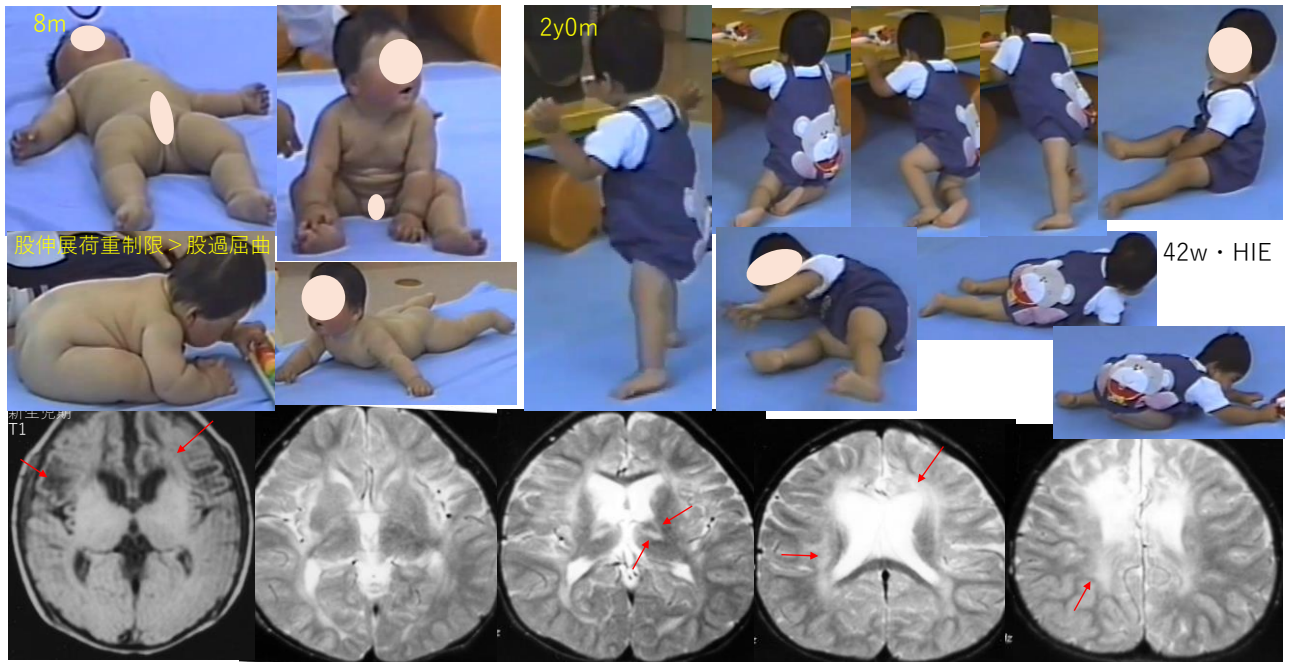


35



病変主座が皮質下白質 →全脳型脳低血流障害

36

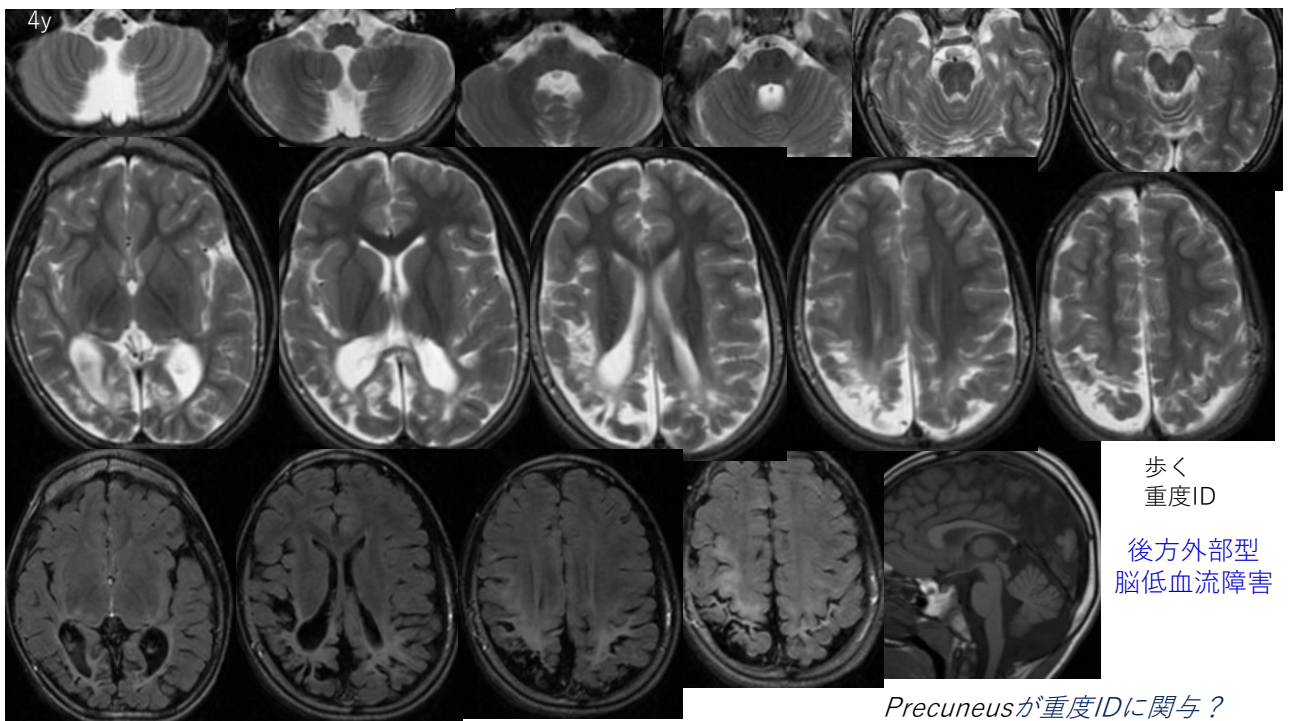


側脳室周囲白質+皮質下白質

視床VL核前部
前頭葉連絡線維

前方外部型脳低血流障害+内部型

37

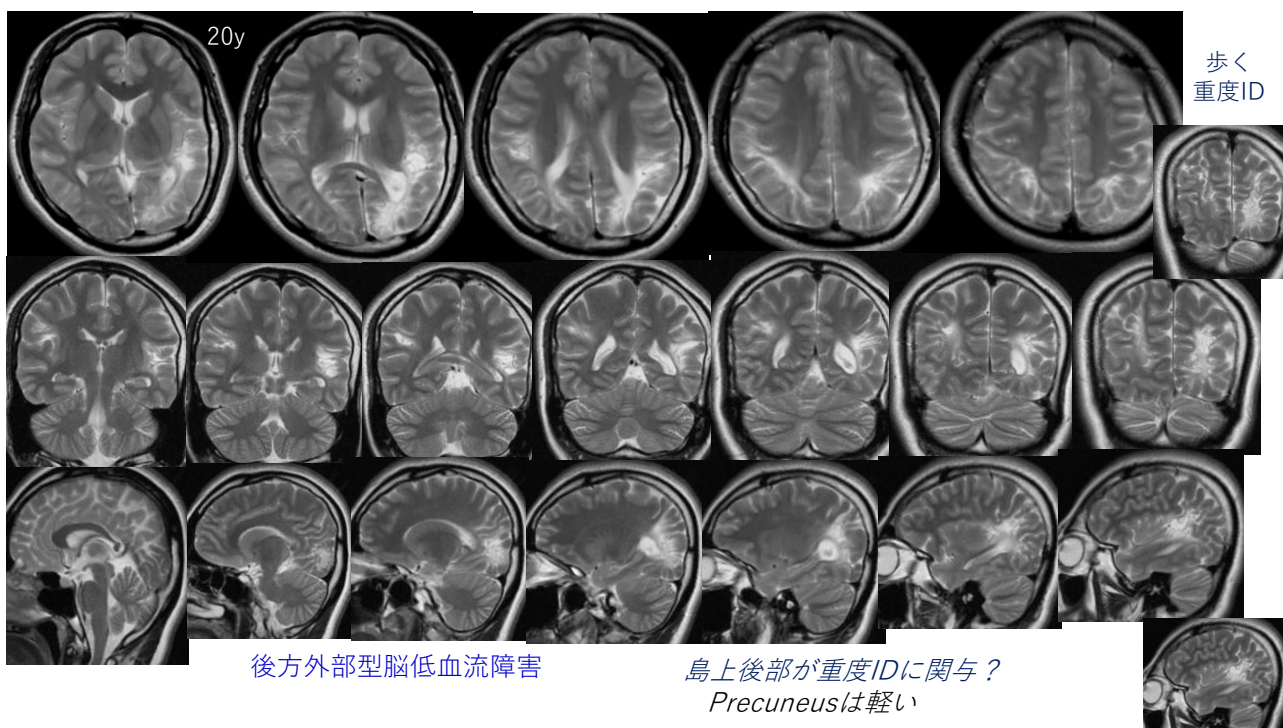


歩く
重度ID

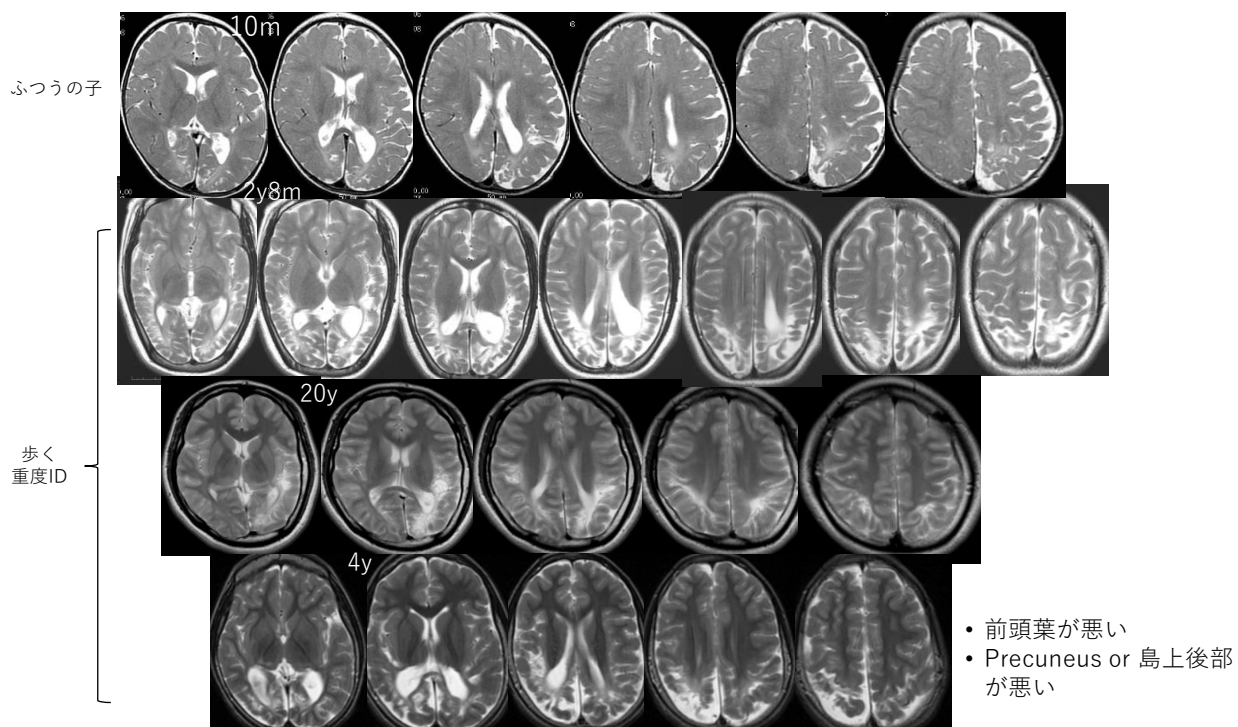
後方外部型
脳低血流障害

Precuneusが重度IDに関与?

38



39



40



41

重症心身障害
横地分類A1

30w

皮質は伸長されているが、
一次的組織障害はない

側脳室隣接部病変
側脳室内側部にもめだつ

c: Periventricular crossroads 中央部嚢胞が
巨大化

Periventricular crossroads 後方嚢胞が
後上角に達し脳回部まで及ぶ

h: 低信号化白質のT2高信号部

g: 脳回内白質T2高信号域

*: 脳回の弱高信号部

後方外周型脳低血流障害

- MCAとPCAの終末枝 内部型低血流域を含む
- MCAとPCAの境界域

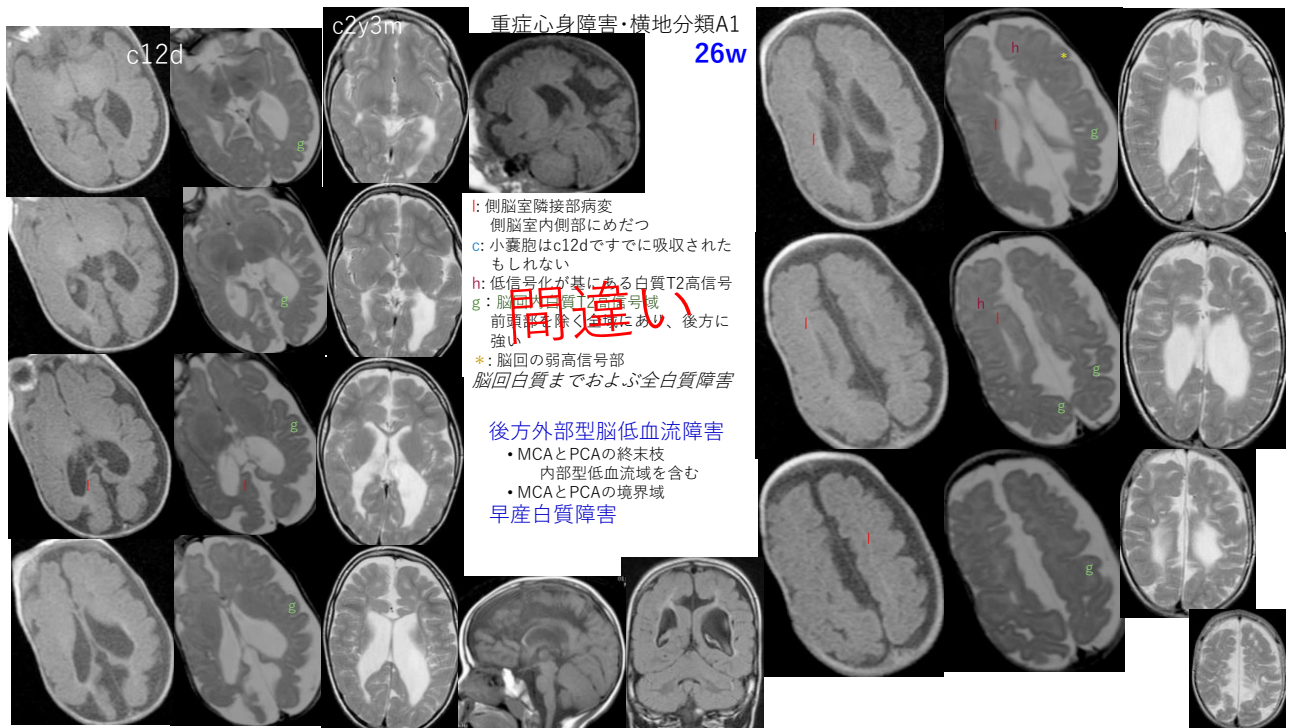
早産白質障害

肢体不自由児

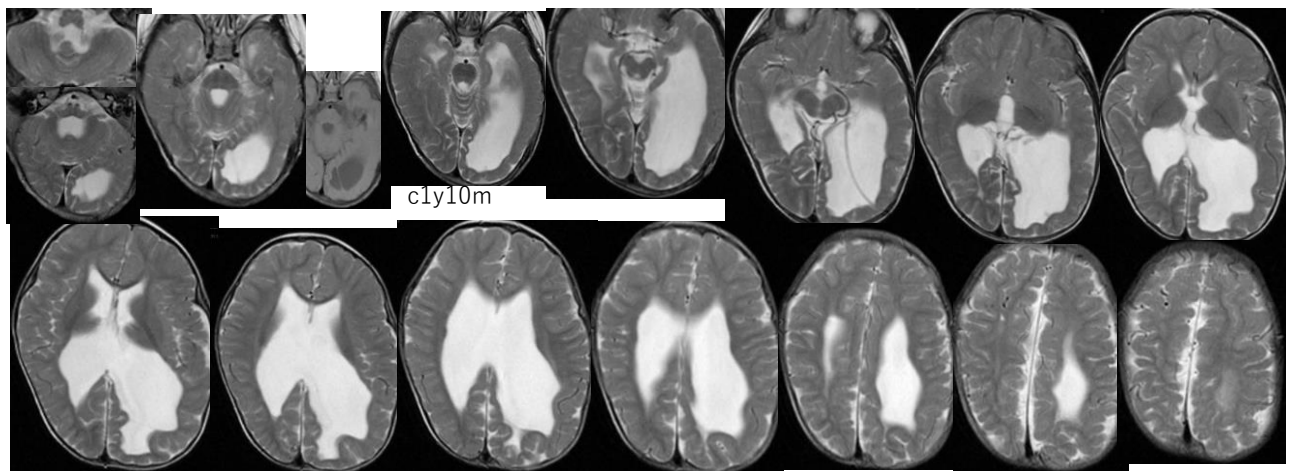
この嚢胞が脳回内白質
まで進展した

間違い

42



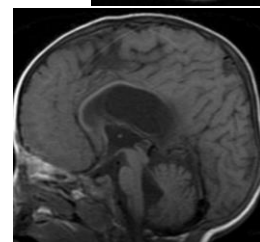
43



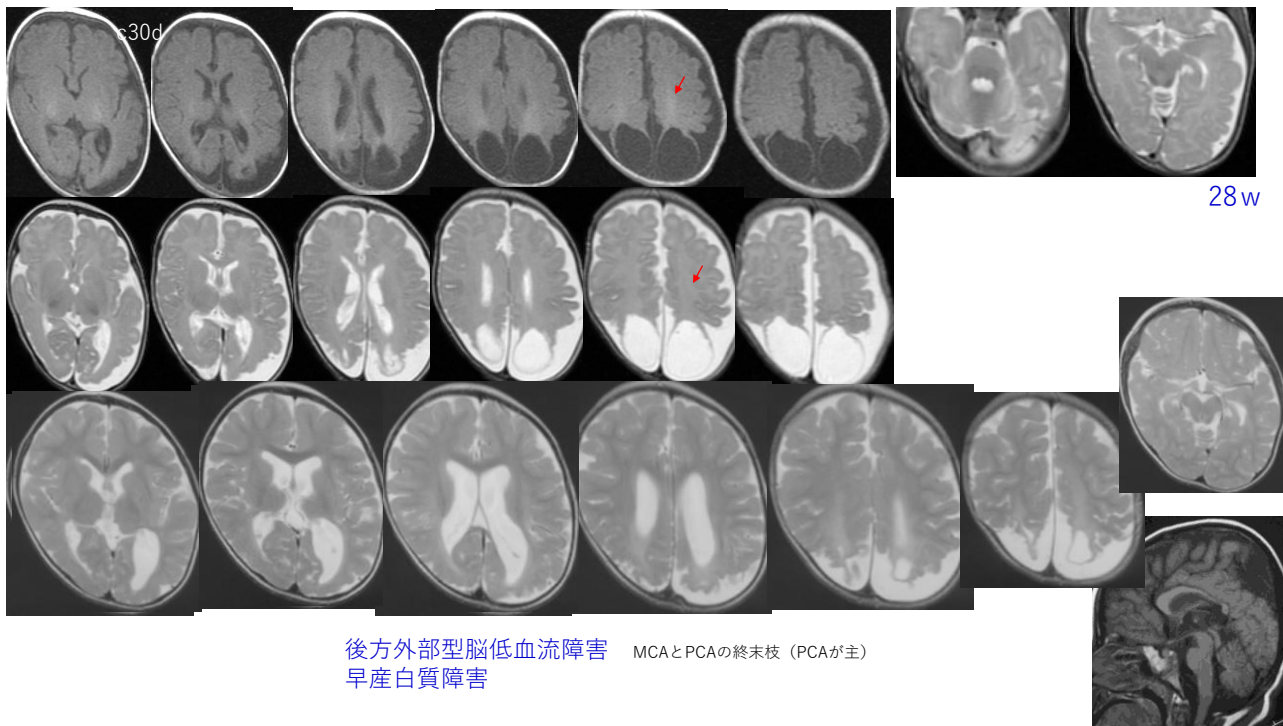
- ・在胎26w ・胎児仮死で緊急帝王切開 ・出血後水頭症でshunt術施行
- ・独歩c3y7m 足底屈が強い ・軽度知的障害

側脳室隣接部病変主体の早産白質病変（水頭症を含む）
× 脳低血流障害

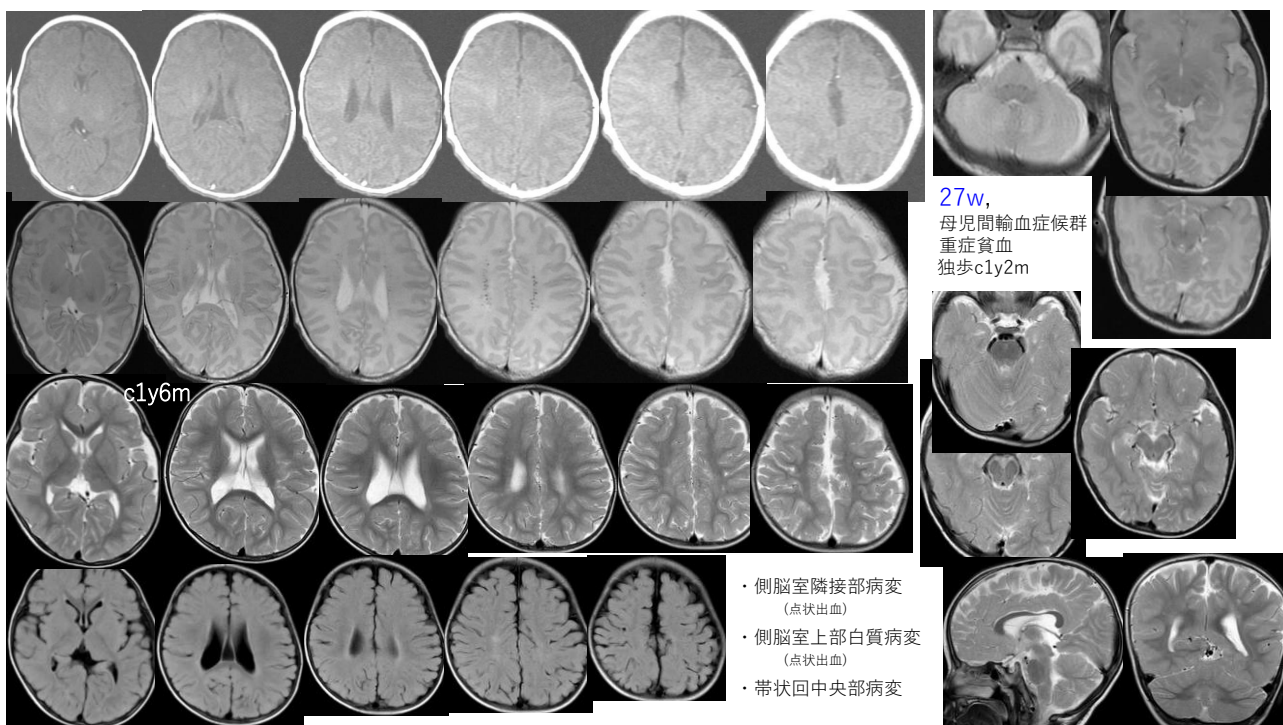
後方脳は脳回白質まで侵されているが、歩く軽度IDである



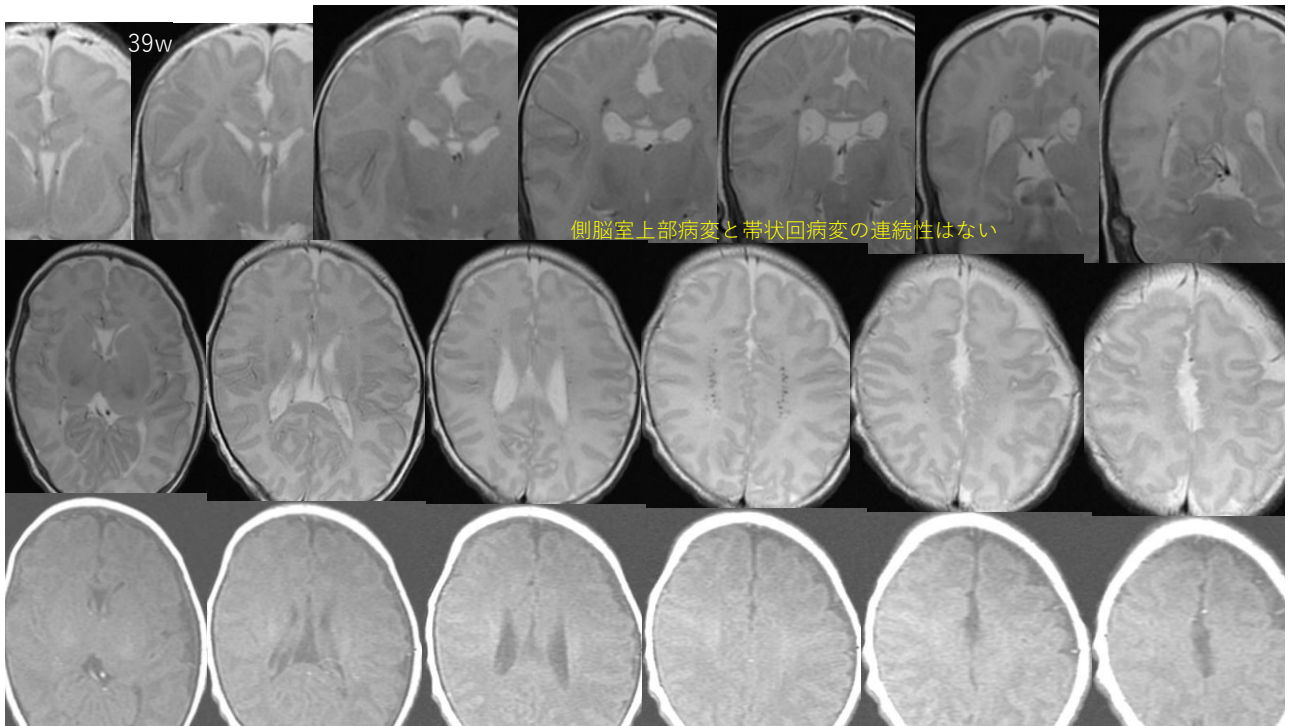
44



45



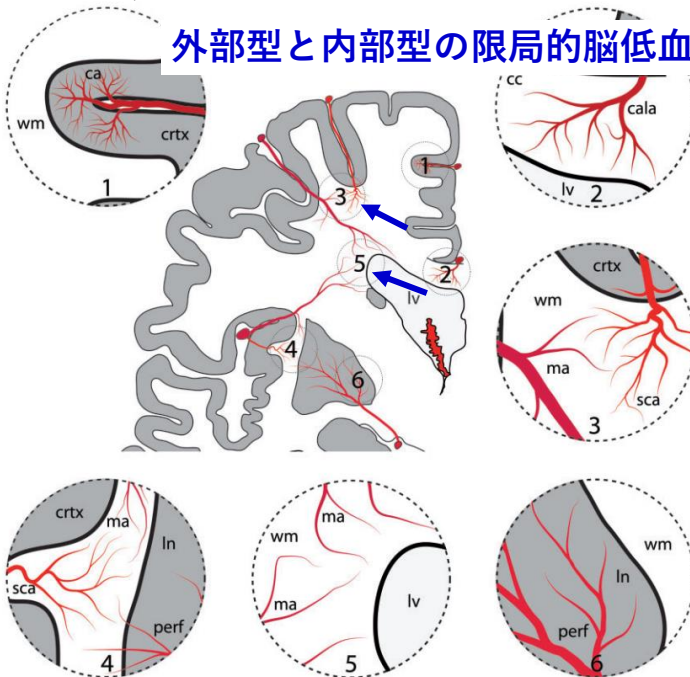
46



47

Smirnov M, et al. *Cerebral white matter vasculature: still uncharted?* Brain 2021;144:3561–75.

外部型と内部型の限局的脳低血流障害の合併



Type 1: Arterial vascularization of the cortex depends on short arterioles originating from the same **pial vessels** (single source juxtaposed (並列) supply).

Type 2: The corpus callosum is supplied by short arterioles originating from the **pial network** (single source juxtaposed supply).

Type 3: Short association U-fibers are supplied by **subcortical arteries** and earliest branches of **medullary arteries** (dual source interdigitated supply).

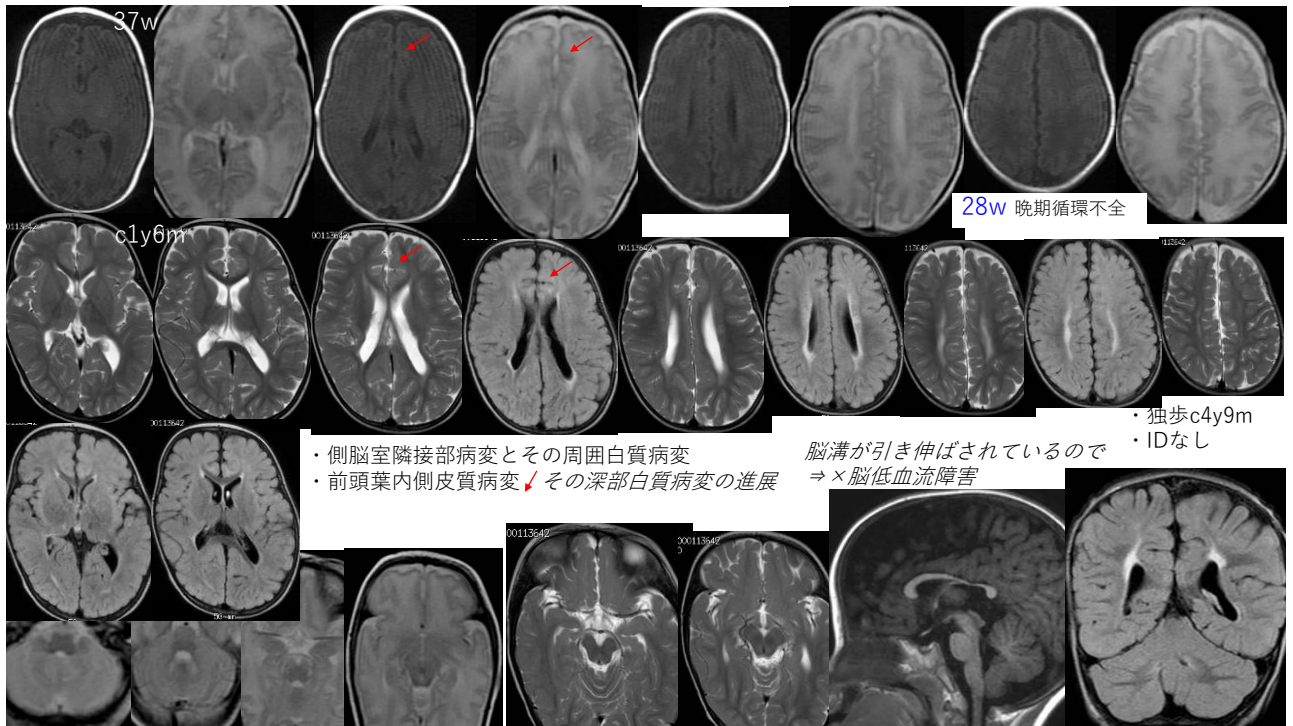
Type 4: The external capsule, claustrum and extreme capsule take up **subcortical arteries**, earliest branches of **medullary arteries**, and terminals of **perforating arteries** of the base of the brain (triple source interdigitated supply).

Type 5: The centrum semiovale is supplied by terminals of **deep white matter arteries** (single source juxtaposed supply).

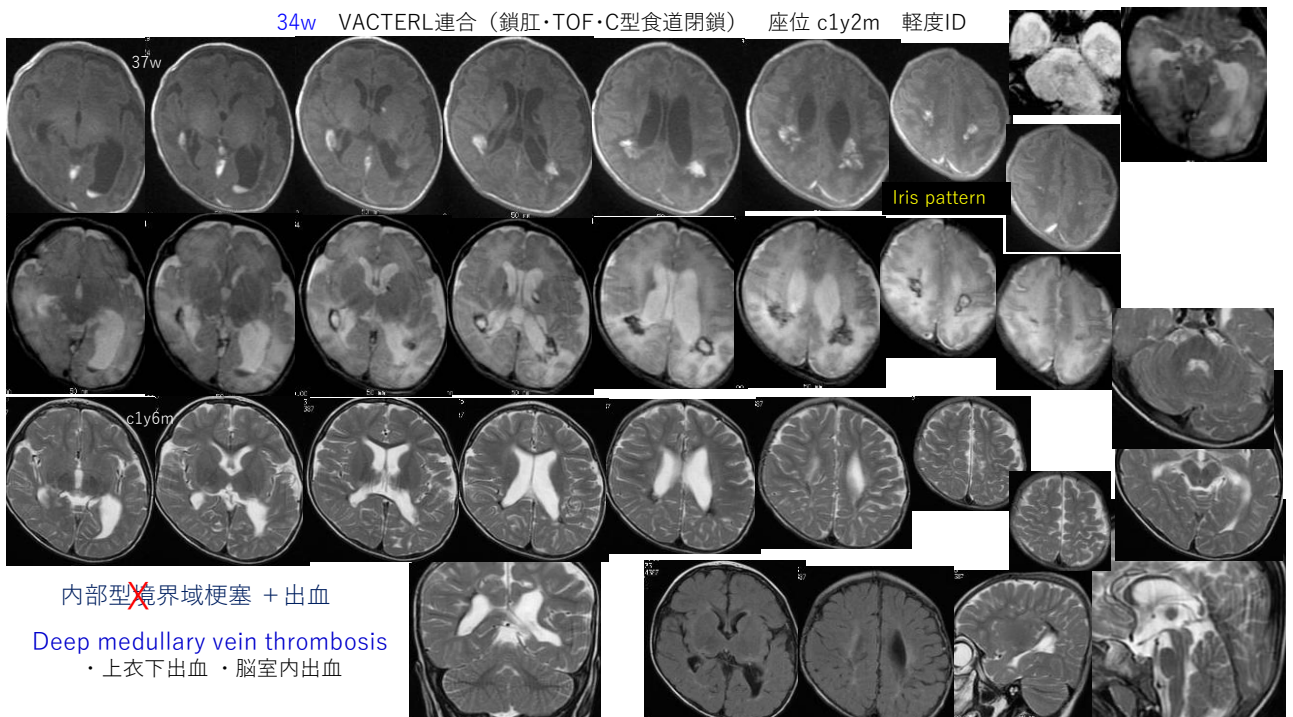
Type 6: Vessels supplying the basal ganglia and the thalamus are long, **perforating arterioles** and arteries originating from the base of the brain (single source juxtaposed supply).

cc = corpus callosum; crt = cortex; ln = lentiform nucleus; lv = lateral ventricle; ma = medullary artery; perf = perforating artery; sca = subcortical artery; wm = white matter.

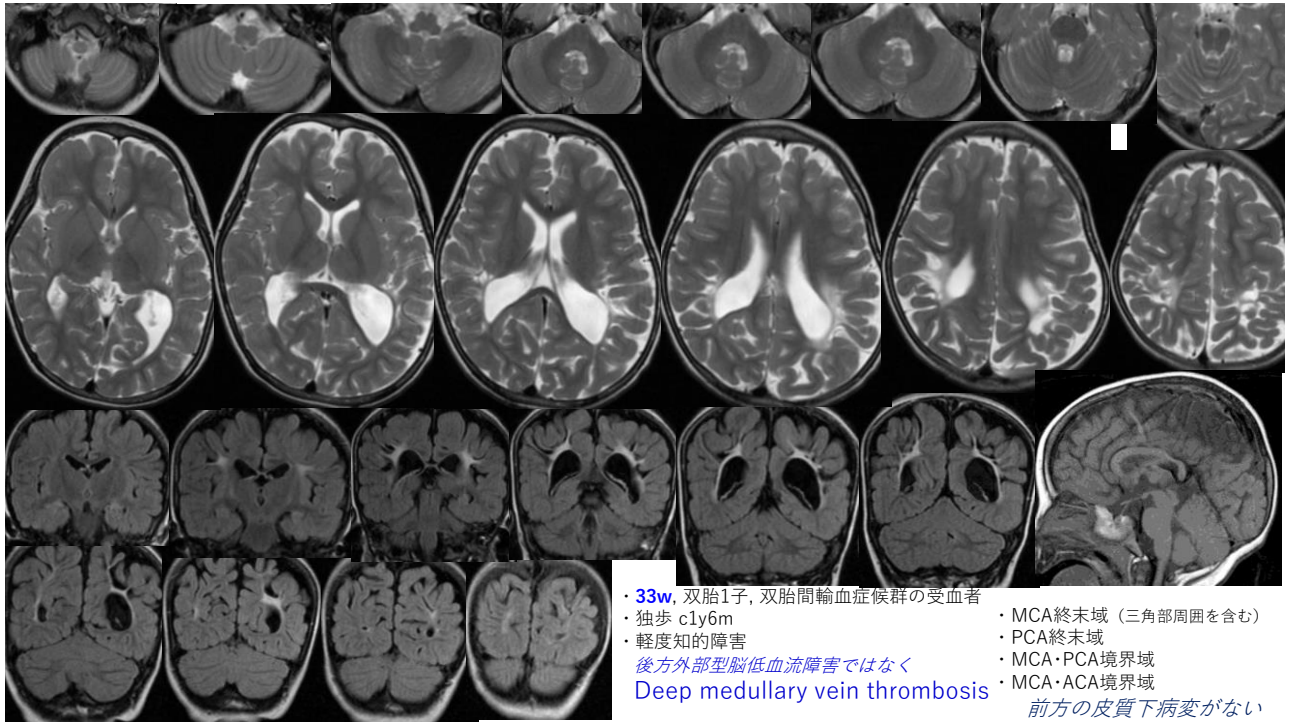
48



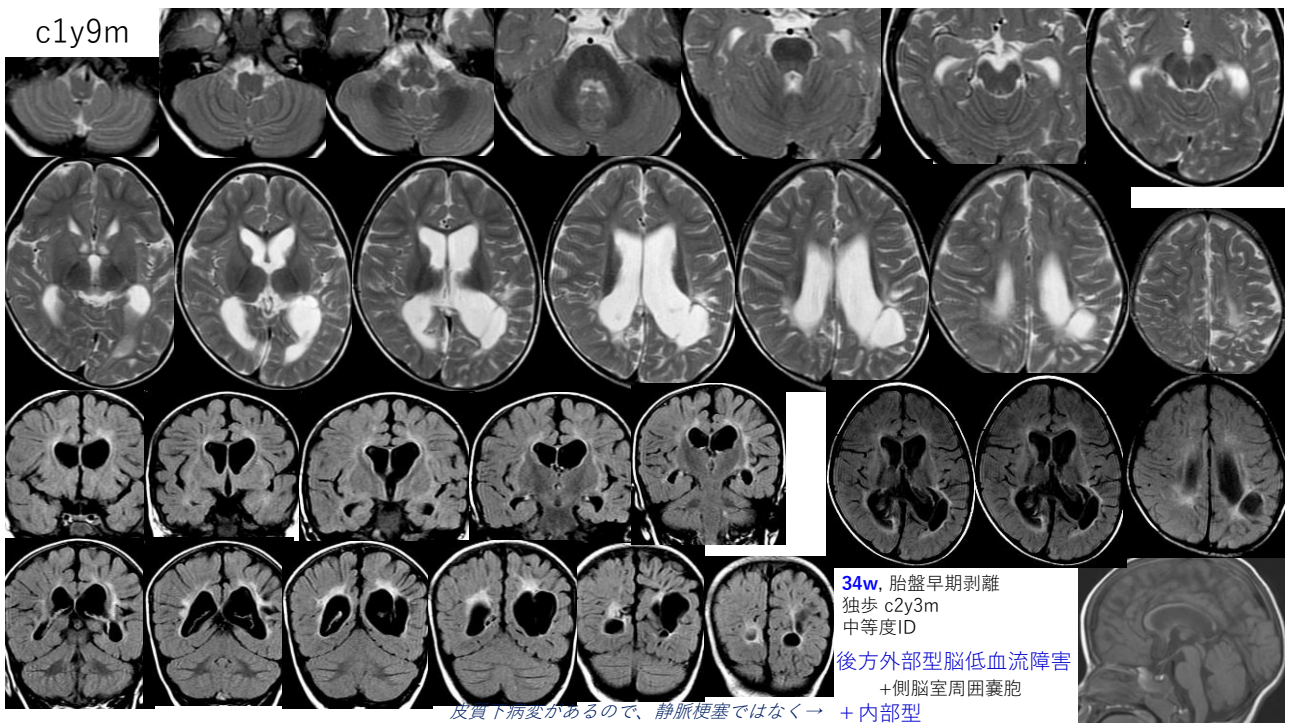
49



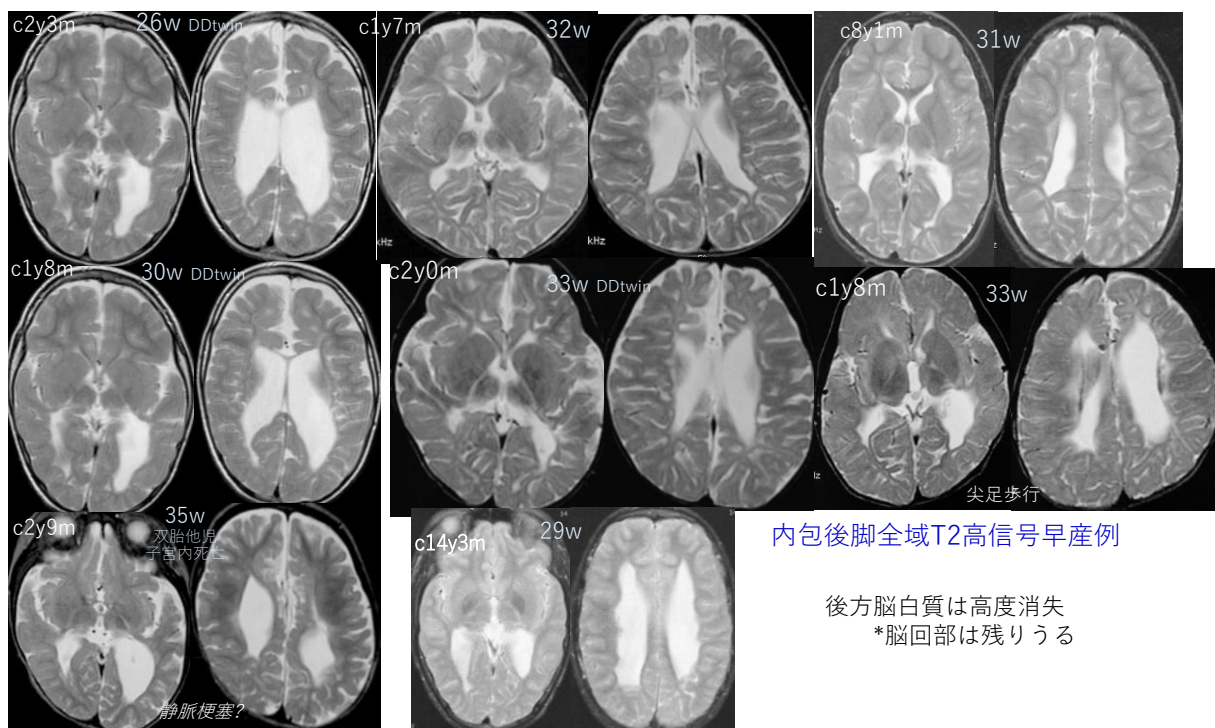
50



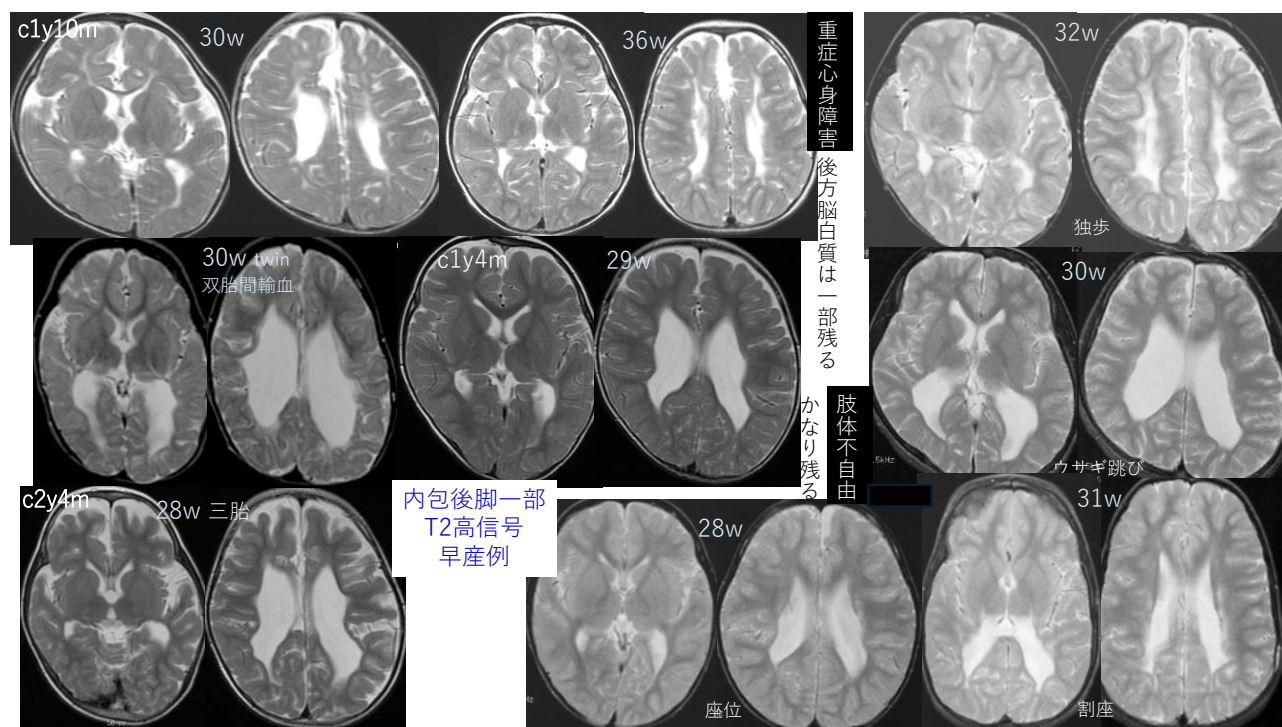
51



52



53



54

周生期脳低血流障害

- 周生期には cortical borderzone or watershed infarctions は存在しないか、極めて稀である
 - 満期時以下のT2高信号白質域は高分化状態であり、低灌流にvulnerableである
 - ・ 頭頂葉深部 ・ 頭頂葉内側部 ・ 後頭葉内側部 ・ 島後部
 - ✓ 従来、この頭頂葉部をPCA-MCA境界域と誤認していた
- 脳低血流障害は、外部型 (後方型・前方型)・内部型・全脳型に区分できる
- 灌流圧の低下は静脈うっ滞・静脈梗塞を来す
 - これも脳低血流障害に含める
 - ✓ このうちdeep medullary vein thrombosisは、内部型と近似した病巣をとる