Basic Kinetic Modeling in Molecular Imaging 2022

Measurement and estimation of flow in brain, heart, liver, muscles, and kidneys using $[O^{15}]H_2O$ PET techniques

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B.T.

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28 Sider 38. Aarg. Nr. 236 30 Øre

Atombombe-Spildstof udnyttes af de danske Læger

To unge københavnske Læger foretager en Række spændende Undersøgelser vedrørende Forkalkning, for højt Blodtryk og Børnelammelse

To unge københavnske Læger modtager med Mellemrum fra England nogle Kolber, som indeholder et Spildprodukt fra Fremstillingen af Atombomber. Det drejer sig om en radioaktiv Luftart, der gaar under Benævnelsen »Krypton 85«, og her i Danmark anvendes Luftarten til en Række læge-videnskabelige Undersøgelser, som man tillægger stor Betydning.

Under Fremstillingen af Atombomber paa det store og hemmelige Fabriksanlæg Harwell i England fremkommer der under Processerne en Del Stoffer, som man ikke kan bruge ved selve Bombe-Produktionen. Derimod har de to unge Læger, den 28-aarige Niels Lassen og den 27-aarige Ole Munck, fundet en overordentlig nyttig Anvendelse af et af disse Spildstoffer og konstrueret Apparater, i hvilke den nævnte radioaktive Luftart spiller en væsentlig Rolle ved Bestemmelsen af Blodgennemstrømningen i Menneskets Hjerne.

Saadan virker Apparatet, som USA er interesseret i

De to Læger foretager deres Undersøgelser paa den neurologiske Poliklinik paa Rigshospitalet, hvor B.T. har besøgt dem. Her fortæller de om deres Undersøgelser, hvortil de forleden har faaet stillet 25,000 Kr. til Raadighed af Videnskabernes Fond og Chr. X's Fond.

— I Virkeligheden startede det rent tilfældigt, siger de to Læger. Vi blev gjort opmærksom paa, at man var interesseret i at finde frem til en Metode, efter hvilken man hurtigt og sikkert kan bestemme Blodgennemstrømningen i Hjernen.

Vi vidste, at man i Amerika havde en Metode. Men den kunde ikke overføres til danske Forhold. Den amerikanske Metode er analytisk, og den er for langsom og for dyr efter vore Forhold. Vi fandt saa frem til en automatisk Beregningsmetode, som vi nu gennemprøver. Det er vort Haab at kortlægge, hvor meget Blod der under forskellige Sygdomme strømmer gennem Hjernen. Desuden undersøger vi

meget udbredte, og man ved egentlig ikke ret meget om, hvorledes de opstaar og paavirker Patienterne.

Den rent praktiske Undersøgelse foregaar paa den Maade, at Patienterne indaander almindelig Luft i hvilken vi via forskellige Apparater blander dette Stof »Krypton 85«. Undersøgelsen varer i 15 Minutter, og mens den staar paa, tager vi en Række Blodprøver af Patienterne. Vi tager baade Blod fra Arterierne, inden den radioaktive Ilt kommer til Hjernen, og fra Venerne, naar den radioaktive Ilt har passeret Hjernen. Blodprøverne undersøges derpaa i et Apparat, vi har tegnet og ladet fremstille. Det er en automatisk Tællemaskine, hvor man med Geigerrør kan tælle, hvor meget Blod der er strømmet gennem Hjernen, og se, hvor meget Ilt der er optaget. Vi kan af Gennemstrømningsmængden og den optagne Ilt se, hvor hurtigt Blodet strømmer, og om der undervejs ved Passagen i Hjernen er Hindringer, f. Eks. Forkalkninger.

Med vort Apparat kan der foretages 18 Analyser paa 4½ Time, og dette er meget hurtigere, og vi mener ogsaa sikrere end ved de øvrige kendte Undersøgelsesmetoder. Apparatet har kostet henved 10,000 Kroner at konstruere. Vi fortsætter vore Undersøgelser, og i de sidste Maaneder har vi foretaget Prøver paa flere Patienter. Naar vi har samlet tilstrækkeligt stort Materiale og bearbejdet det, vil vi fremlægge det for Lægevidenskaben, som forhaabentlig saa rent praktisk kan drage Nytte af det. Vi har arbejdet et Aars Tid med den nye Metode, men der vil endnu gaa lang Tid, inden vi er helt færdige.

De to unge københavnske Læger

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What is tissue perfusion?

rBF: regional (tissue) blood flow (ml/(100g tissue*min))
rBF is functional, nutritive tissue flow: Blood moving through capillaries
Not rBV: regional blood volume (MR perfusion)

rBF= rBV/MTT MTT: mean transit time (min)

Blood Volume
mL/100g tissue

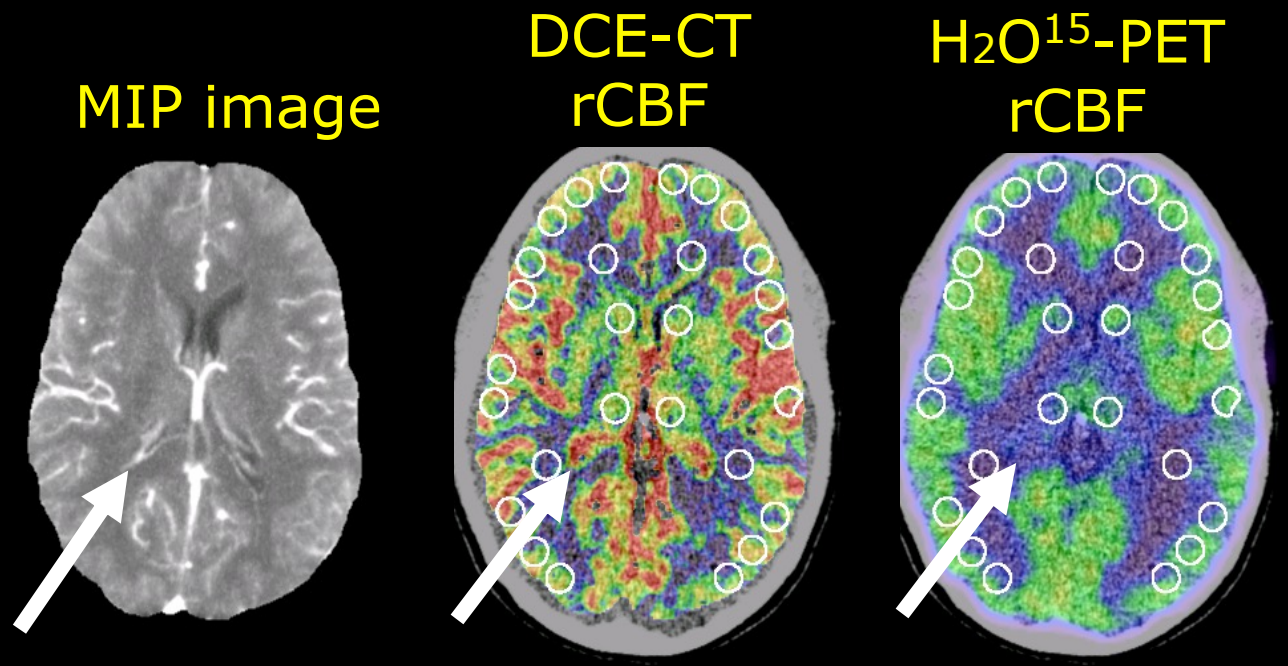
“Vascular” Blood Flow
mL/min

“Tissue” Blood Flow
mL/(100g tissue * min)

Intravascular contrast vs freely diffusible tracer

You can't quantify rCBF with an intravascular tracer

Theory is good for capillary flow, but flow in other vascular structures are messing things up



High flow in vascular structure, but no capillary bed

Gruner JM, Paamand R, Kosteljanetz M, Broholm H, Hojgaard L, Law I. Brain perfusion CT compared with (1)(5)O-H(2)O PET in patients with primary brain tumours. Eur J Nucl Med Mol Imaging. 2012;39:1691-1701.

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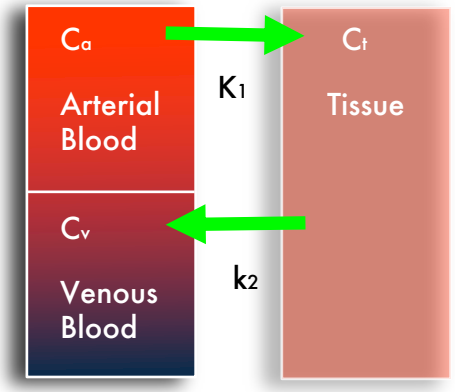
Forces working on the tracer
General considerations: The one-tissue compartment model

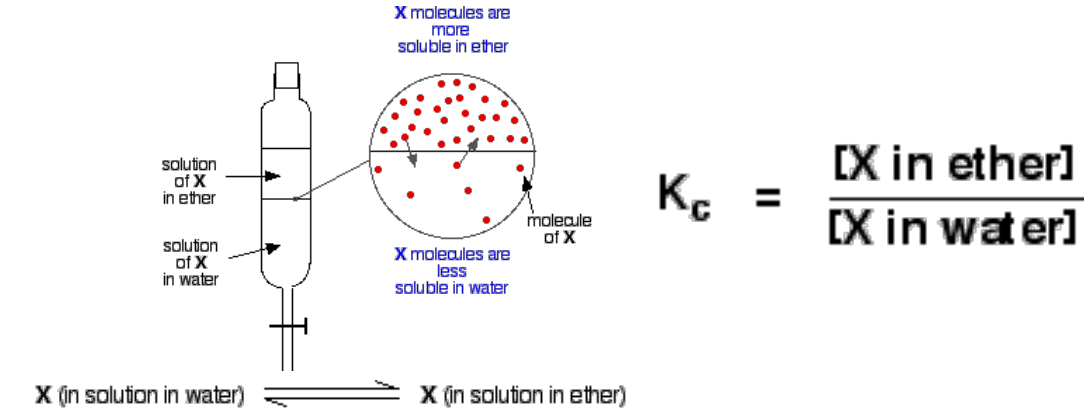
Definitions:
p: Partition Coefficient between 2 compartments:
Ratio of equilibrium tracer concentrations:
(measured in vitro)



V_t: (Apparent) Volume of Distribution:
Ratio at equilibrium of apparent tracer Volumes to total Volume (Estimated/fitted)

$K_1/k_2 = C_t(t)/C_v(t) = V_t \approx p$
[unitless; g/g; ml/g; ml/ml]

At venous side almost diffusion equilibrium



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Values for Partition Coefficient

Tissue
Hematocrit
Pathology

TABLE 1. *Partition coefficients for whole brain ($\bar{\lambda}$), gray matter (λ_g), and white matter (λ_w)*

	Dimensions for partition coefficient values		
	g/g	ml/g	ml/ml
$\bar{\lambda}$	0.96	0.90	0.95
λ_g	1.04	0.98	1.03
λ_w	0.87	0.82	0.86

TABLE 2. *Brain partition coefficient of water as a function of hematocrit*

Hematocrit (%)	Water content of blood (g/ml)	λ_g (ml/g)	λ_w (ml/g)	$\bar{\lambda}$ (ml/g)
25	0.895	0.94	0.78	0.86
35	0.873	0.96	0.80	0.88
45	0.851	0.99	0.82	0.90
55	0.829	1.01	0.84	0.93

λ_g, λ_w, and $\bar{\lambda}$, partition coefficients for gray matter, white matter, and whole brain, respectively.

TABLE 3. *Regional values of the brain partition coefficient of water*

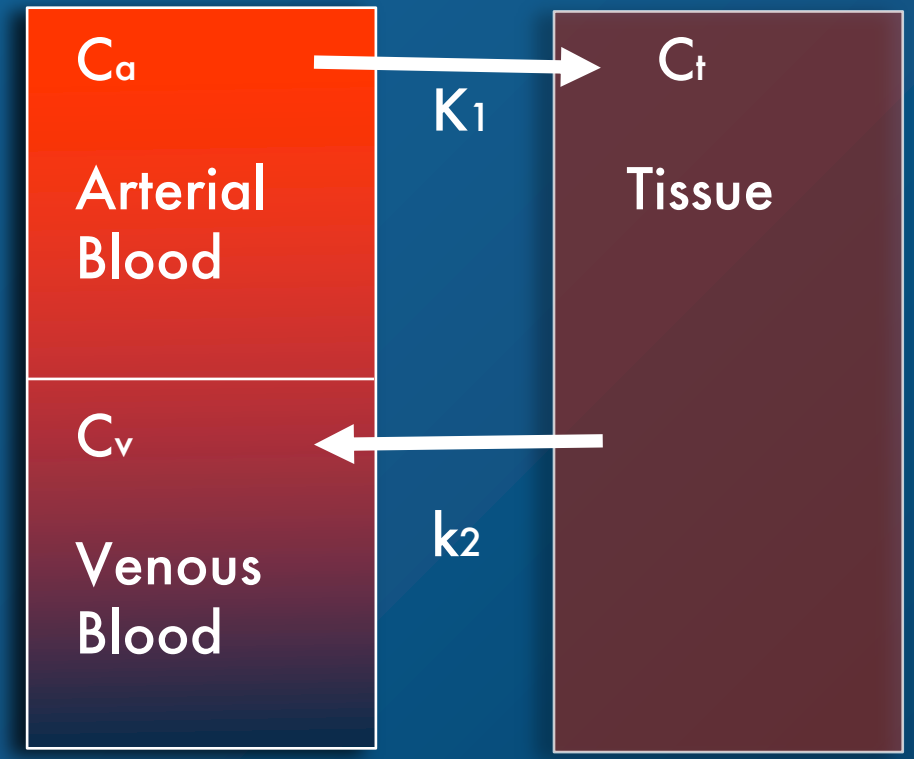
	Water content (g/100 g)	Partition coefficient (ml/g)
Gray matter		
Cerebral cortex	84.3[a]	0.99
Thalamus	75.1[a]	0.88
Caudate nucleus	81.4[b]	0.95
White matter		
Centrum semiovale	70.7[a]	0.83
Corpus callosum	75.7[a]	0.89
Edematous centrum semiovale	81.8[a]	0.96

[a] Data from Stewart-Wallace (1939).
[b] Data from Randall (1938).

Herscovitch P, Raichle ME. What is the correct value for the brain-blood partition coefficient for water? J Cereb Blood Flow Metab 1985;5(1):65-9.

How to measure regional Blod Flow

General considerations: The one-tissue compartment model



A Freely Diffusible Tracer

$dC_t(t)/dt = K_1\, C_a(t) - k_2\, C_t(t)$

Δ Tissue conc = Influx - outwash

Solution:

$C_t(t) = K_1\, C_a(t) \otimes e^{-k_2 t}$

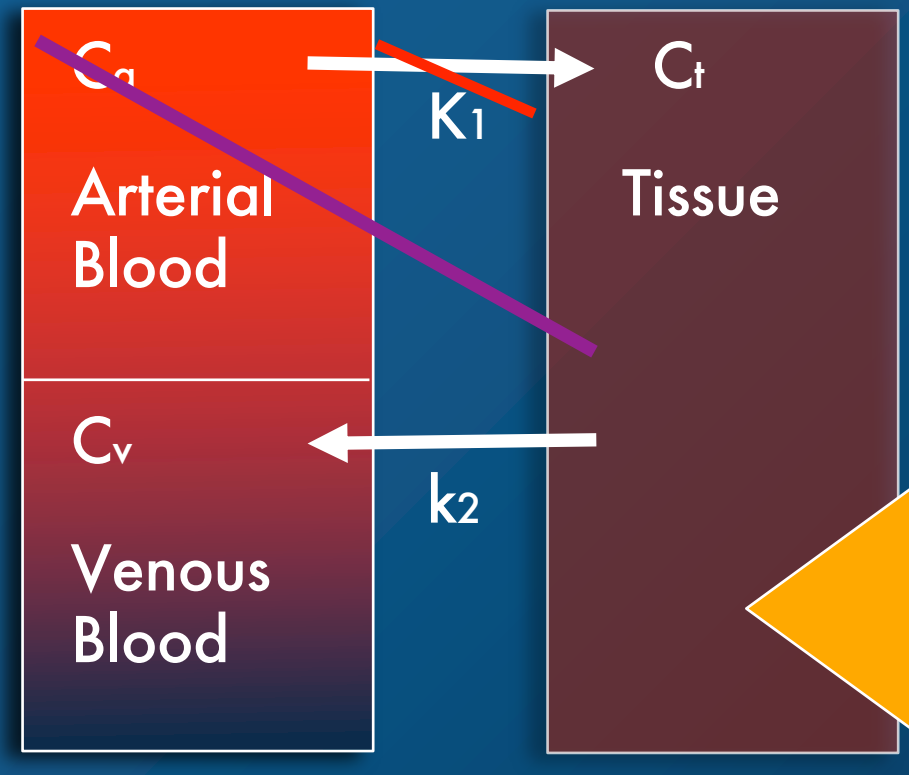
How many passengers at a give time, t ?

k_2 [min^{-1}]: Washout Rate Constant

K_1 = Unidirectional clearence of blood from tracer, influx rate [ml $g^{-1}min^{-1}$].

Will return to this later

Special considerations: only washout



$dC_t(t)/dt = K_1 C_a(t) - k_2 C_t(t)$

Δ Tissue conc = Influx - outwash

Solution:

$C_t(t) = e^{-k_2 t}$; $K_1 = k_2 p$

Delta function

Only Washout/Tissue clearance curve/Desaturation

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Xenon clearance method

Only Washout/tissue clearence
Residue detection during desaturation
Fraction of bolus in tissue as function of time

$$K_1 = k_2 p = \ln(2)/T_{1/2} p$$

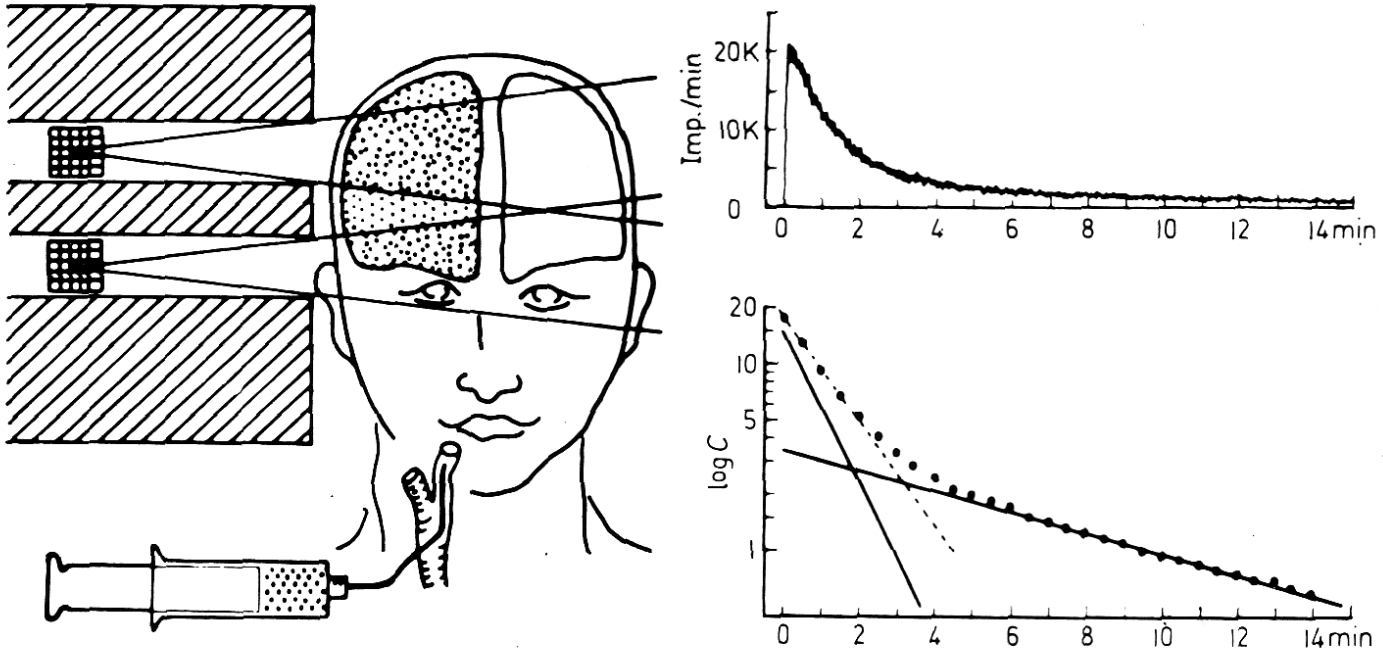

Fig. 2. Xenon-133 used for two-dimensional CBF in man: the Lassen–Ingvar intra-arterial injection technique.

Grey matter: 80 ml/(100g min)
White Matter: 20 ml/(100g min)

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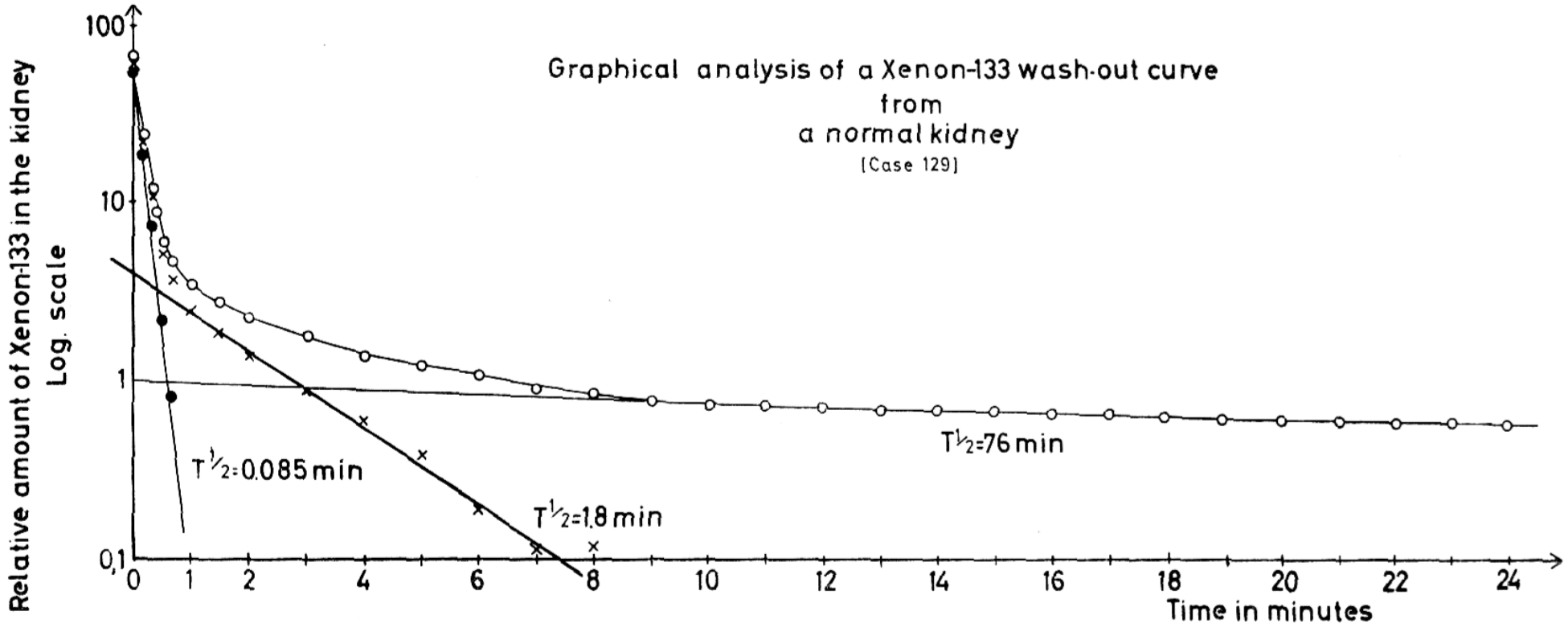
Xenon clearance method



- Skin, Muscles, Fat tissue, Tendons

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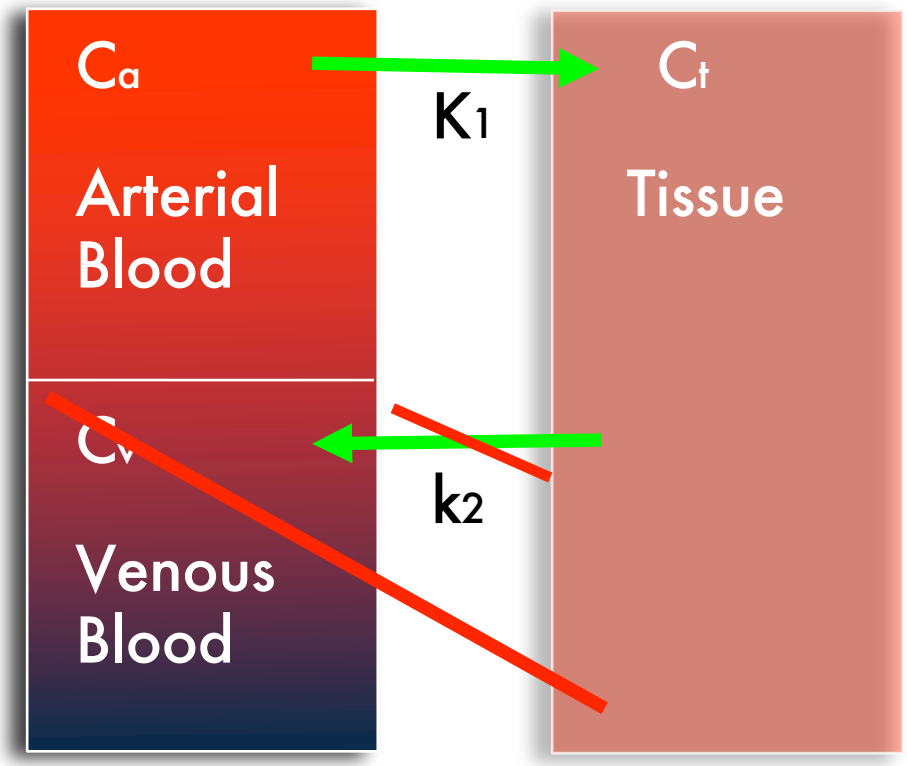
Special considerations: no washout

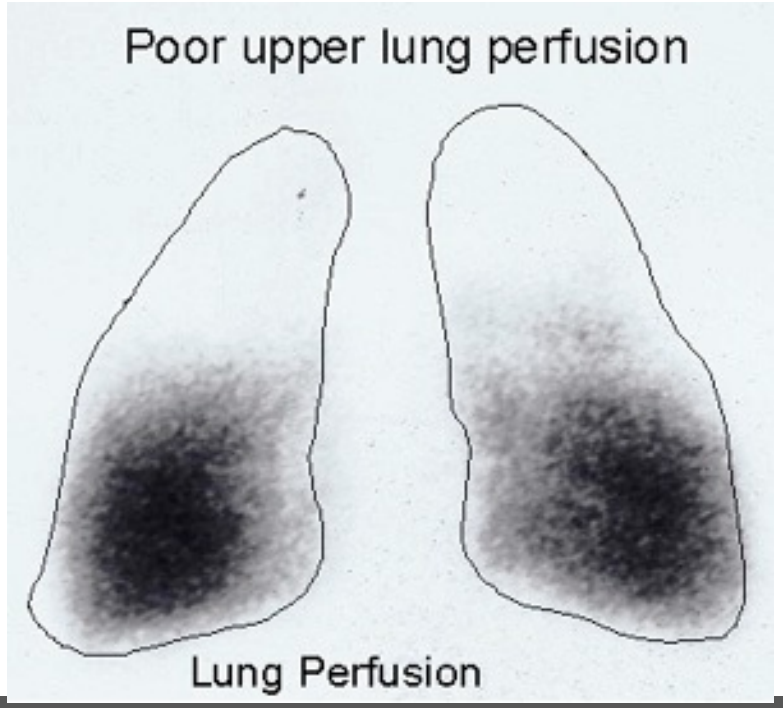


$dC_t(t)/dt = K_1 C_a(t) - k_2 C_t(t)$

Δ Tissue conc = Influx - outwash

$C_t(t) = f\, C_a(t)$

Perfect Trapping:
Example: Microspheres



Regional Cerebral Blood Flow in Pigs Estimated by Microspheres

F. F. Madsen[1], F. T. Jensen[2], M. Væth[3], and J. Ch. Djurhuus[4]

1) MS = small spheres 15 my labelled radioactively or fluorescence
2) inject in left ventricle of heart - sample arterial blood in abdominal aorta over time
3) Slices are cut out and activity counted

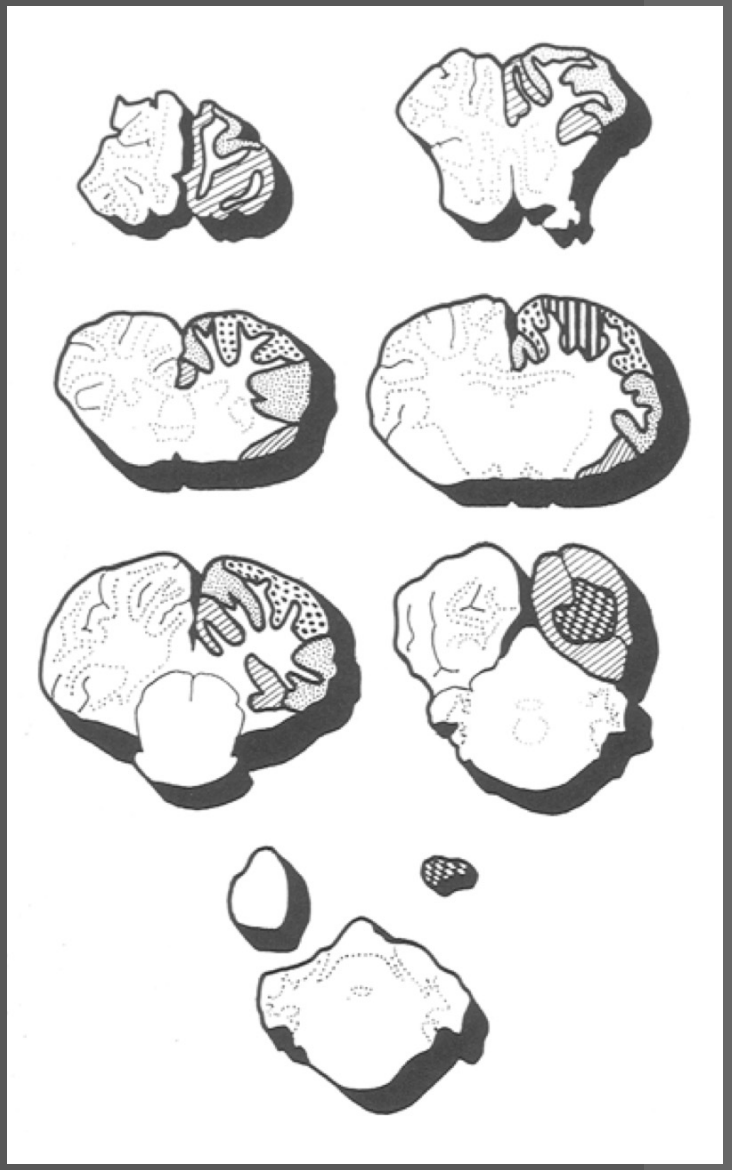
Flow was calculated according to the formula:

$$F_i = N_i \times RF/A_t$$

where F_i is flow in the region of interest (ml/min × g), N_i the activity in the region of interest (counts/min × g), RF the sampled volume in the reference test (ml/min) and A_t the total activity in RF (counts/min).

Assumptions:

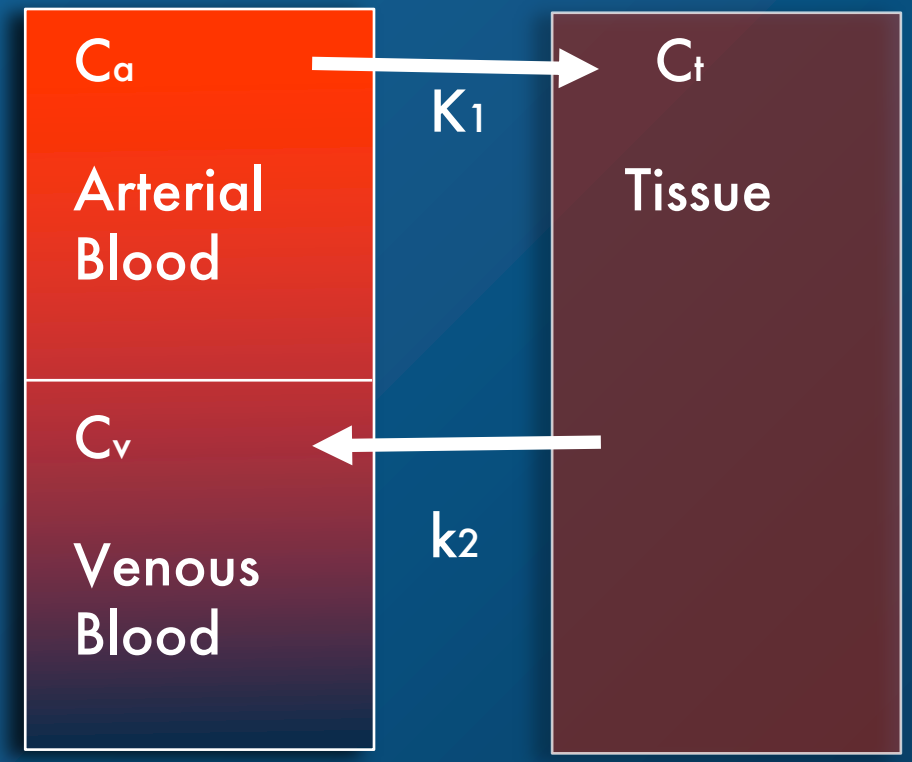
1) an even mixing of the MS in the blood
2) the MS should be trapped proportionally to the regional cerebral blood flow
3) the MS should be trapped during first passage, (0.5 % i sag sin)
4) the MS should not interfere with rCBF or regional physiological steady state.



REGION H

How to measure regional Blod Flow

General considerations: The one-tissue compartment model



A Freely Diffusible Tracer

$dC_t(t)/dt = K_1\ C_a(t) - k_2\ C_t(t)$

Δ Tissue conc = Influx - outwash

Solution:

$C_t(t) = K_1\ C_a(t) \otimes e^{-k_2 t}$

K_1 = Unidirectional clearence of blood from tracer, influx rate [ml $g^{-1}min^{-1}$].

k_2 [min^{-1}]: Washout Rate Constant: E: extraction fraction

$K_1 = E\ f$, if E=1 => $K_1 = f$ (rCBF, Perfusion)

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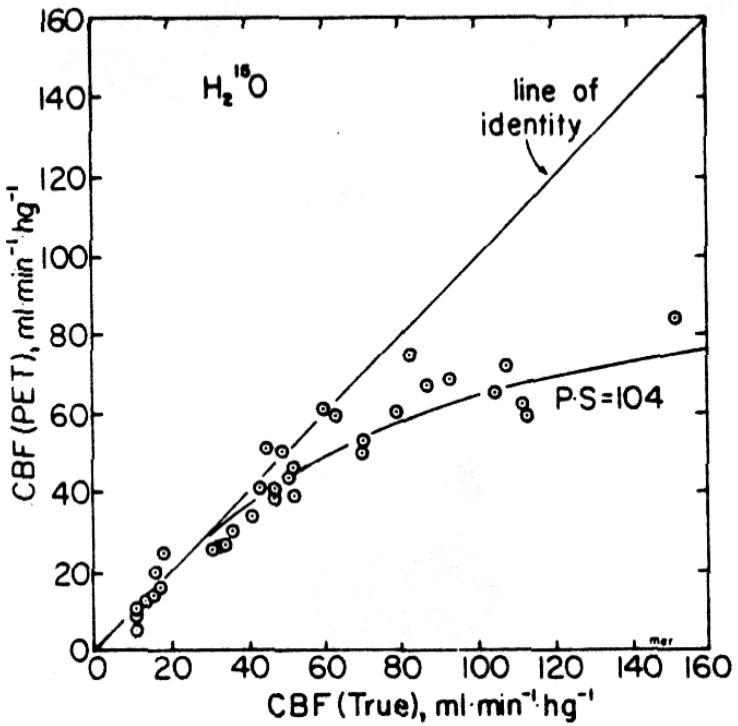
Assumptions - Single Tissue Compartment Model

- Tracer do not influence physiological processes
- Constant physiological state during measurement
- $[^{15}O]H_2O$ is freely diffusible across BBB – no: E = 0.87
- Compartmental Instantaneous mixing
- ROI filled with 1 tissue with homogenous tracer conc.
  - Free exchange between tissue water og $[^{15}O]H_2O$
  - No other tissues in ROI (Vascular, White Matter, CSF): no: limited resolution



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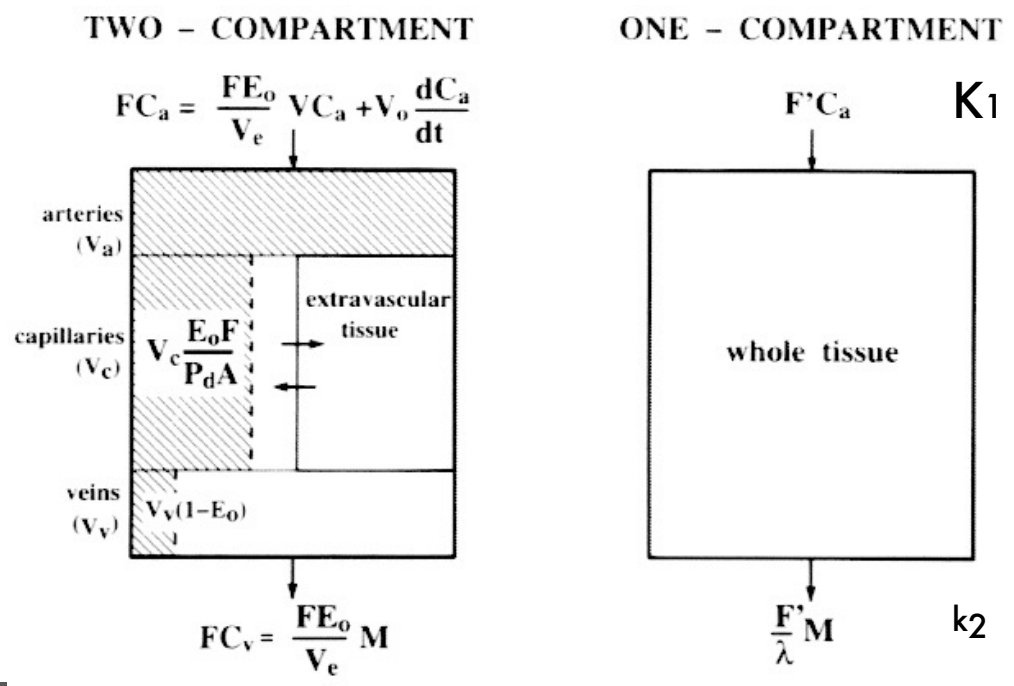
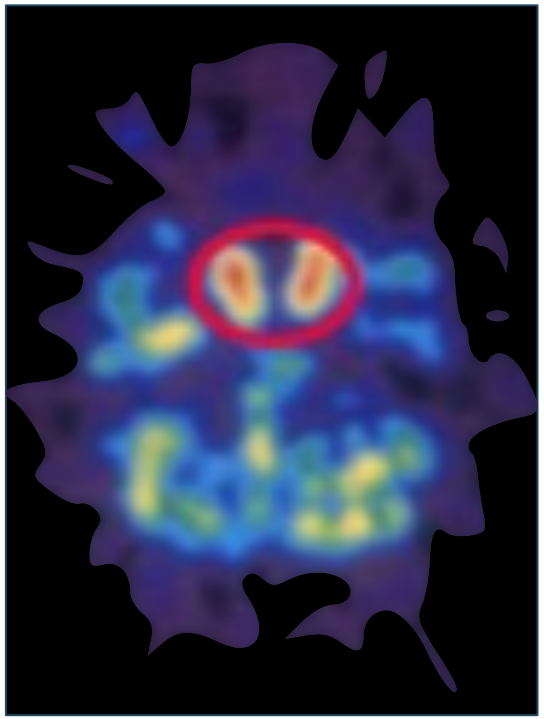
How do we deal with unextracted [^{15}O]H_2O?

Vb: arterial vascular fraction: correct for "image signal that look like arteries"
Present standard: 1 tissue 2 compartment model (1T2K$_{Vb}$), 180 sec aquisition

$$C_t(t) = C_a(t)\,V_b + (1-V_b)K_1\,C_a(t) \otimes e^{-(K_1/Vt)\,t}$$





Ohta S, Meyer E, Fujita H, Reutens DC, Evans A, Gjedde A. Cerebral [(15)O]water clearance in humans determined by PET: I. Theory and normal values. J Cereb Blood Flow Metab 1996;16(5):765-780.

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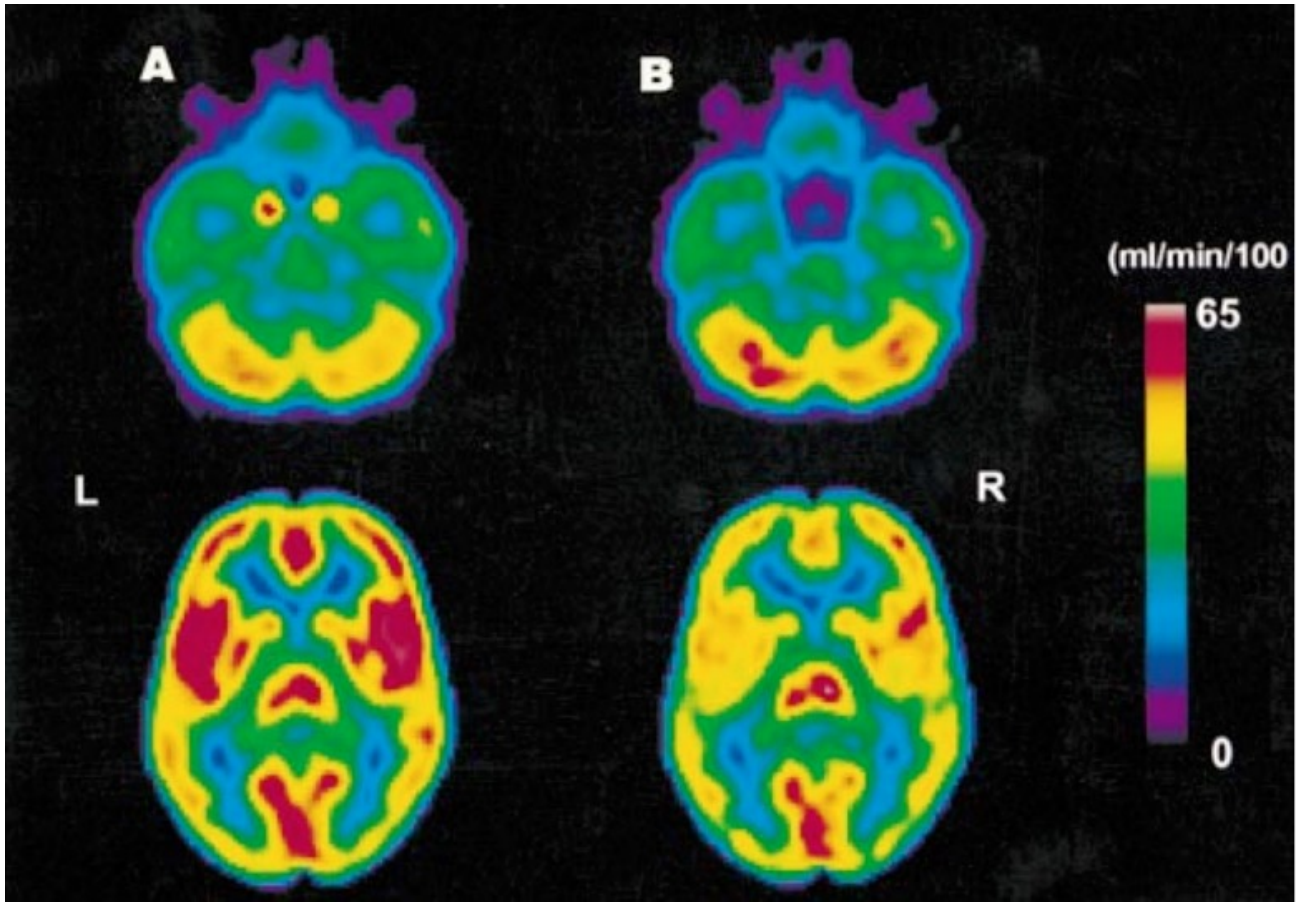
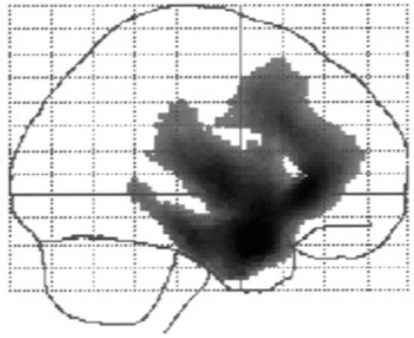
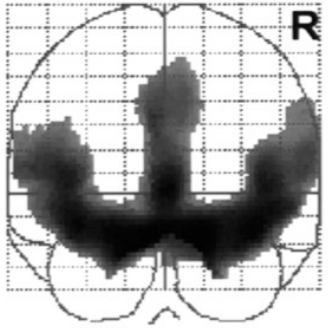
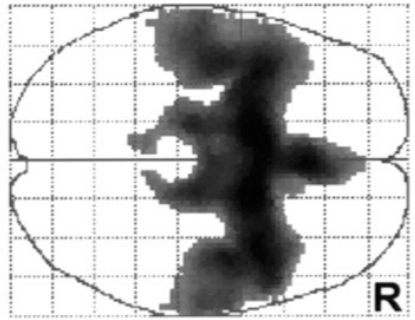
Effects of correcting for Vb on rCBF quantification









2-WI - 3-WI

Okazawa H, Vafaee M. Effect of vascular radioactivity on regional values of cerebral blood flow: evaluation of methods for H(2)(15)O PET to distinguish cerebral perfusion from blood volume. J Nucl Med 2001;42(7):1032-9.

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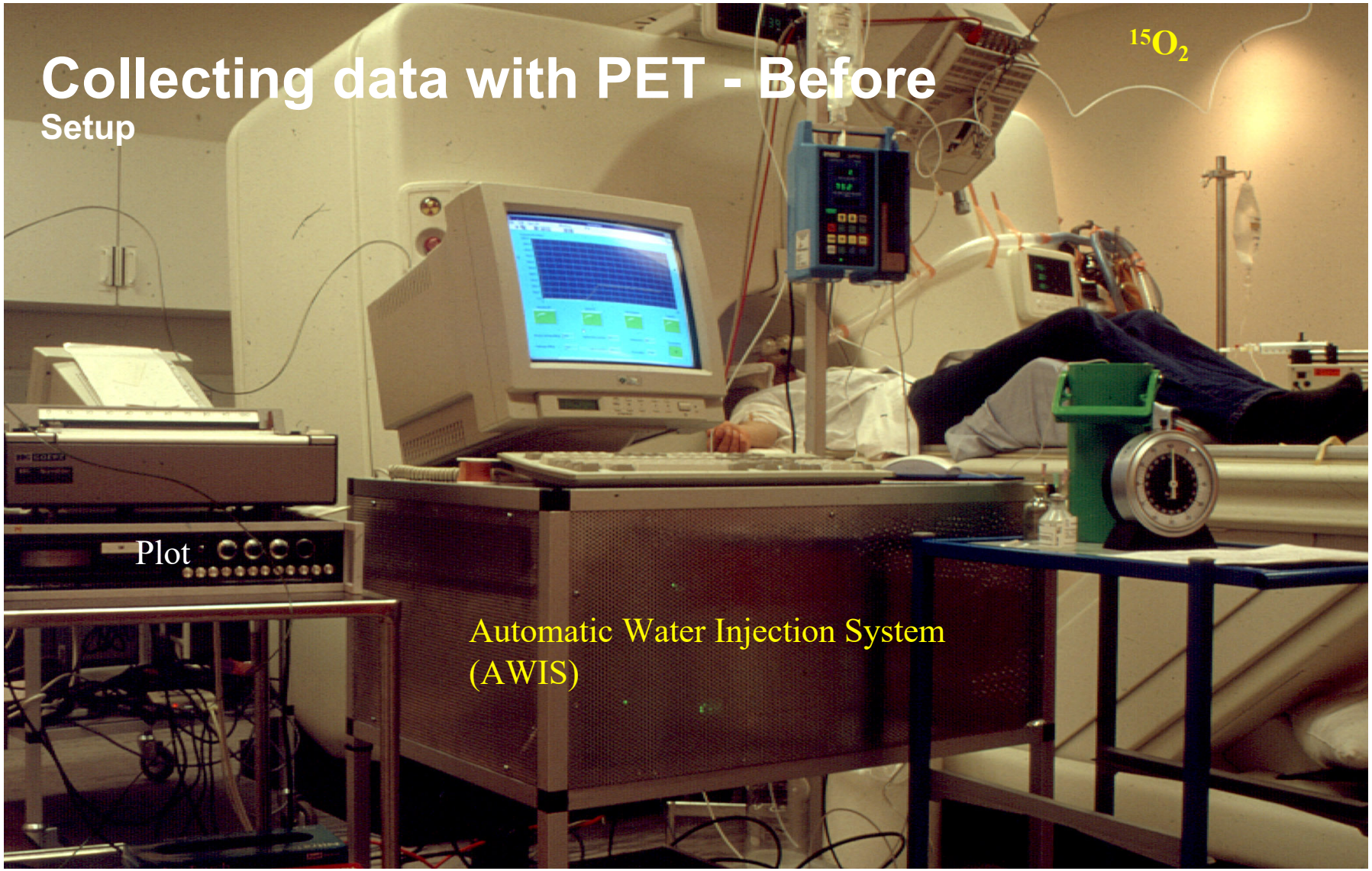
Collecting data with PET - Before

Setup



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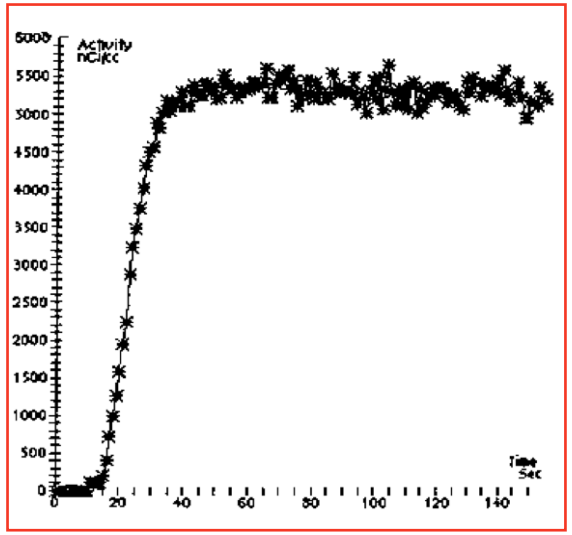
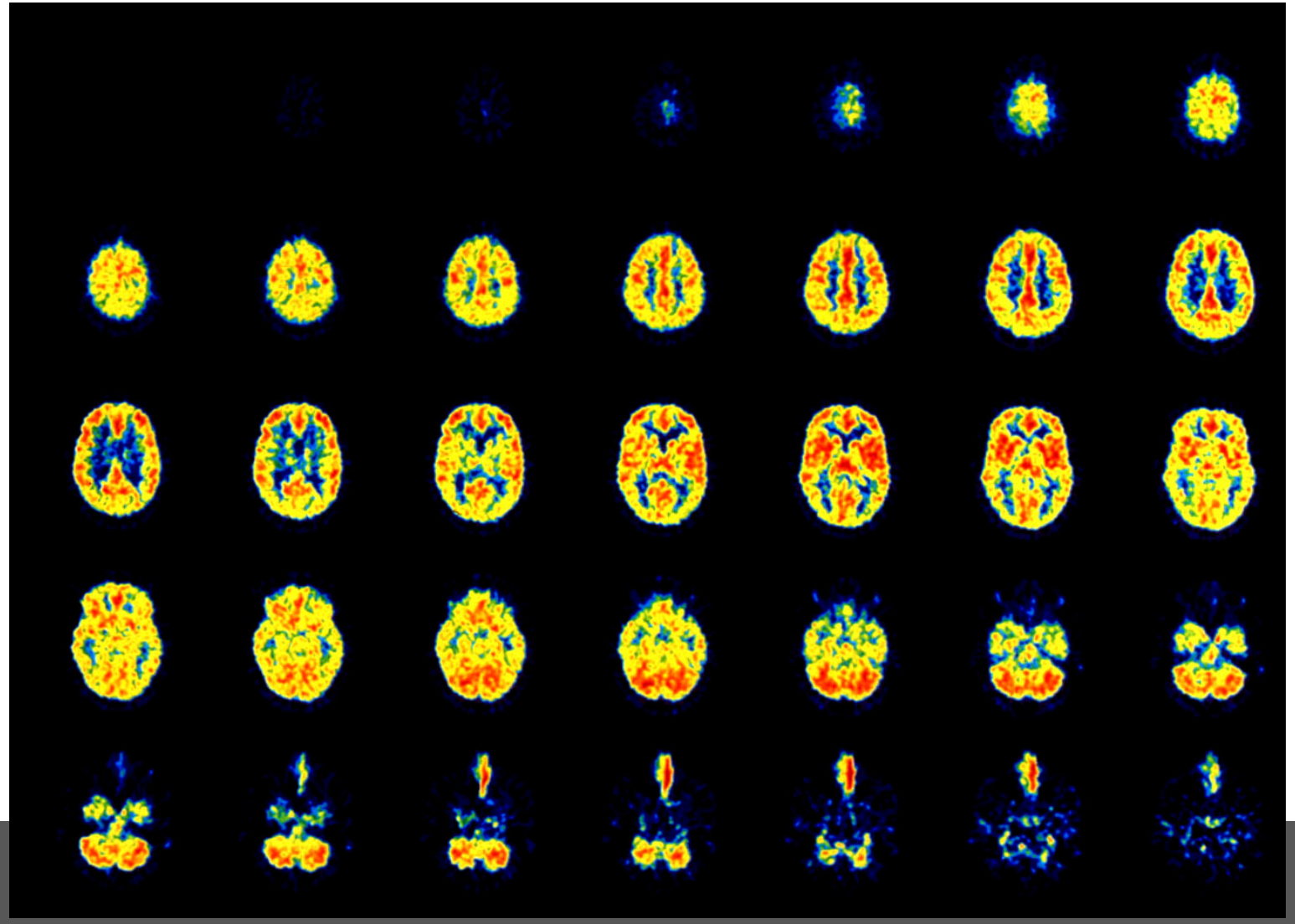
Regional Cerebral Blood Flow - 90 sec distribution image, PET $[^{15}O]H_2O$



Observed Tissue Response function Ct(t)



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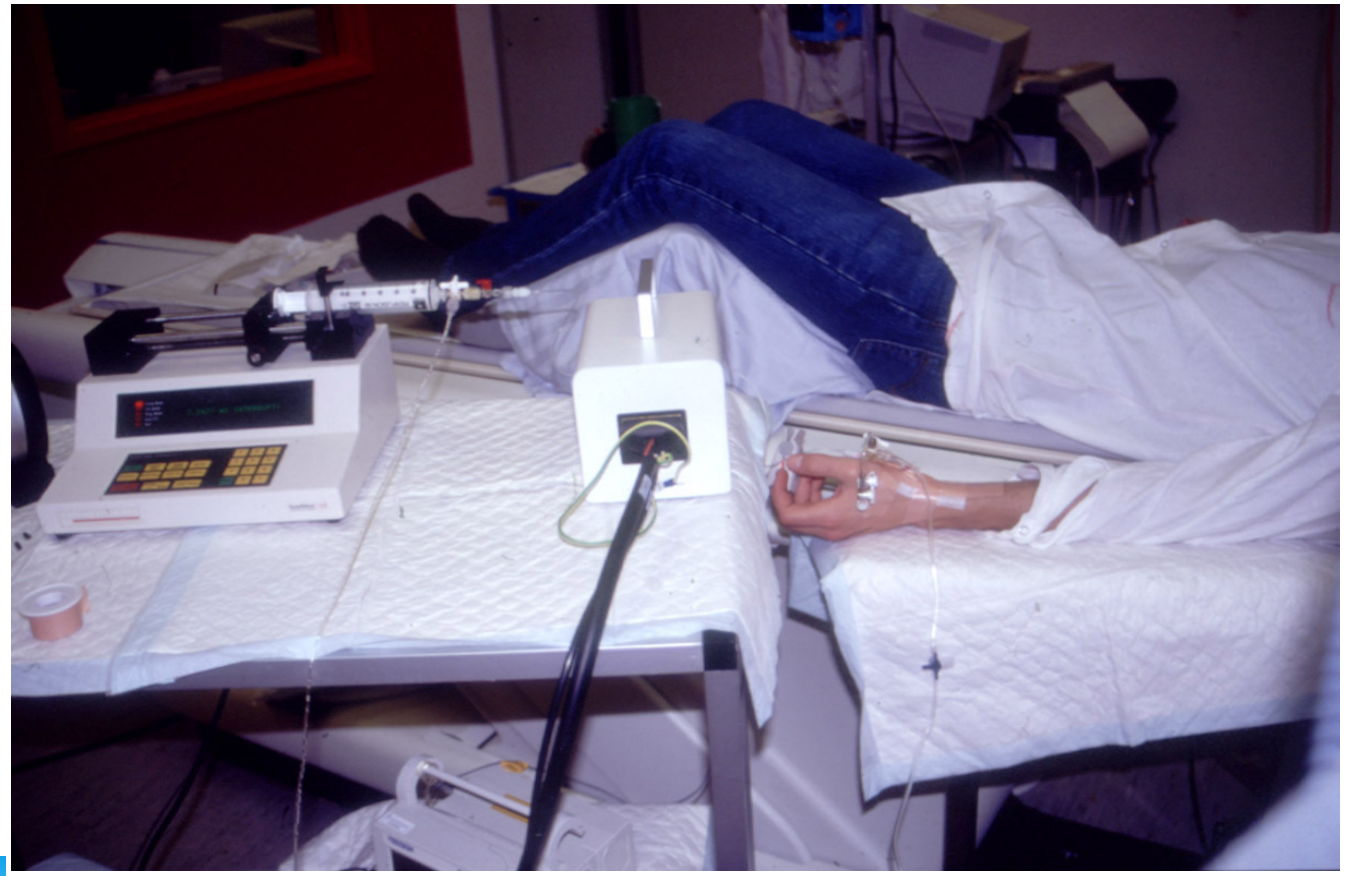
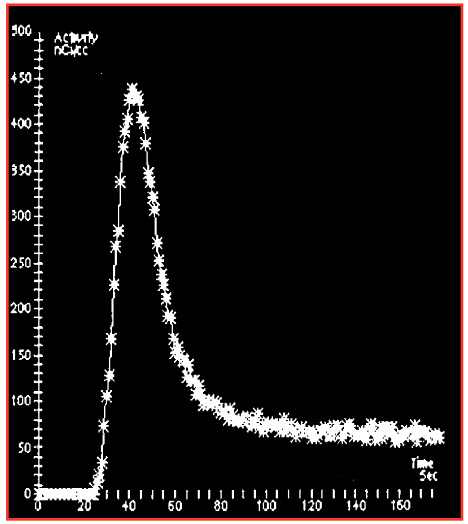
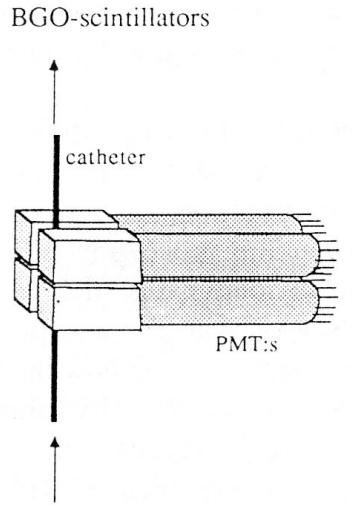
Arterial input function ($C_a(t)$): Applied test function







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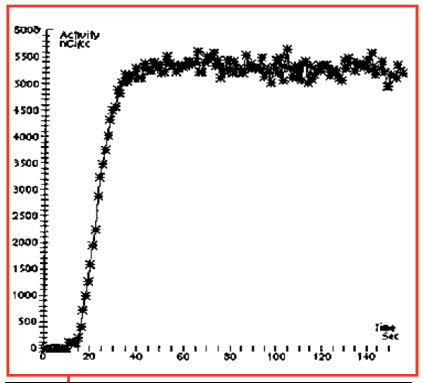
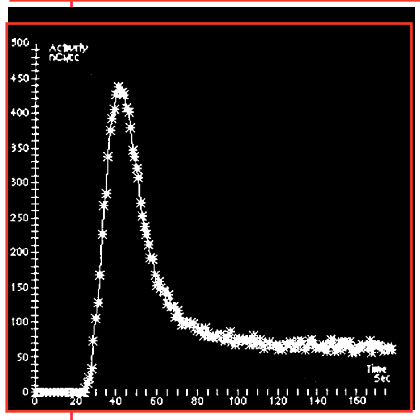
Input Function- adjustment



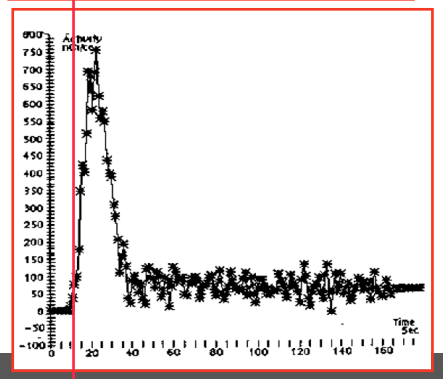
Response function from brain tissue, Ct(t)



Original input from artery, Ca(t), AIF

Problem?

O^{15} $T_{1/2}$ = 2min



rCBF Overestimation CBF ≈ AUC (Tissue)/AUC(AIF)

Delay & Dispersion (=Smear) corrected input function

Calculated for whole brain - Assumed to apply regionally

Iida, H. et al. J Cereb Blood Flow Metab 6, 536-545 (1986).

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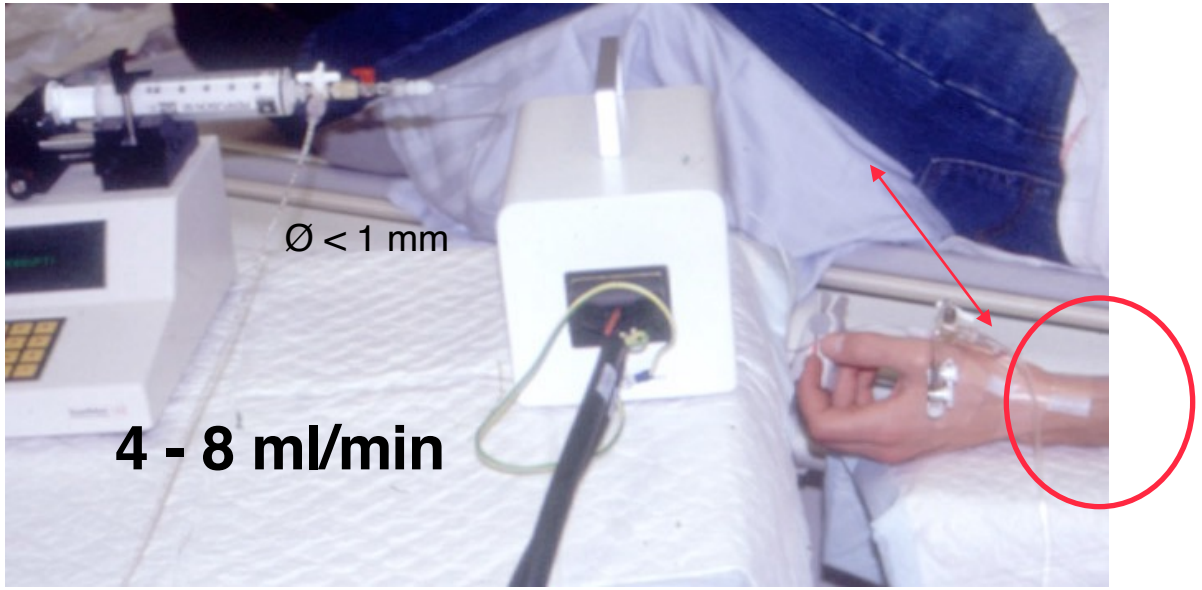
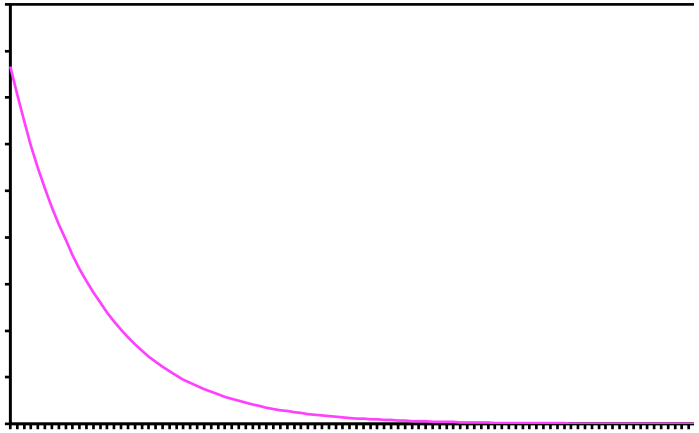
Dispersion Sources = ”smear”



Internal:
- Vascular transport to cannulation

External:
- Cannulation, 3 way valve
- Diameter of tube (< 1 mm)
- Speed of aspiration (4-8 mL/min)

Dispersion function



τ : Dispersion parameter

$$d(t) = \frac{1}{\tau}\exp^{\frac{-t}{\tau}}$$

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Arterial cannulation – gold standard, but prefer not to

- Trauma:
  - Invasiveness
  - low, but non-negligible risk of complications
- Robustness:
  - Artery Access
  - Anticoagulant therapy
  - Patient Acceptability
  - Patient Fragility
    - Children
    - Chronic disease
- Cost:
  - Anesthesiologist
  - Logistic/Planning
  - Staff training/availability
    - Physicist/techs
- Technical issues:
  - Calibrating 2 different measurement devices (scanner/sampler)
    - Measurement
    - Clocks
  - Noise induced by corrections

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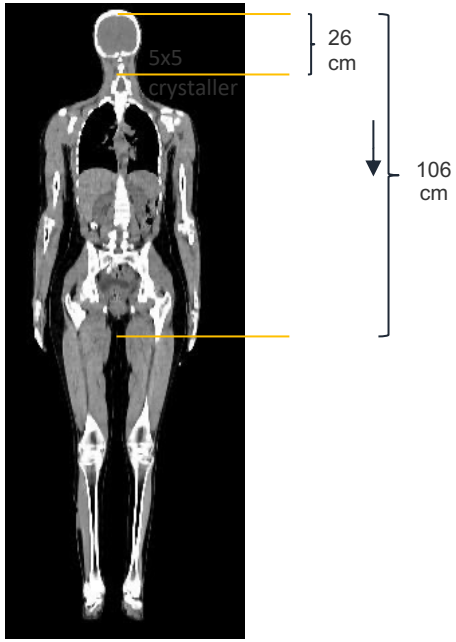
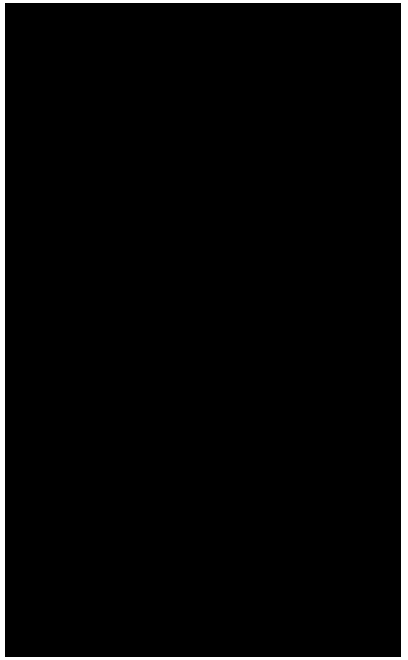
New setup - Using the big scanner - Total body PET/CT

- Siemens PET/CT Quadra – x 4 detector rings





400 MBq $[^{15}O]H_2O$ 12 min dynamic acq

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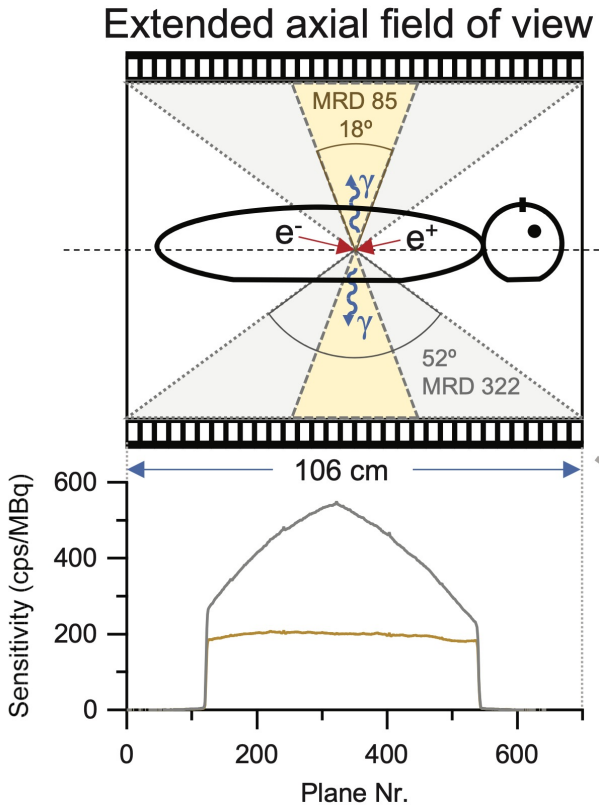
Effects of large axial field of view (AFOV)

Large acceptance angle with

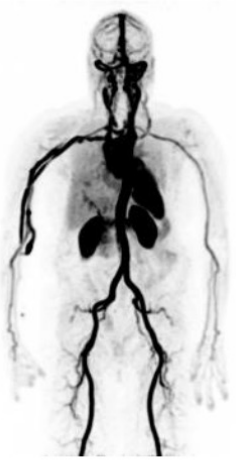
Extended axial field of view



- Increased sensitivity = more counts x (10-30)
  - Increased temporal resolution (1 sec (msec?)) or
  - Better image quality or
  - Decrease in acquisition time or
  - Increase in acquisition time or
  - Lower dose injected
- Increased coverage
  - Image derived input function (IDIF)
  - Simultaneous multiorgan acquisition

G. A. Prenosil *et al.*, *J Nucl Med* (2021).

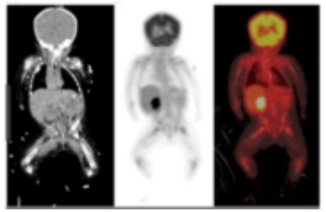
Whole-Body PET/CT Imaging - Perspectives



High-sensitivity

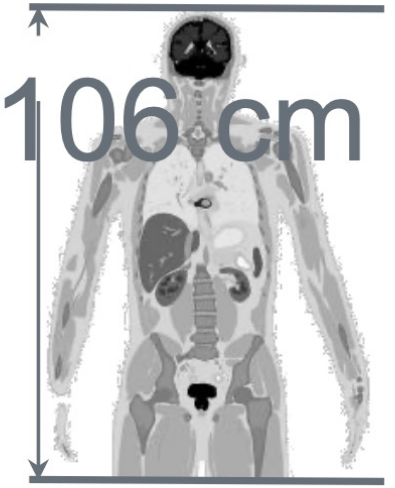
Fast acquisition

Low radiation burden



Quantitative accuracy

Multi-tracer studies

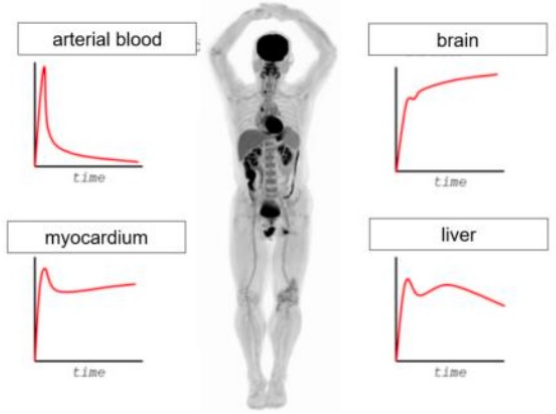


Organ interaction, e.g. brain-gut, brain-spine, brain-heart

Late low-dose Imaging
→ immune cells

Drug discovery

High temporal resolution



Whole-body parametric imaging

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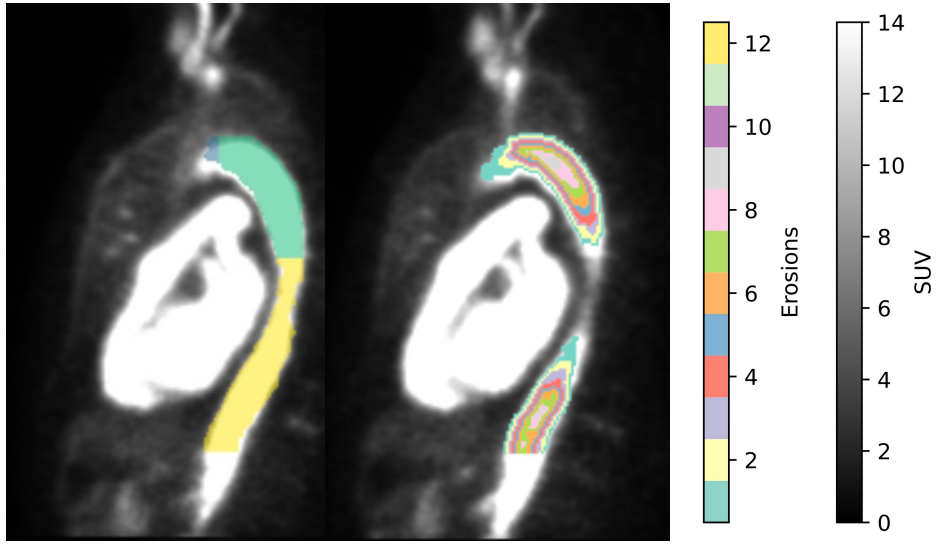
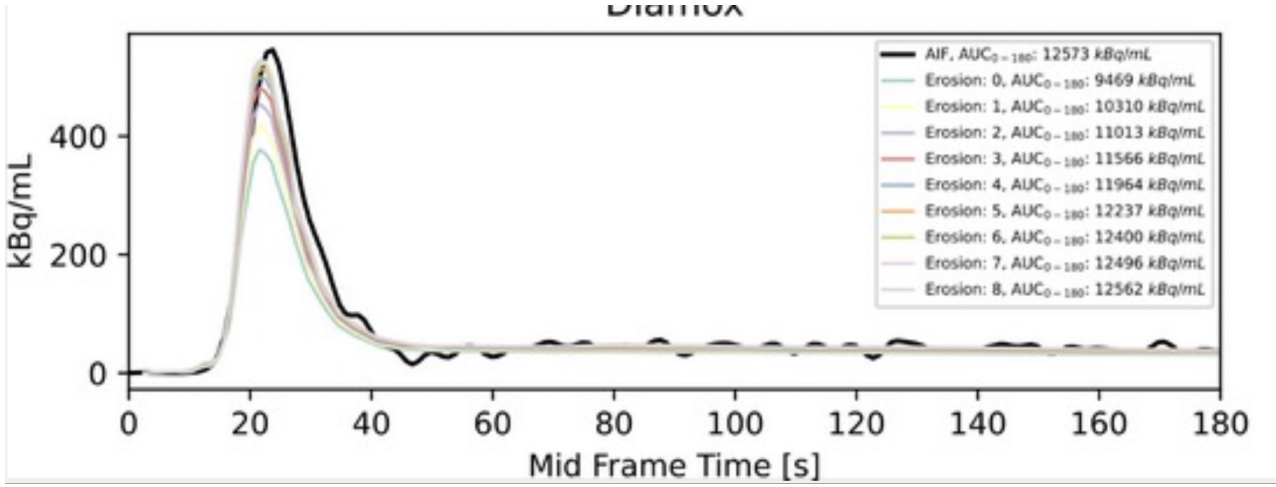
Image vs artery derived input function

- AI based Aorta segmentation of low dose CT
- Erosion 8-10 mm
- Sample activity in centre 1- 4 mL in upper Aorta Descendens





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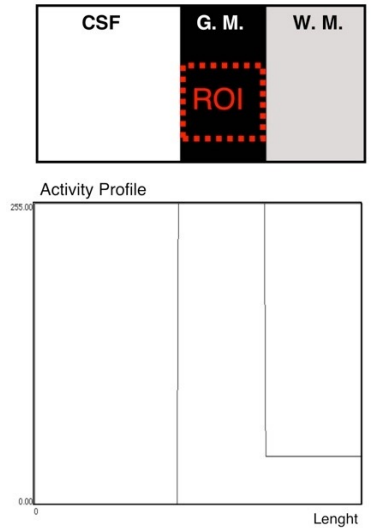
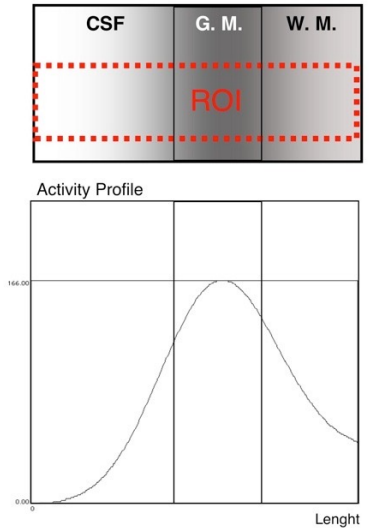
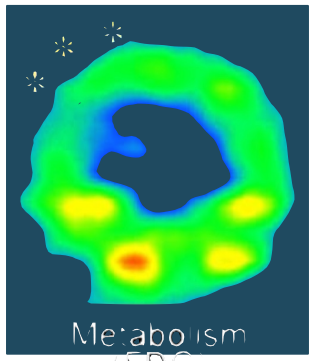
The Partial Volume Effect – resolution is limited

A Ideal Resolution

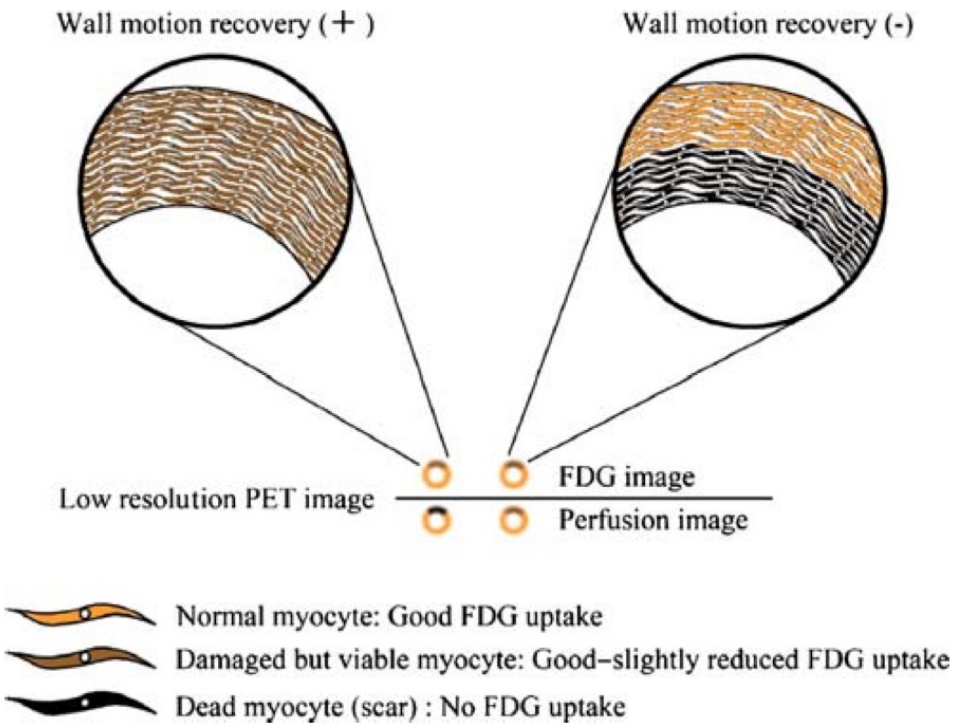


B PET Scanner





Many tissues in ROI (tissue heterogeneity)
Spill-in/out



Kudo, T. Eur j Nucl Med Mol Imaging **34**:S49-S61. **Metabolic imaging using PET**

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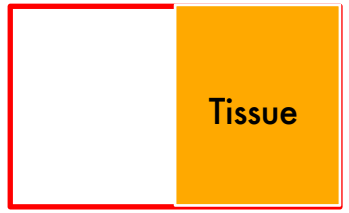
Two classes of models – wash in and wash out

$C_t(t) = f\, C_a(t) \otimes e^{-(f/Vt)\, t}$;
f (E ≈1) = K_1 => K_1 determines Perfusion information
Very Partial Volume sensitive
More Stabile

ROI



α = 0.5 g/ml
K_1 = 1.0 min^{-1}
f = 2.0 ml $g^{-1} min^{-1}$
α Perfusable tissue fraction

$C_t(t) = f\, \alpha\, C_a(t) \otimes e^{-(f/p)\, t}$

$f = K_1 / \alpha$; $K_1 = p\, k_2$, $f = p\, k_2 / \alpha$

=> k_2 determines Perfusion information
Not Very Partial Volume sensitive
More Noisy

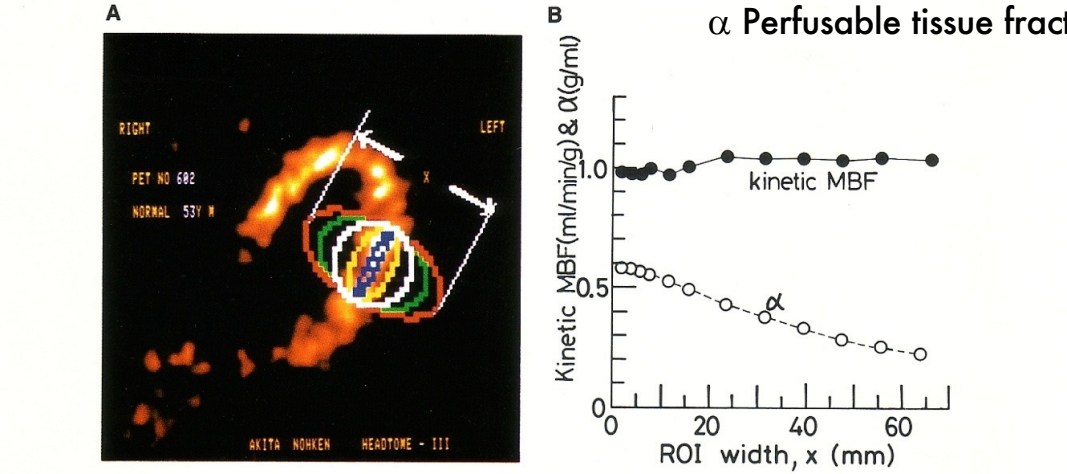


FIGURE 6. *Various regions of interest (ROIs) in the myocardium of a normal volunteer (N3)* (Panel A). *Myocardial blood flows (MBFs) were calculated according to the present kinetic method for these ROIs. ROI size dependence of the calculated MBF and α obtained by the kinetic method* (Panel B). *The calculations were made for ROIs indicated in left panel . Calculated MBF values revealed no significant changes, while the calculated tissue fractions were decreased with increasing ROI size.*

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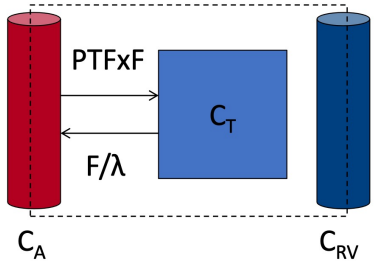
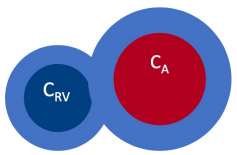
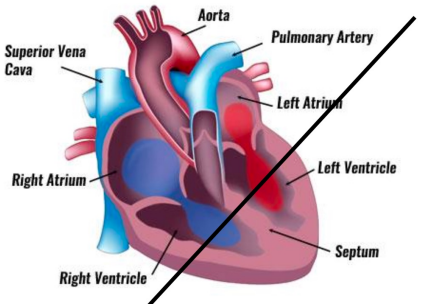
Myocardial blood flow (MBF) with $[^{15}O]H_2O$

- Linear relationship between K1 and MBF
- Remove right and left ventricle BV in model

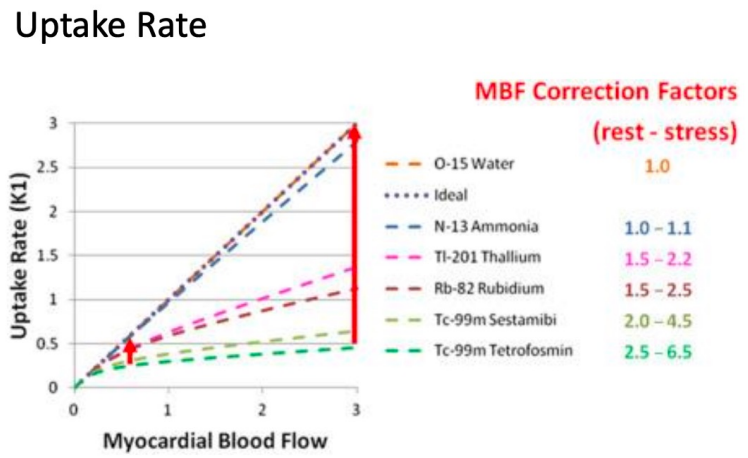


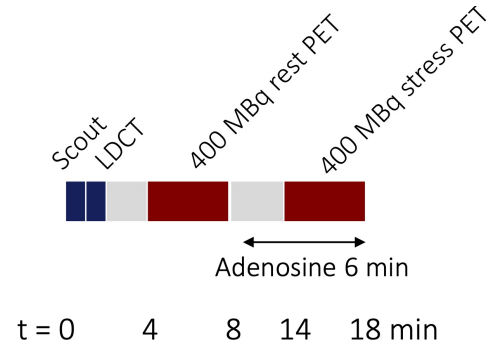




$$C_T(t) = PTF \cdot F \cdot C_A(t) \otimes e^{-F/\lambda t}$$

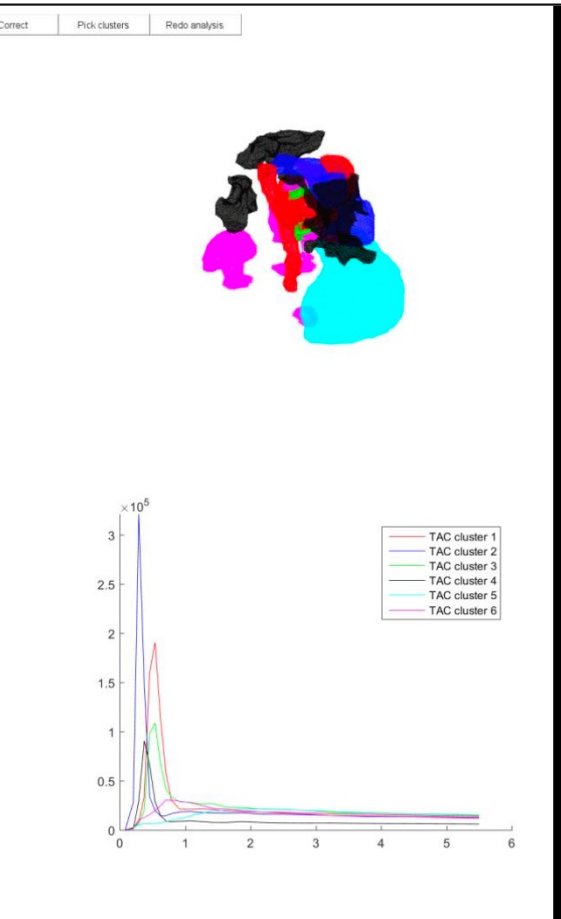
$$C_{PET}(t) = C_T(t) + V_A C_A(t) + V_V C_{RV}(t)$$

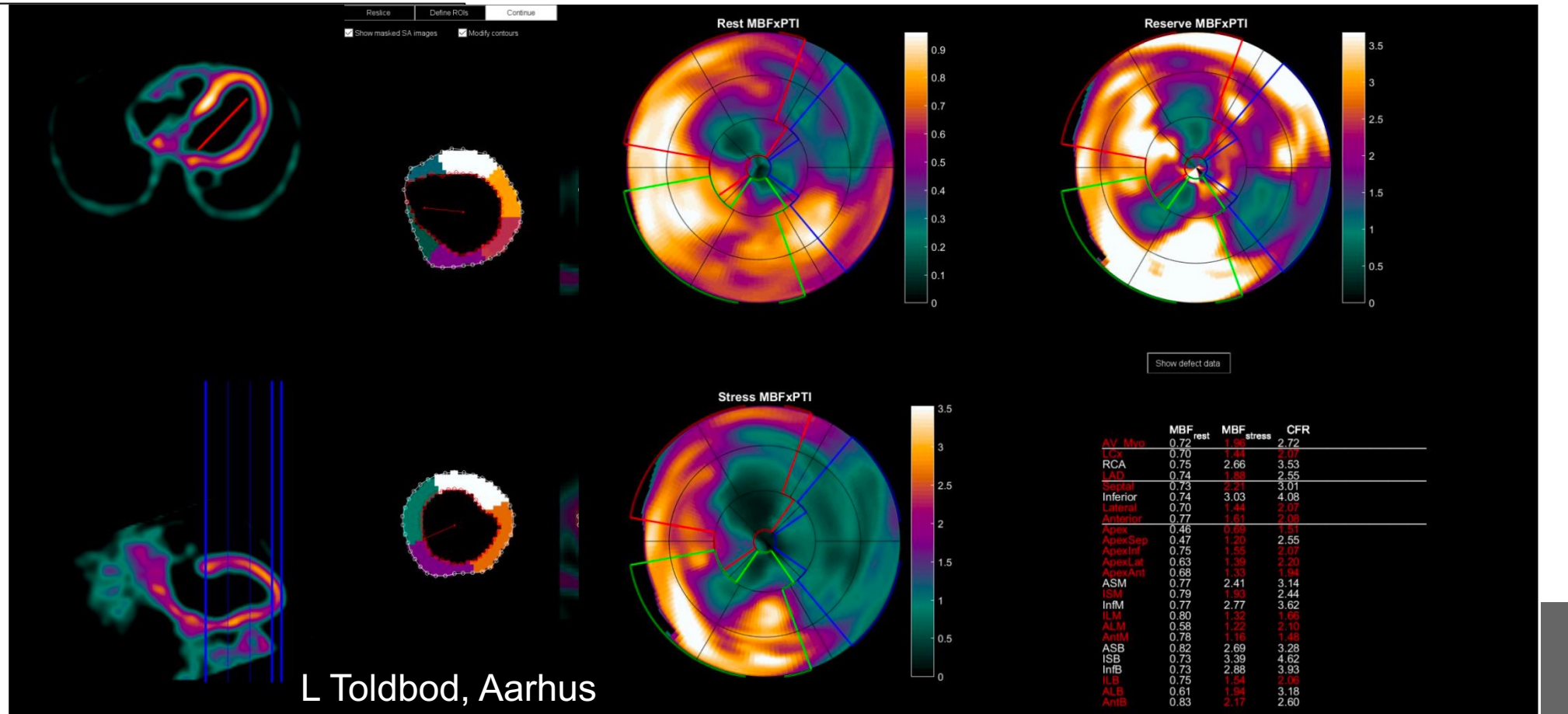




Analyse

Read DICOM → Extract IDIF → Make parametric Images → Reorient and Segment → Results





	MBF rest	MBF stress	CFR
AV_Myo	0.72	1.98	2.72
LCx	0.70	1.44	2.08
RCA	0.75	2.66	3.53
LAD	0.74	1.89	2.55
SupAnt	0.73	2.21	3.01
Inferior	0.74	3.03	4.08
Lateral	0.70	1.44	2.07
Anterior	0.77	1.61	2.08
Apex	0.46	0.69	1.51
ApexSep	0.47	1.20	2.55
ApexInf	0.75	1.55	2.07
ApexLat	0.63	1.39	2.20
ApexAnt	0.68	1.33	1.94
ASM	0.77	2.41	3.14
ISM	0.79	1.93	2.44
InfM	0.77	2.77	3.62
ILM	0.80	1.32	1.66
ALM	0.58	1.22	2.10
AntM	0.78	1.16	1.48
ASB	0.82	2.69	3.28
ISB	0.73	3.39	4.62
InfB	0.73	2.88	3.93
ILB	0.75	1.54	2.06
ALB	0.61	1.94	3.18
AntB	0.83	2.17	2.60

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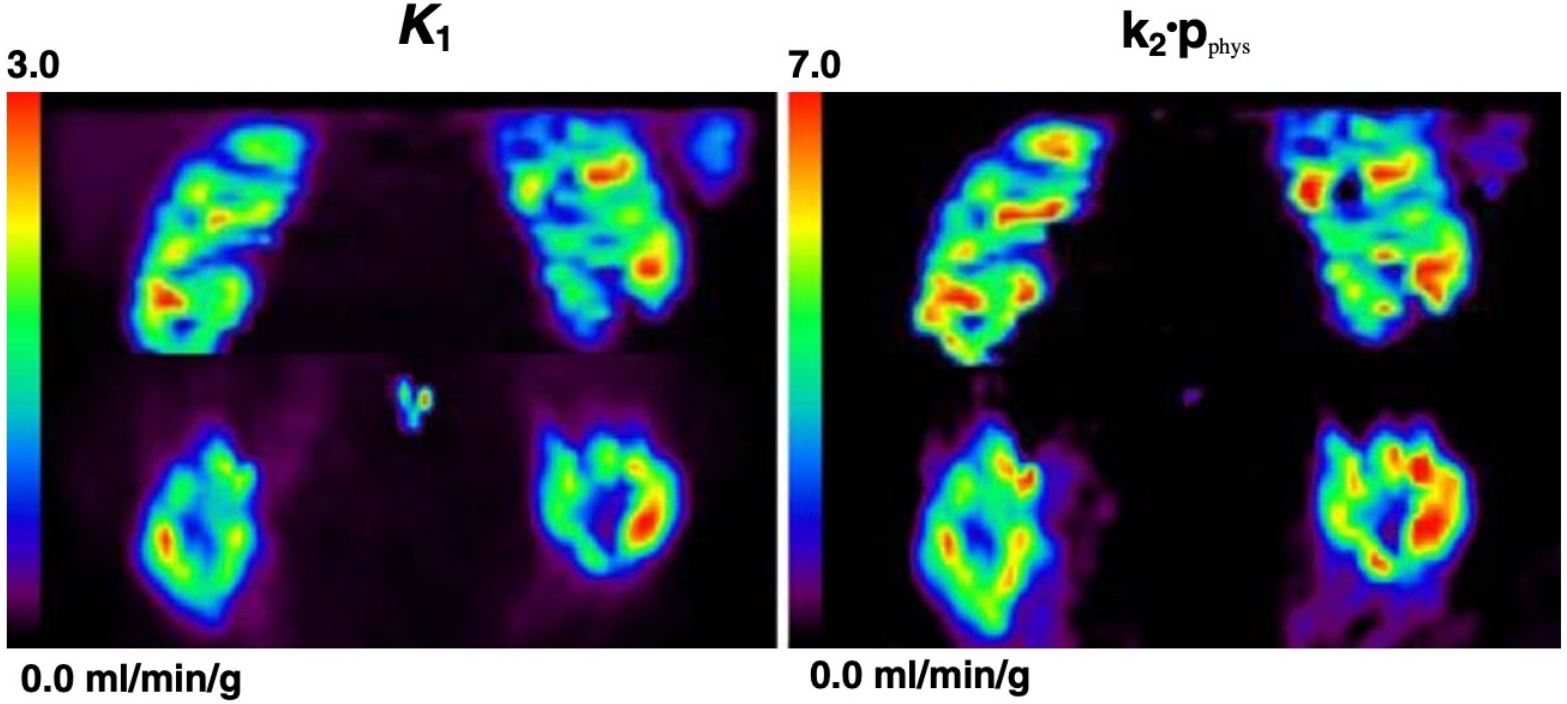
Renal perfusion with $[^{15}O]H_2O$

- Limited studies

$$C_t(t) = C_a(t)\,V_b + (1-V_b)K_1\,C_a(t) \otimes e^{-(K_1/V_t)\,t}$$

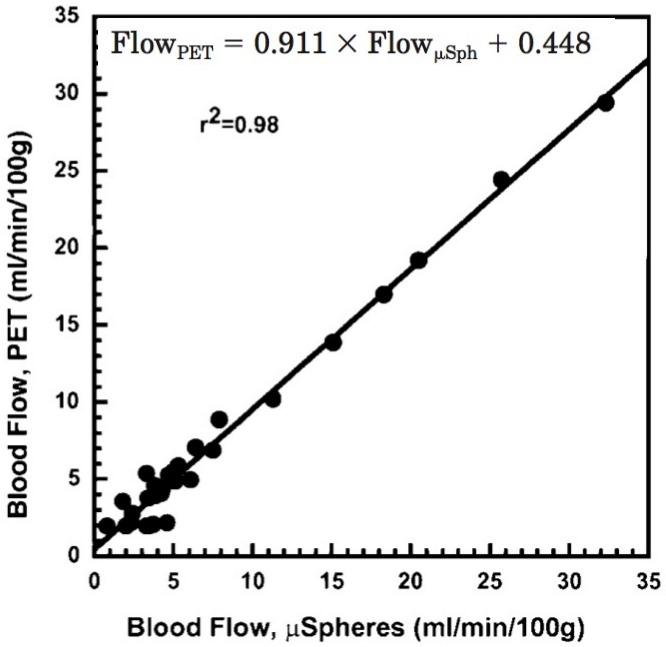


N. Kudomi *et al.*, *Eur J Nucl Med Mol Imaging* **36**, 683 (2009).

J Appl Physiol 92: 1709–1716, 2002;
10.1152/japplphysiol.00445.2001.

Regional measurement of canine skeletal muscle blood flow by positron emission tomography with $H_2{}^{15}O$

ALAN J. FISCHMAN,[1,2,4] HONGBING HSU,[1,4] EDWARD A. CARTER,[2,3,5]
YONG M. YU,[2,3,5] RONALD G. TOMPKINS,[2,3,5] J. LUIS GUERRERO,[3]
VERNON R. YOUNG,[2,3] AND NATHANIEL M. ALPERT[1]



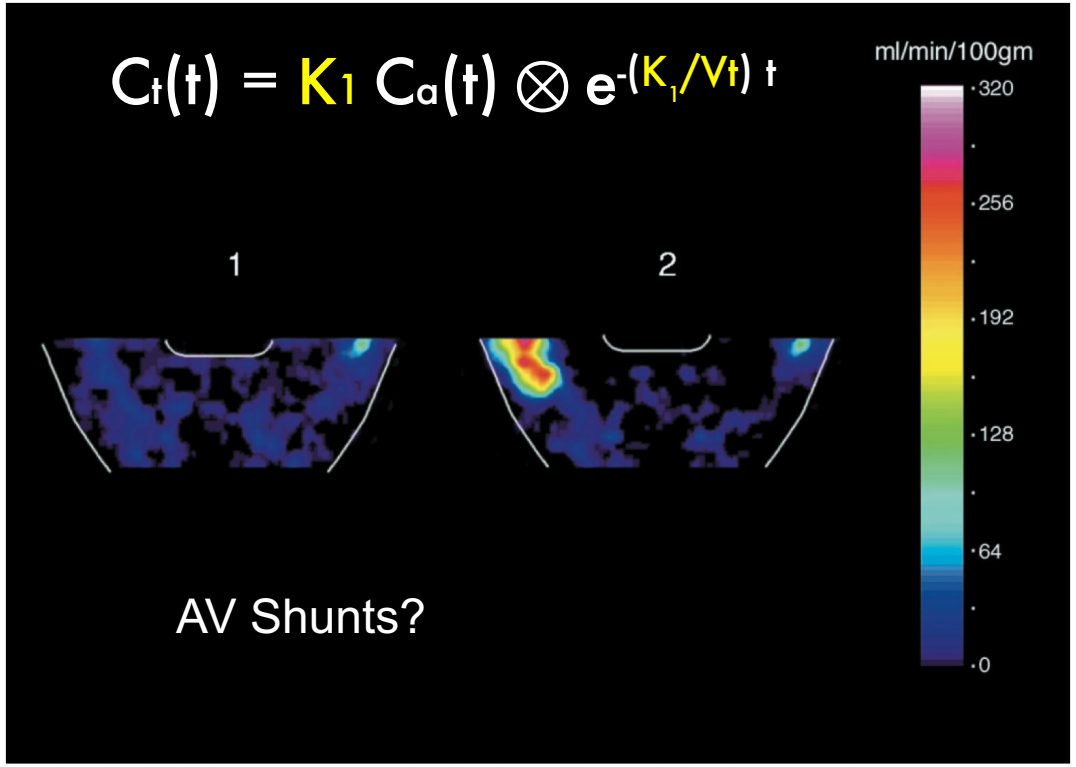


Fig. 7. Examples of blood flow maps (coronal projection) derived by pixel-by-pixel solution of *Eq. 6*. 1. Low flow, baseline map. 2. High-flow map derived after local infusion of adenosine in the right thigh. Blue area in *upper right* of both panels represents bone marrow.

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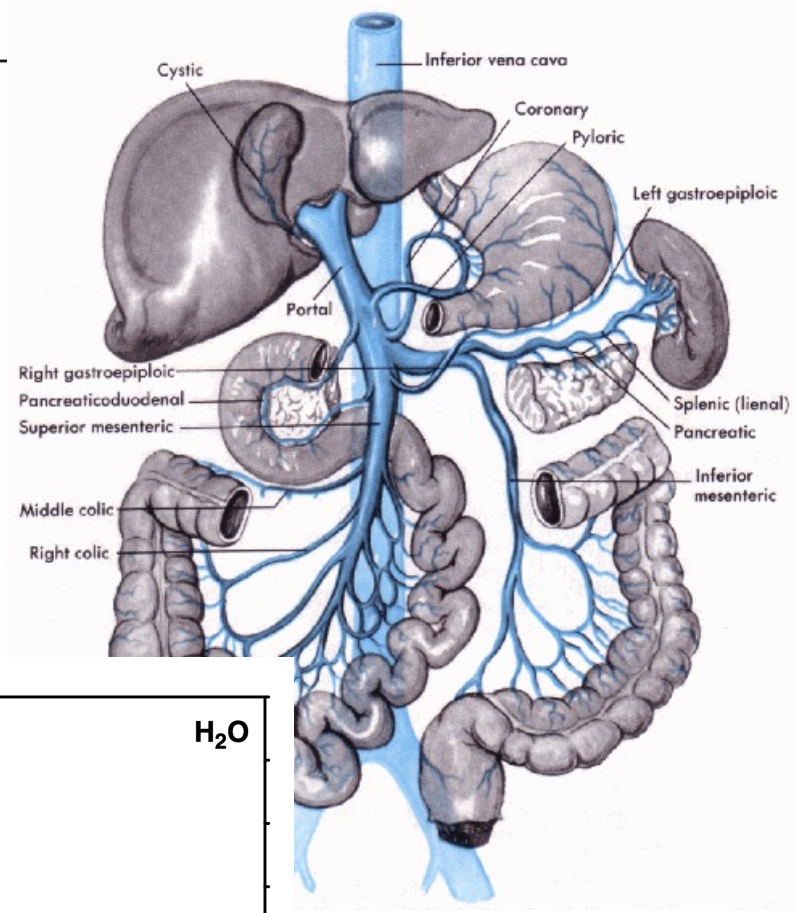
Eur J Nucl Med Mol Imaging (2008) 35:1899–1911
DOI 10.1007/s00259-008-0796-z

ORIGINAL ARTICLE

Non-invasive estimation of hepatic blood perfusion from $H_2{}^{15}O$ PET images using tissue-derived arterial and portal input functions

N. Kudomi · L. Slimani · M. J. Järvisalo · J. Kiss · R. Lautamäki · G. A. Naum · T. Savunen · J. Knuuti · H. Iida · P. Nuutila · P. Iozzo

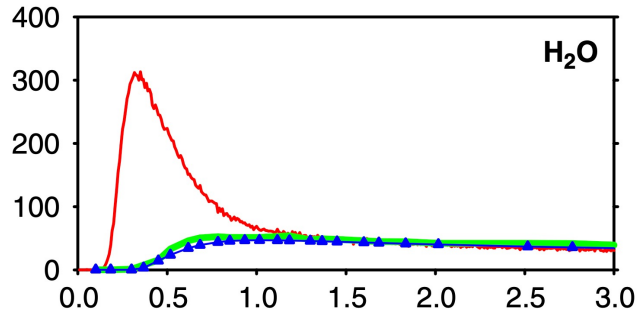


Possible, but complicated

-dual liver input (1/3 hepatic artery, 2/3 portal vein)

- non-invasive estimation of input from portal vein

- Portal vein is tissue curve from intestines



M. Winterdahl *et al.*, *Eur J Nucl Med Mol Imaging* **38**, 263 (2011).

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Clinical use of CBF
The Diamox test

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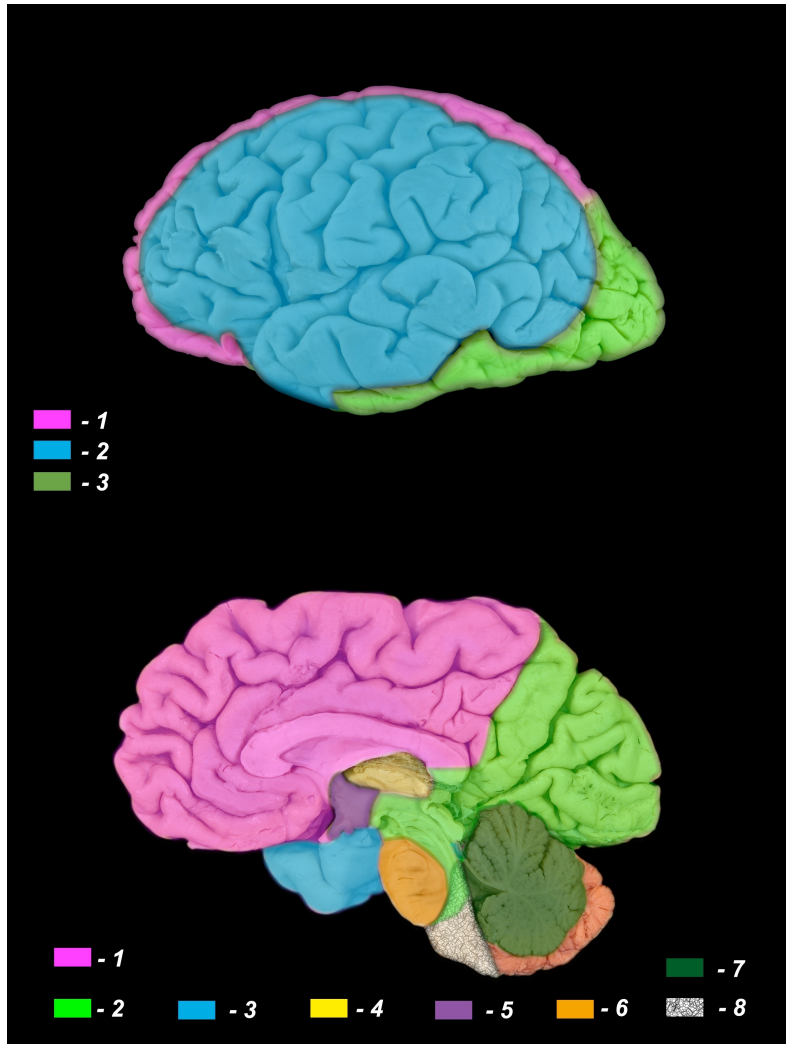
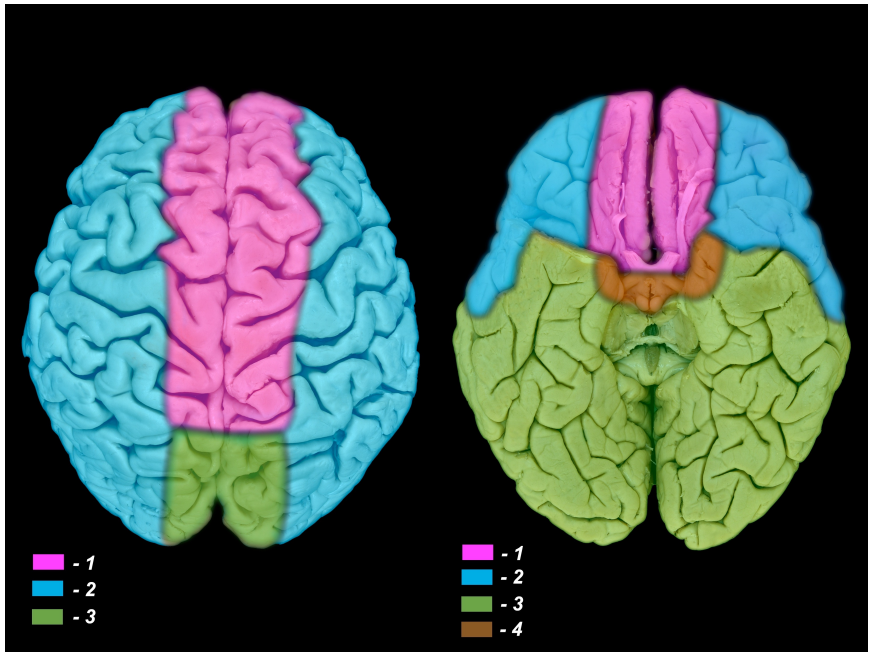
Vascularisation of the cerebral cortex





Borderline regions are associated with the potentially greater risk of ischaemia leading to brain stroke

„watershed infarct”

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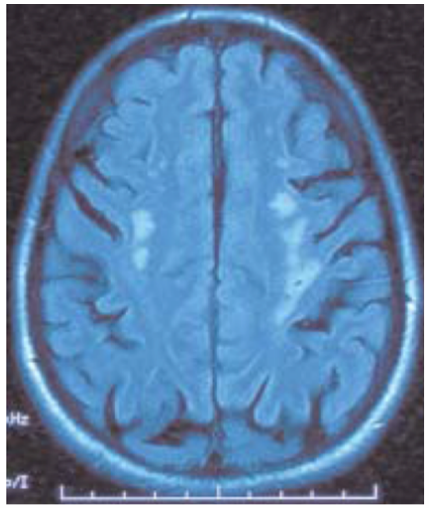
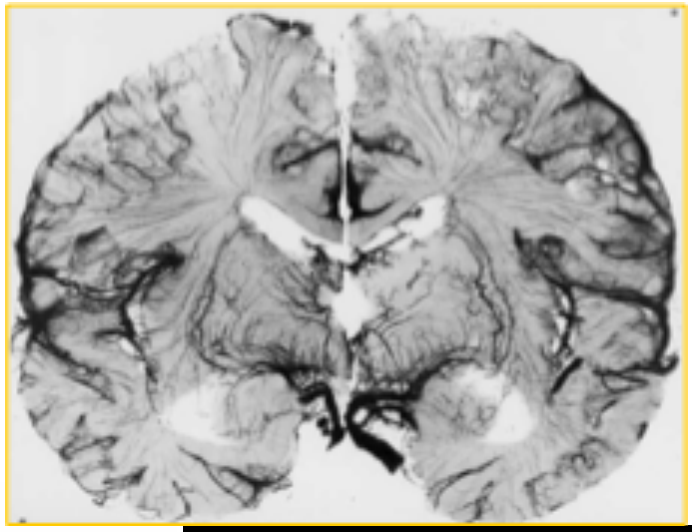
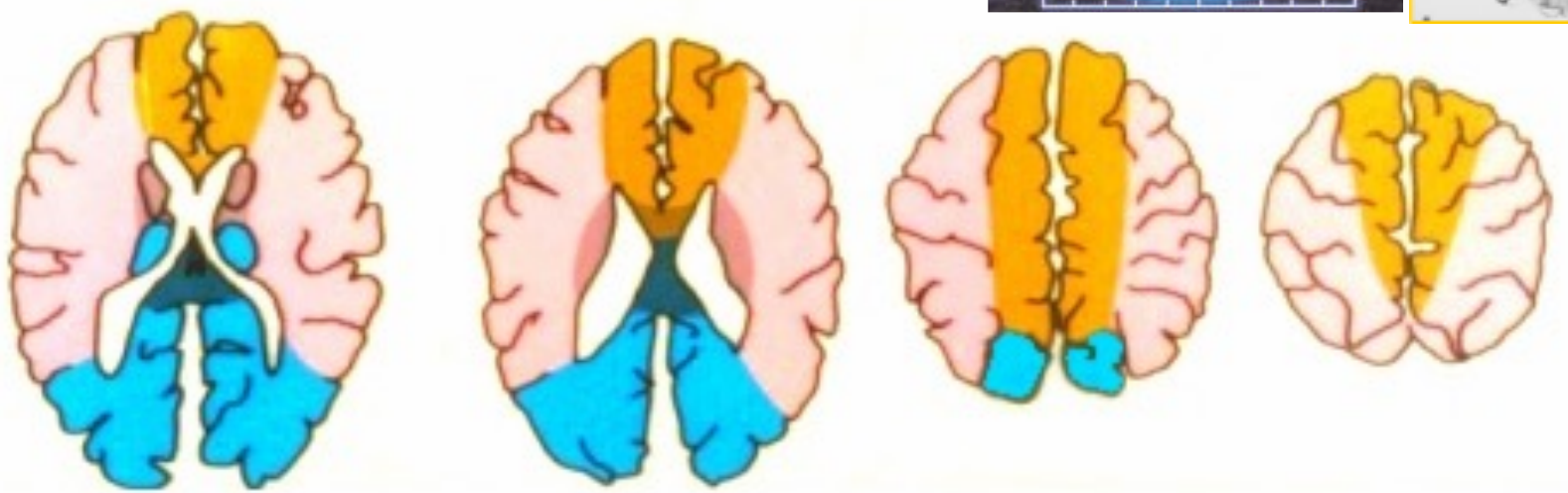
Small arterial vessels:

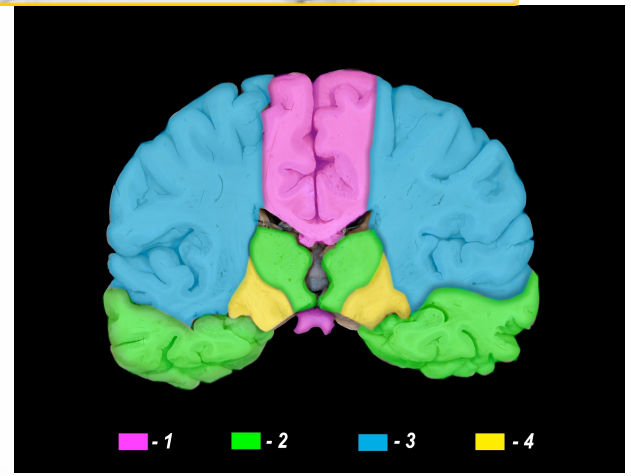
-Deep (perforating) vessels

- functionally terminal vessels
do not form collateral circulation









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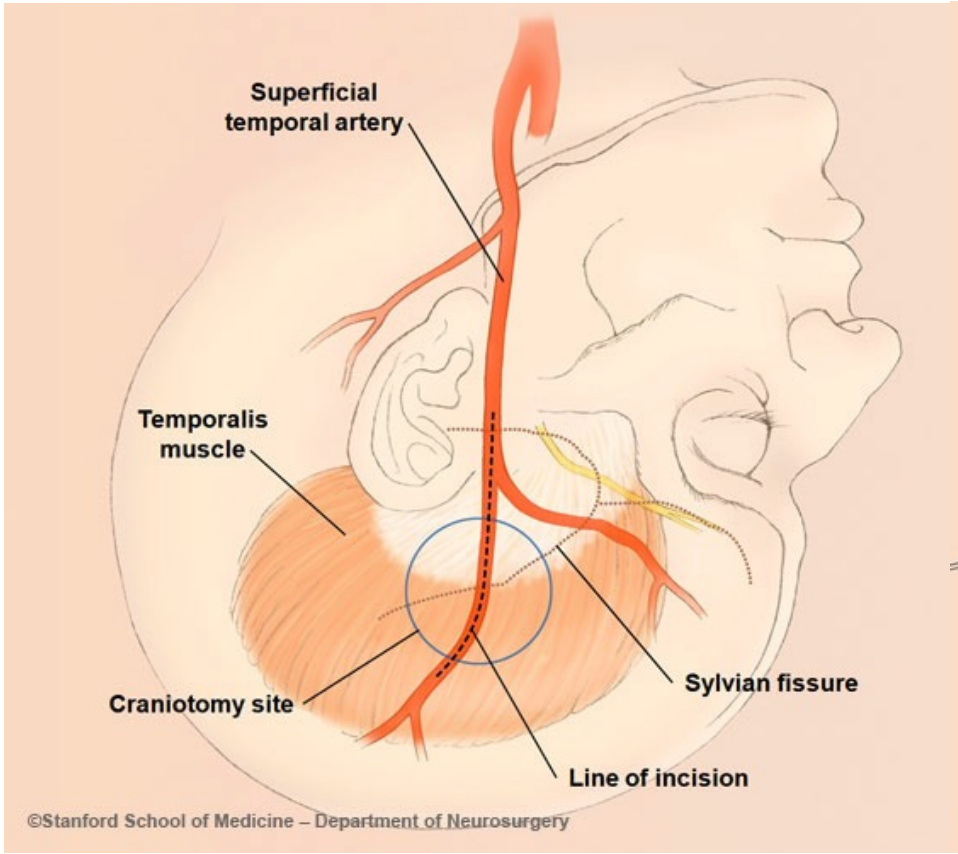
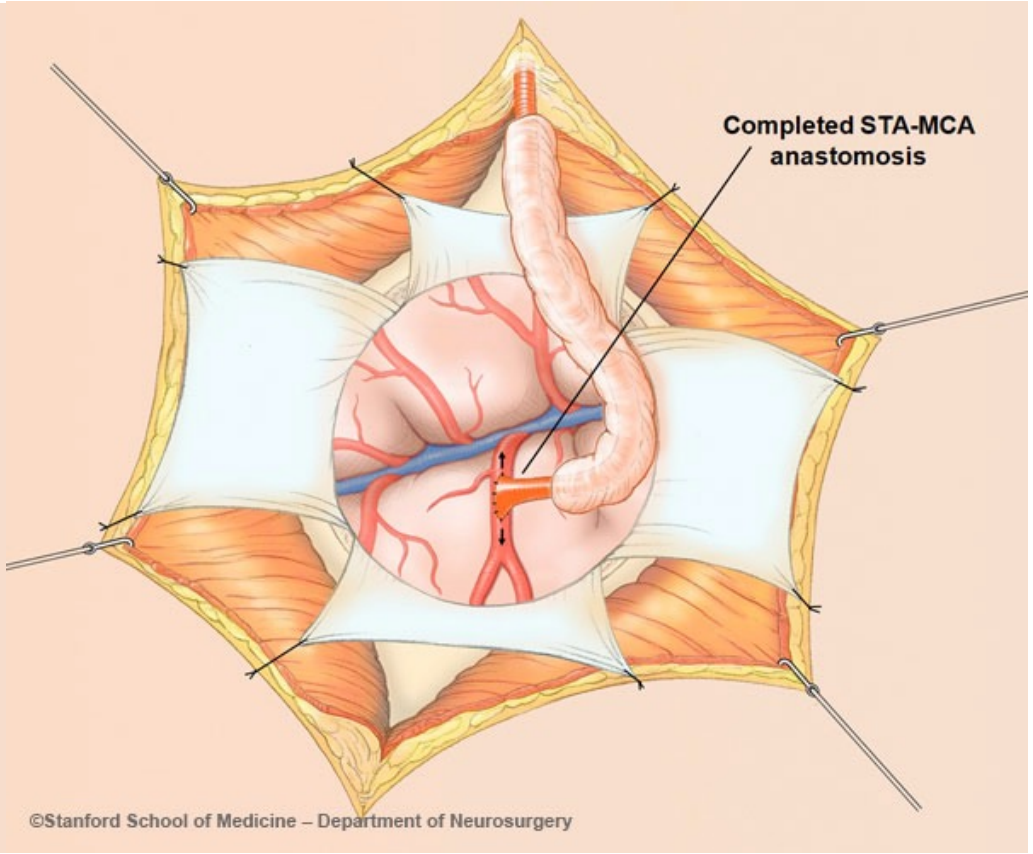
Treating internal carotid occlusions: EC-IC bypass

Direct superficial temporal artery (STA) to middle cerebral artery (MCA) bypass





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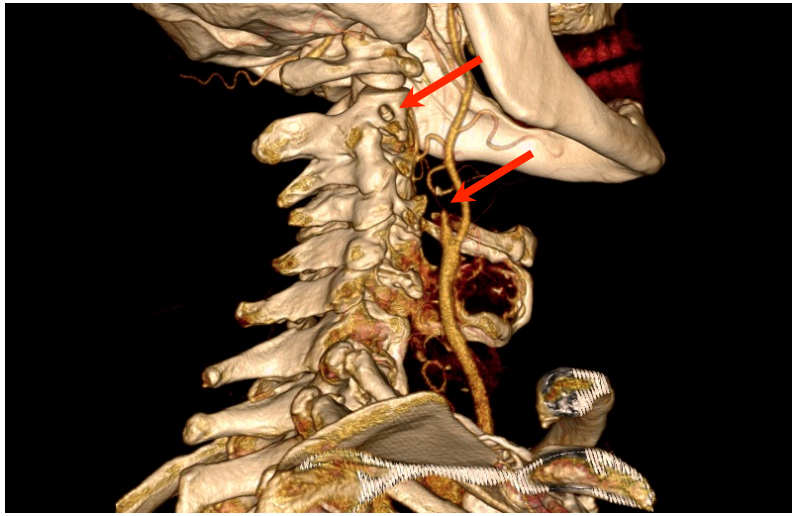
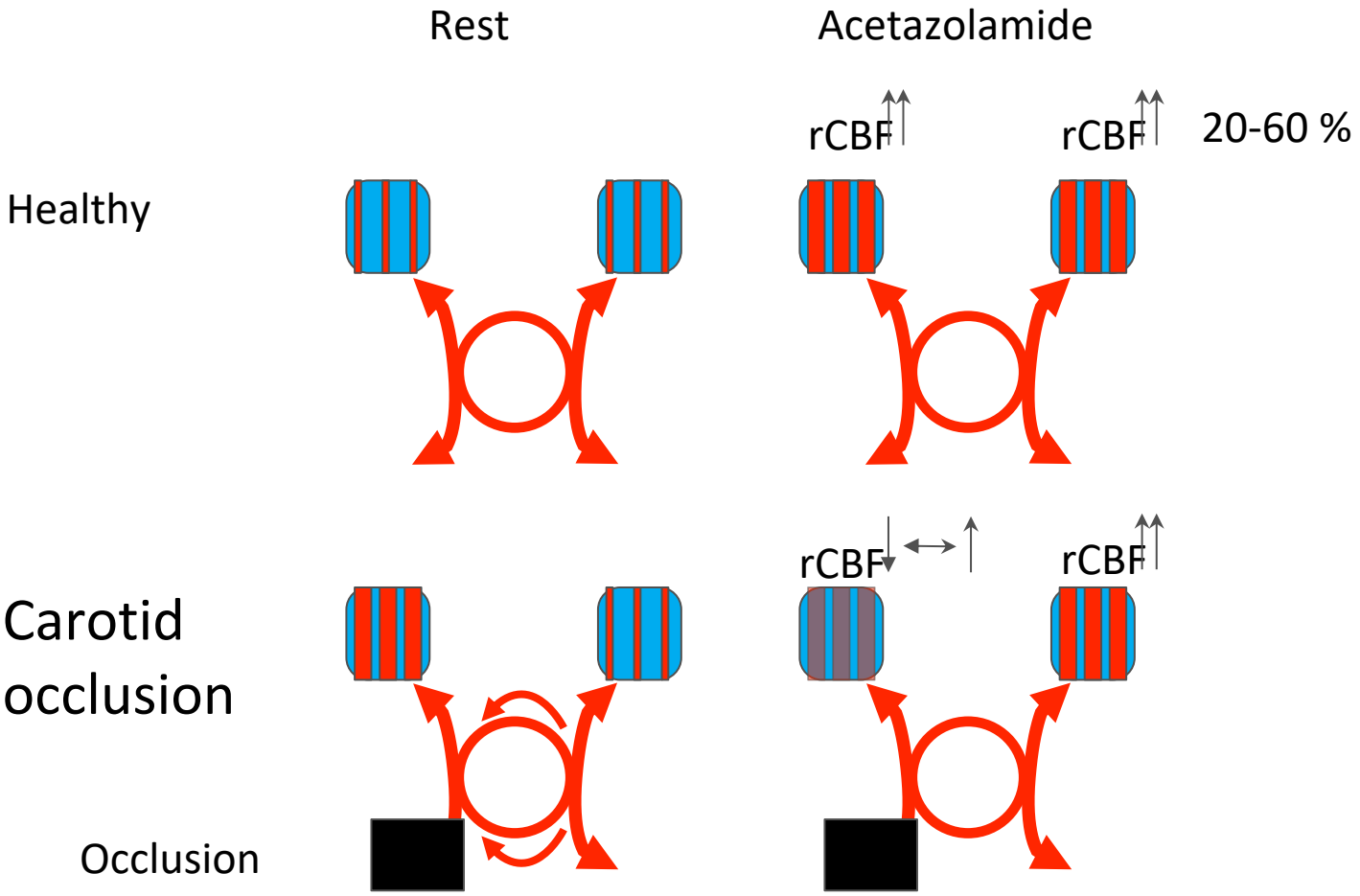
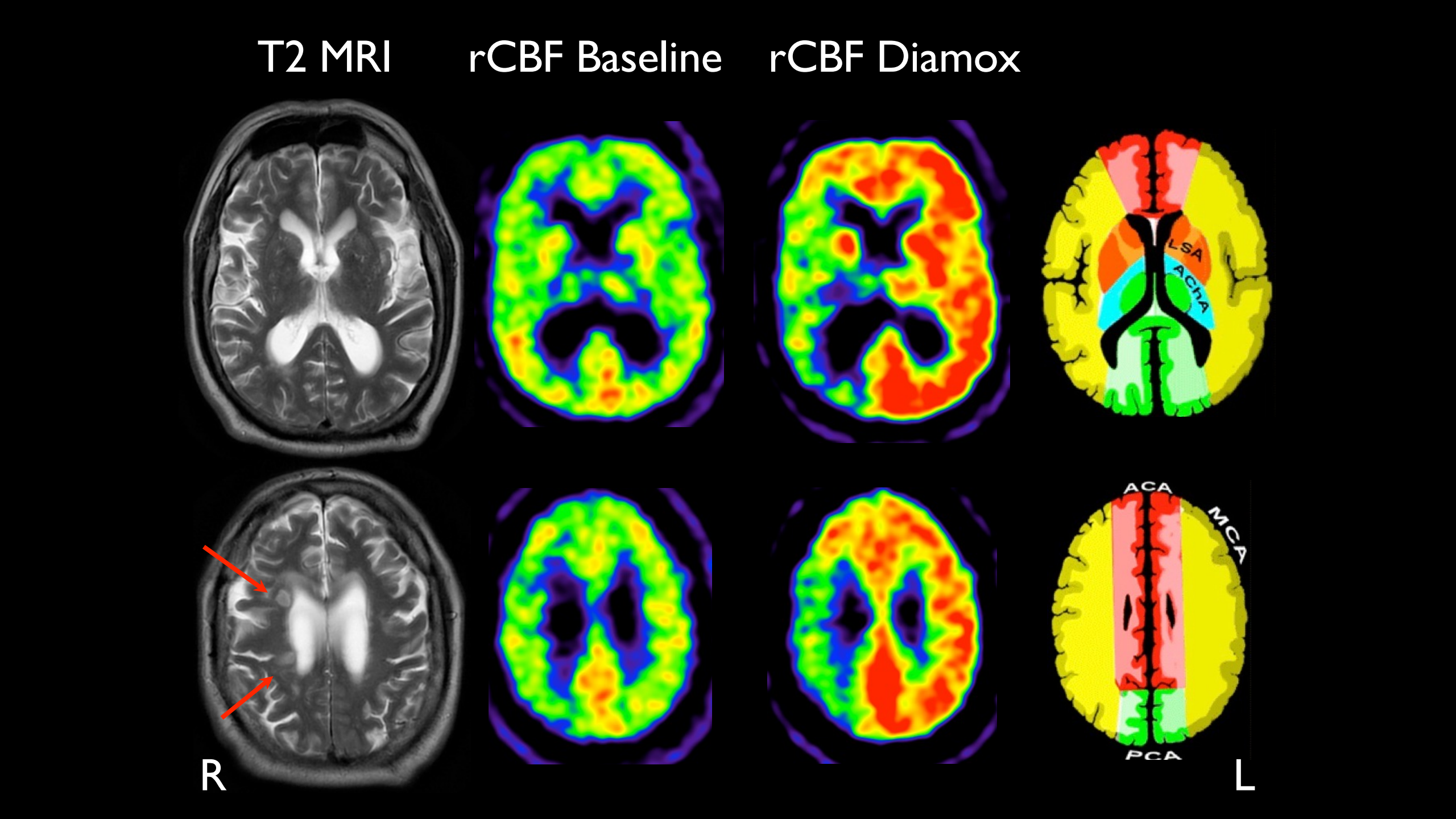
The reverse Robin Hood Syndrome



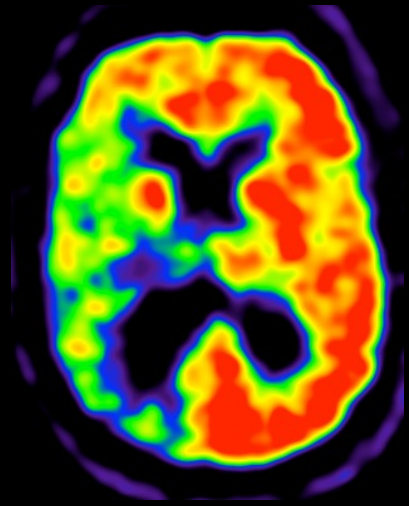


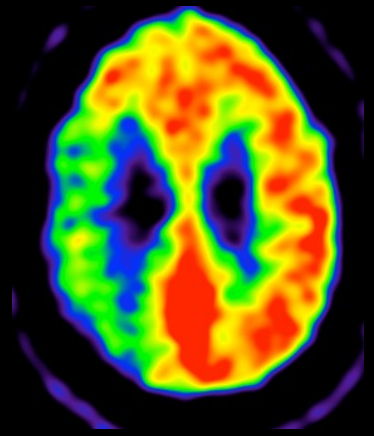

T2 MRI
rCBF Baseline
rCBF Diamox
LSA
AChA
ACA
MCA
PCA
R
L

Follow-up

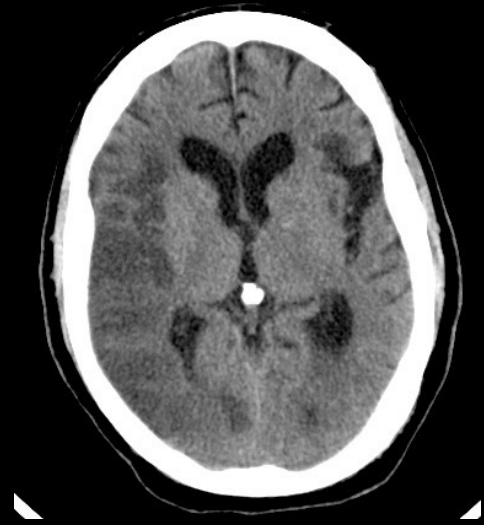
- Refused surgery
- 2 months after PET
  - Pneumonia
  - Septicaemia
  - Hypovolemia
  - Hypotension
  - R Stroke

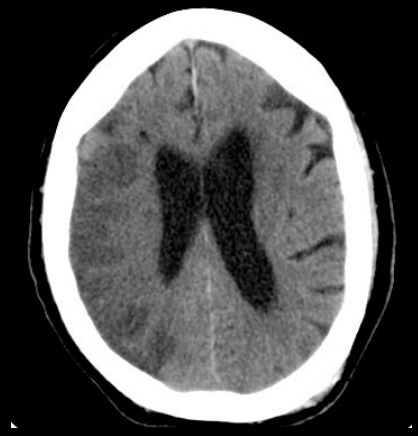
rCBF Diamox





CT 2 mth post PET





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Department of Clinical Physiology, Nuclear Medicine and PET

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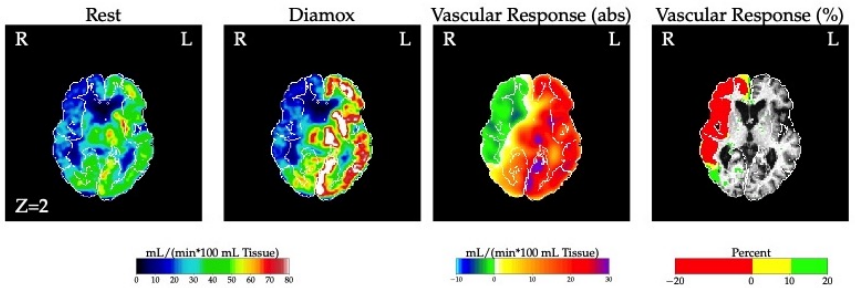
Standard Diamox report

Rigshospitalet

Klinik for Klinisk Fysiologi, Nuklear medicin og PET
Rigshospitalet
Blegdamsvej 9
2100 København Ø

Cerebrovascular hemodynamic response test with [^{15}O]H_2O PET

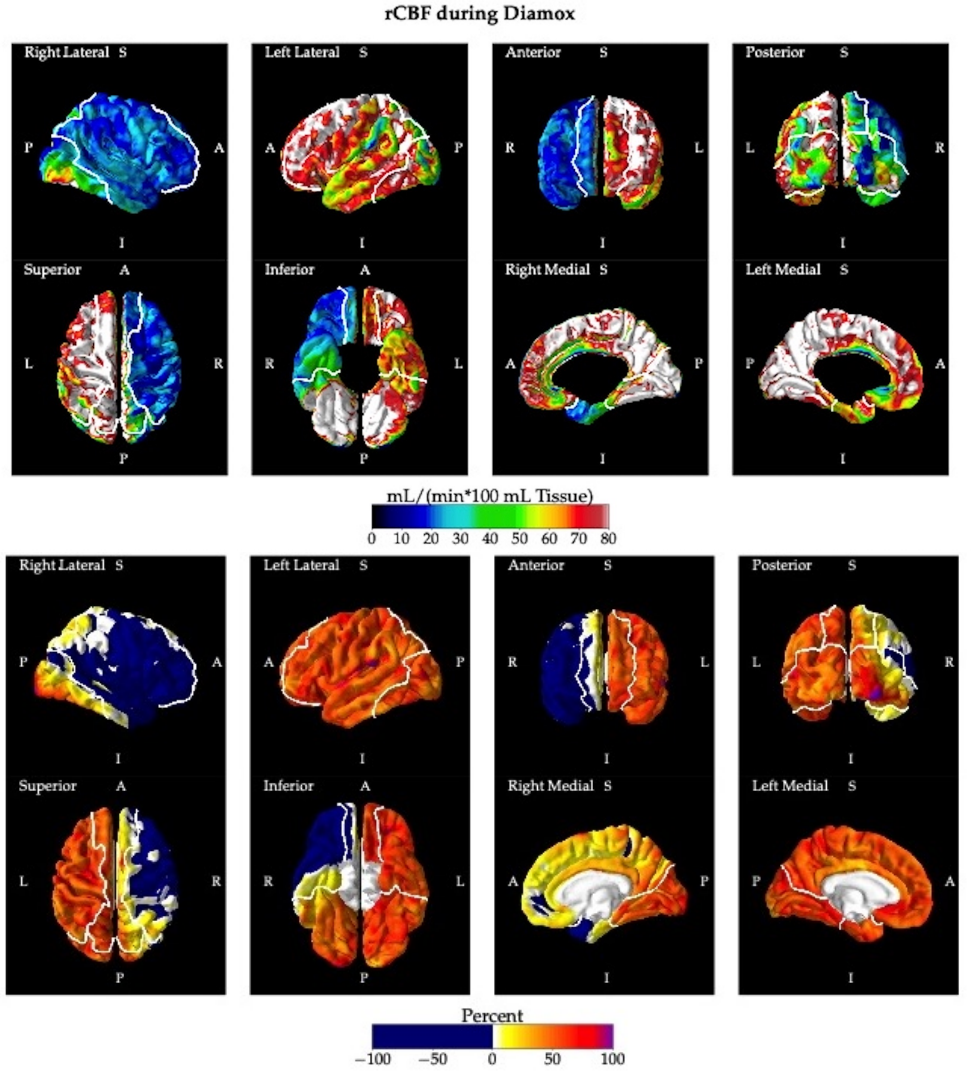
Patient name	CPR	Age	Sex	Scan date	Weight (kg)	Dose (MBq)
					72	800



		Cortical regional cerebral blood flow (mL/(min*100 mL Tissue))					
		Left			Right		
Vascular territories	**Volume (mL)**	**Rest**	**Diamox**	**Change (%)**	**Rest**	**Diamox**	**Change (%)**
ACA	184	41.4	66.7	61.3	24.2	25.4	5.0
Frontal MCA	99	42.0	67.8	61.7	17.7	15.9	-10.2
Parietotemporal MCA	335	36.8	58.6	59.1	18.8	17.3	-8.3
PCA	135	39.8	64.0	60.9	34.3	45.7	33.1
Watershed areas							
Frontal MCA/ACA	11	47.5	76.5	60.9	16.8	16.5	-1.8
Parietotemporal MCA/ACA	32	41.6	67.2	61.6	17.4	18.0	3.2
MCA/PCA	19	39.1	63.9	63.4	22.4	20.3	-9.3
ACA/PCA	14	42.8	69.7	63.0	31.7	39.3	23.9
Anatomical structure	**Volume (mL)**	**Rest**	**Diamox**	**Change (%)**			
Cerebellum	108	34.9	55.9	60.1			
Threshold defined areas in cortical regions		**Volume (mL)**		**Average %**			
Steal		190		-8.5			
<10%		44		4.3			
<20%		33		14.9			

rCBF Change= (Diamox-Rest)*100 /Rest (%).
Rest is based on 1 PET measurement:
hvile-45f-9min-K1
Diamox is based on 1 PET measurement:
diamox-45f-9min-K1

The arterial territories are defined according to Tatu L el al.. Neurology. 1998;50:1699-1708.



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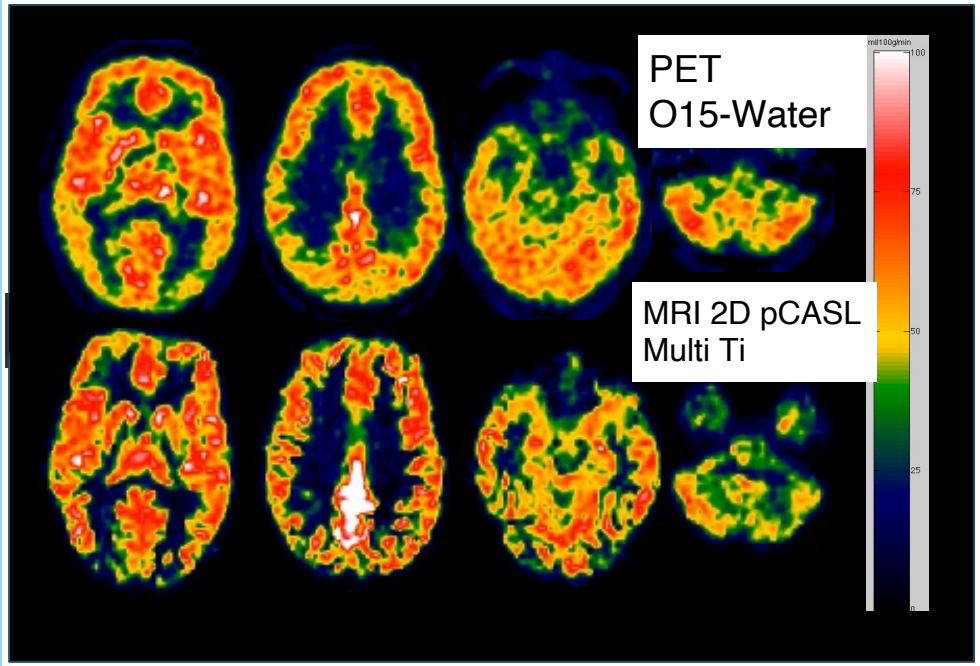
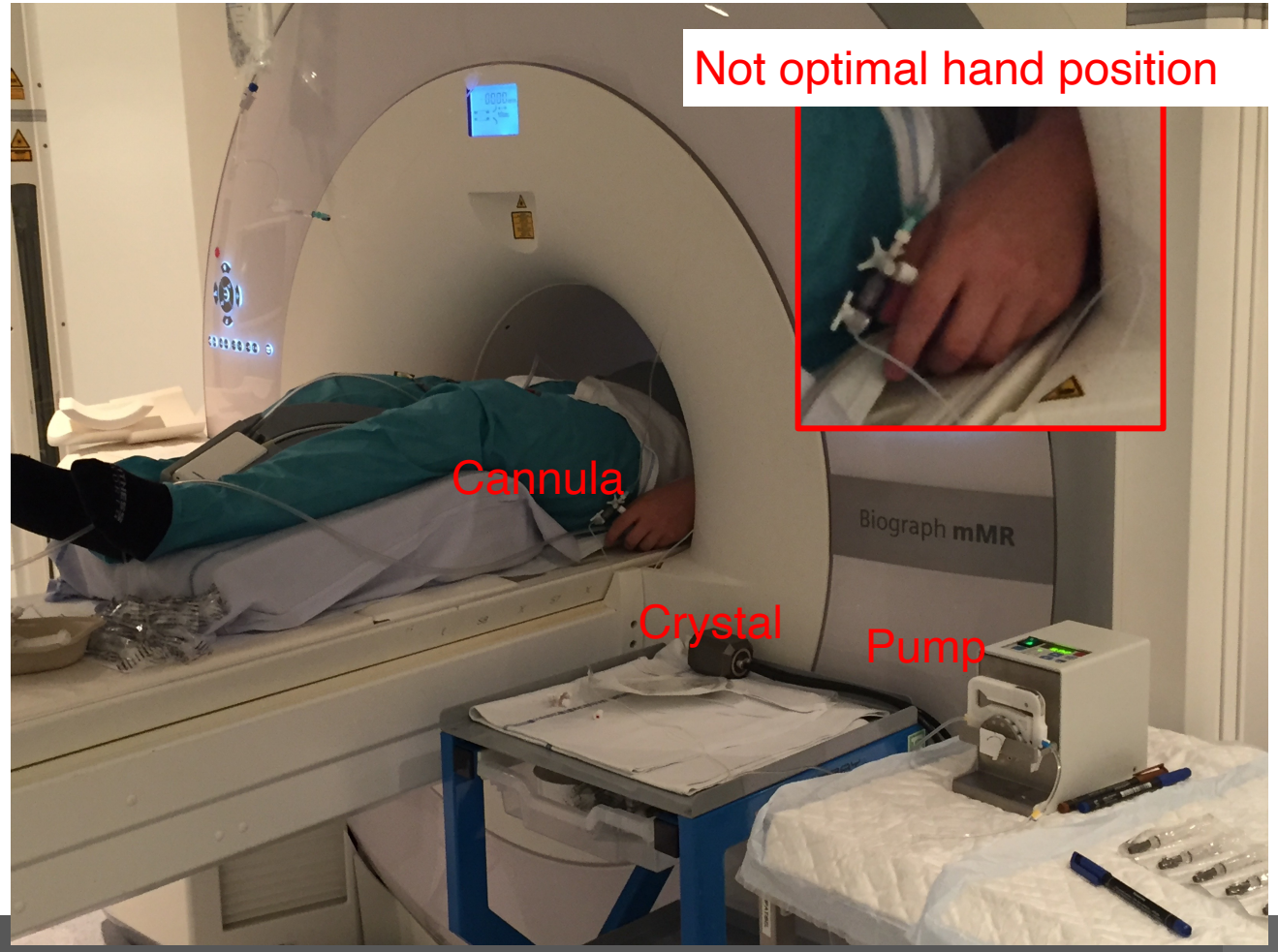
Regional Cerebral Blood Flow PET/MRI O15-Water & Arterial Spin labelling (ASL)



Simultaneous
Measurement
Rest



REGION H

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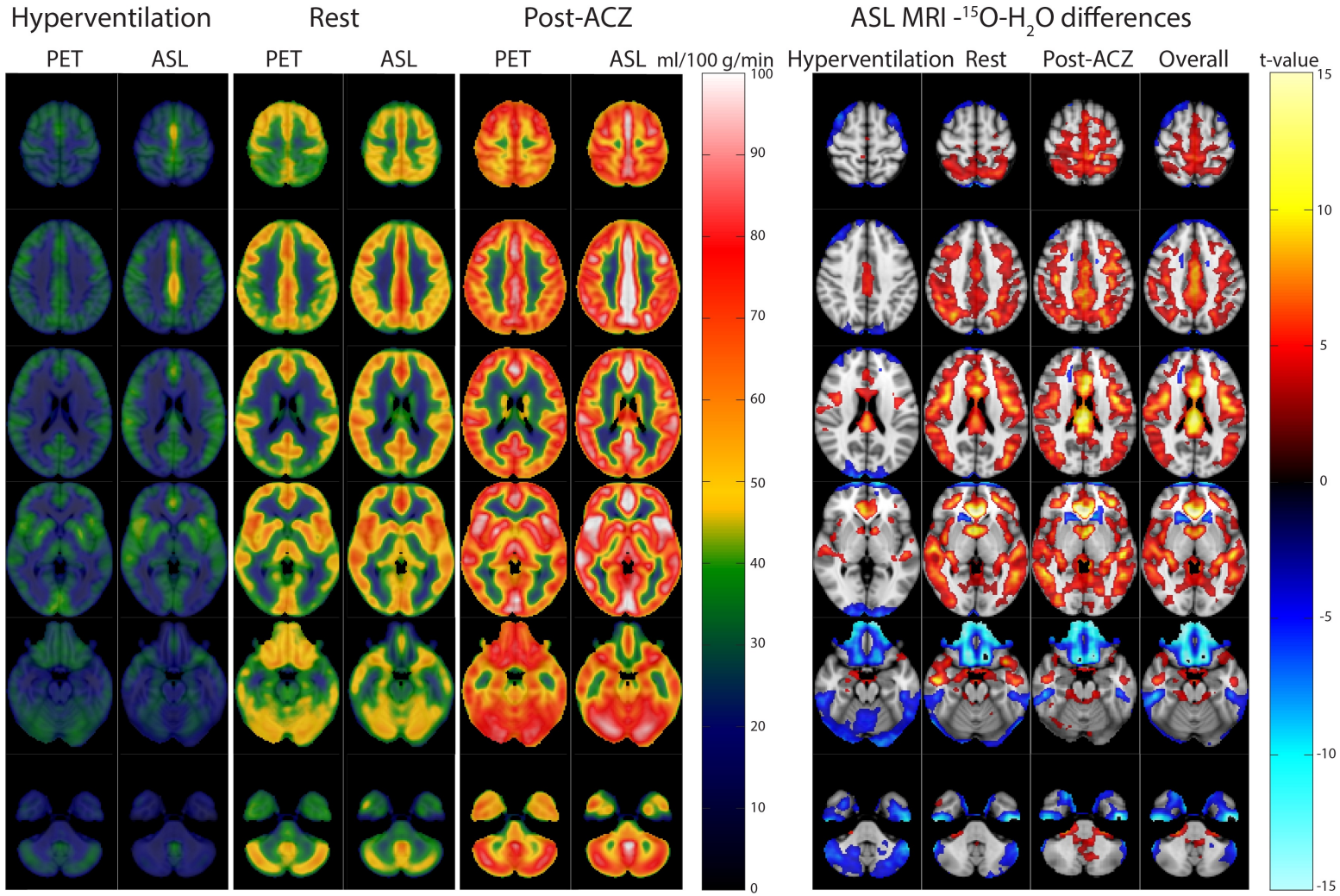
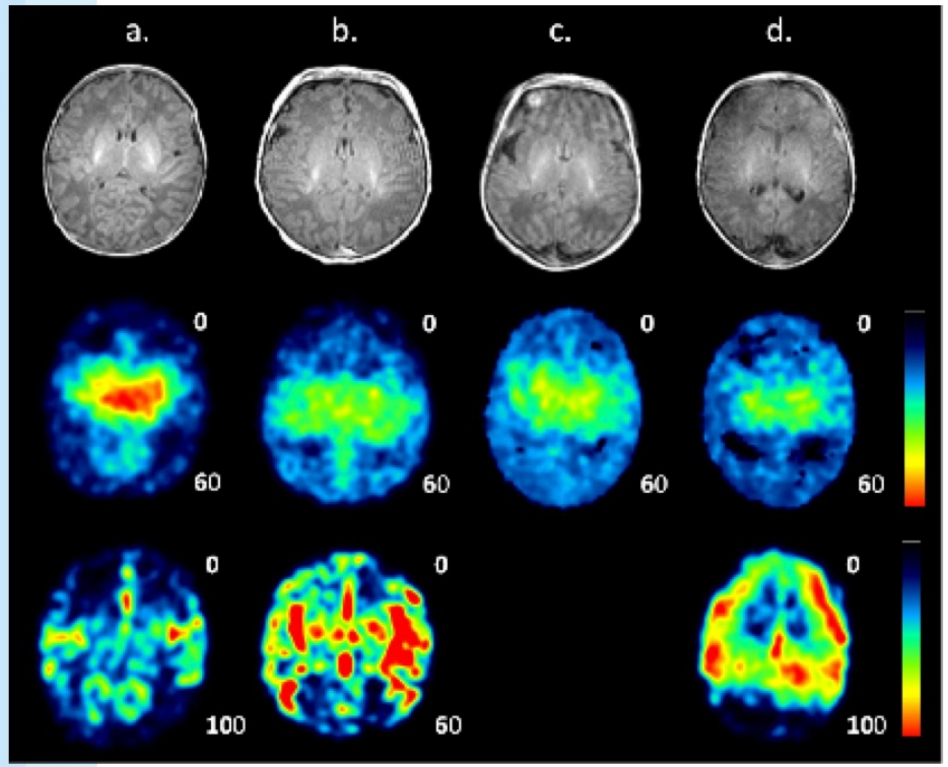
Average ASL and PET CBF images in different perfusion states and differences between techniques



O. Puig *et al.*, *J Cereb Blood Flow Metab* **40**, 1621 (2020).

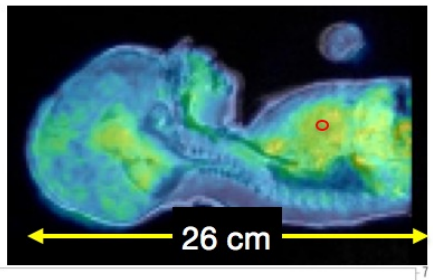
Rigshospitalet

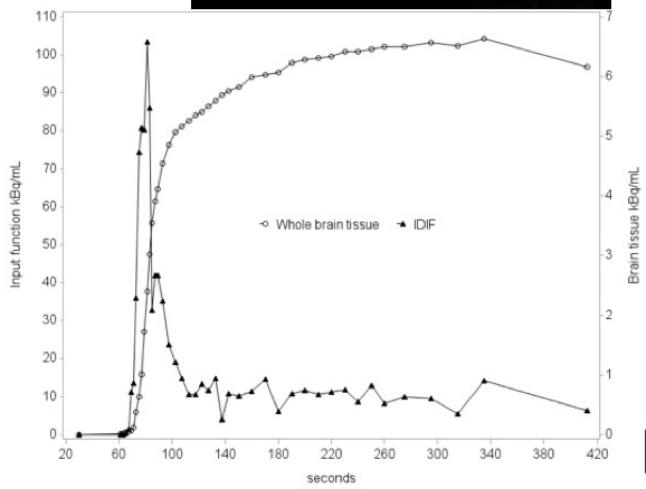
Brain PET/MRI O15-H2O rCBF ASL i healthy newborn children



4 Healthy Newborn Children
Quantitative rCBF
Input: Left ventricle
14 MBq O15 H2O = 0.3 mSv
Simultaneous PASL
AC-RESOLUTE

Clinical Perspective:
Periventricular Leukomalacia (PVL)
Moya-Moya





rCBF (ml/100g/min)

	a	b	c	d	Mean (SD)
WM unmyel	10.1	11.5	10.1	9.3	10.3 (0.9)
WM myel	23.3	15.9	14.6	10.6	16.1 (5.3)
Thalami	42.9	30.3	29.3	22.5	31.3 (8.5)
Whole brain	22.2	17.8	16.2	15.0	17.8 (3.1)

Andersen JB, et al