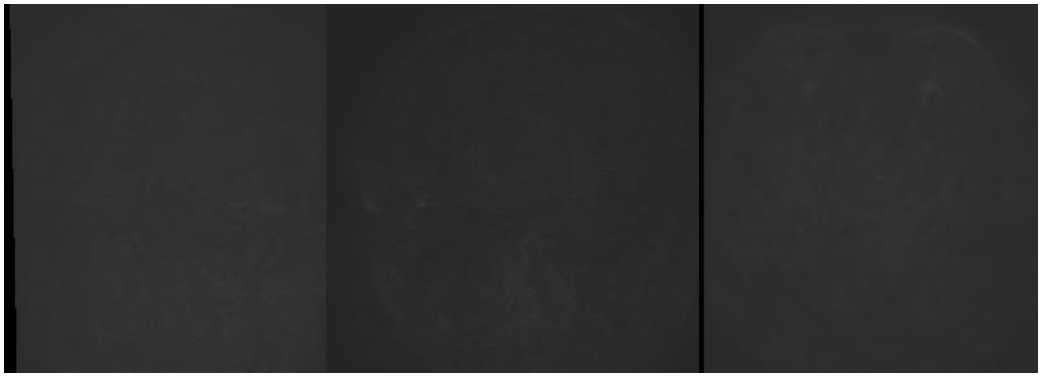

Dynamic Contrast enhanced MRA






Speaker: Yung-Chieh Chang

Date : 106.07.22

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臺中榮民總醫院
Taichung Veterans General Hospital

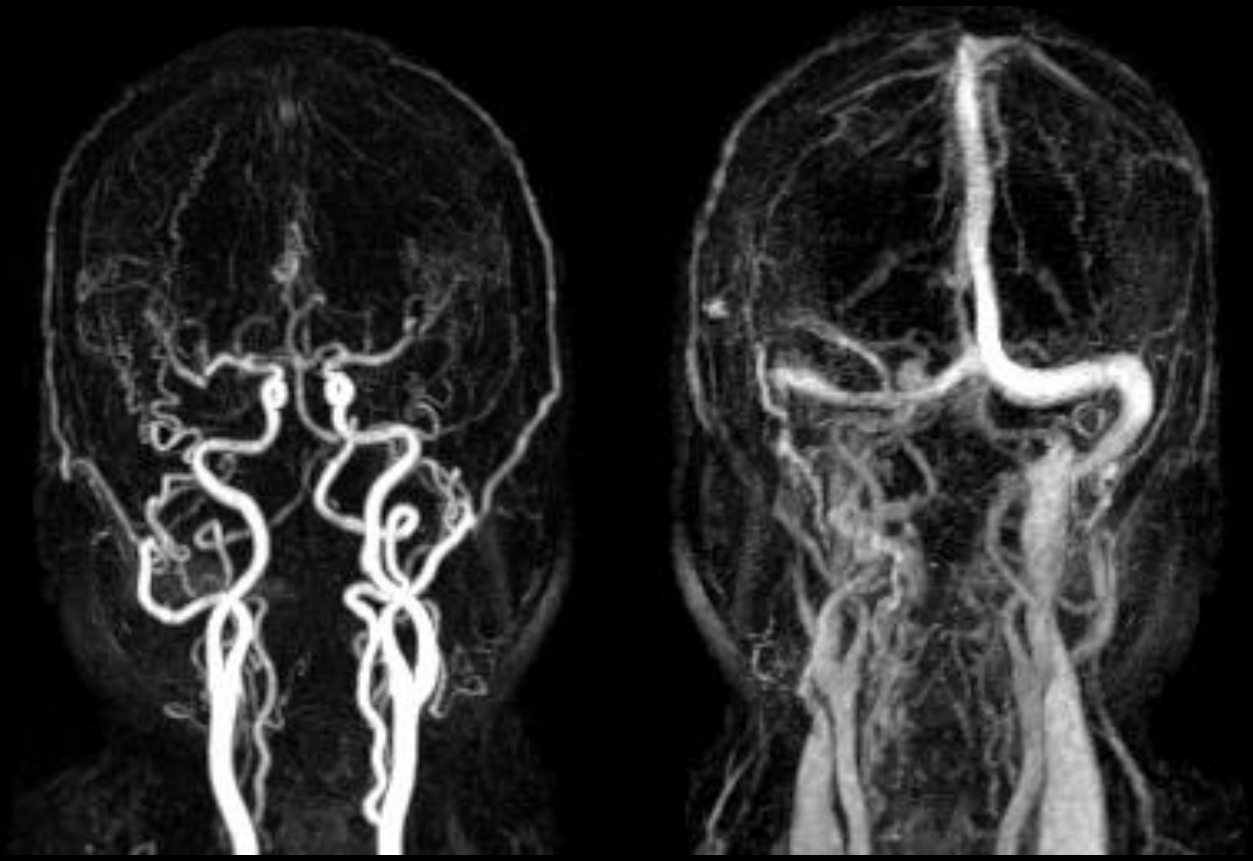
Outline

- **Basic and advanced principles of Diffusion Weighted Images (DWI) - 1**
  1. Echo Planar Imaging **(EPI)**
  2. Diffusion weighted imaging **(DWI)**

- **Basic and advanced principles of Diffusion Weighted Images (DWI) – 2**
  1. Diffusion-weighted whole-body imaging with background body signal suppression **(DWIBS)**
  2. Intravoxel Incoherent Motion **(IVIM)**

- **Dynamic Contrast enhanced MRA**
- **Preliminary conclusions and discussion**

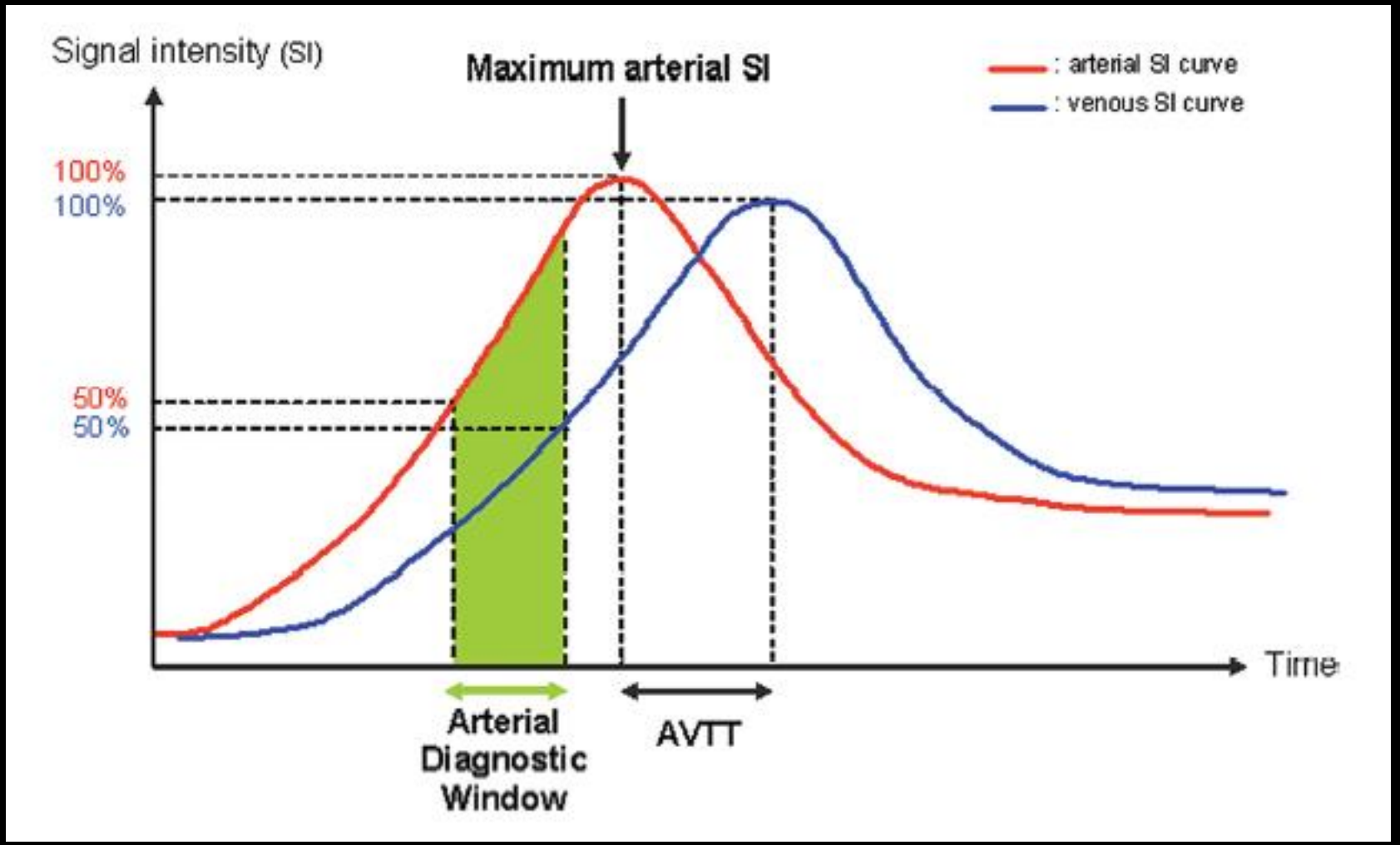
Conventional CEMRA



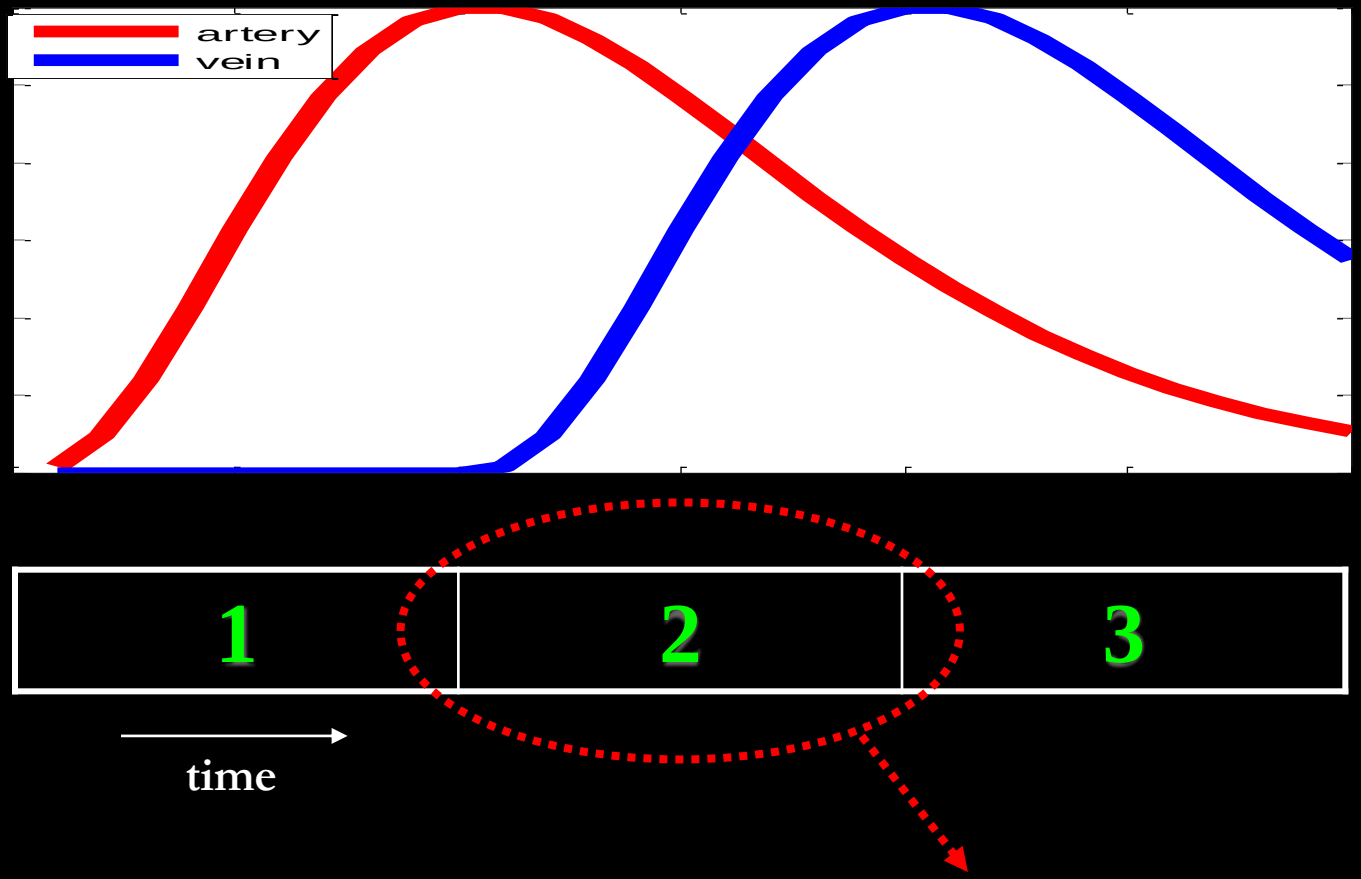
Arterial phase

Venous phase

Conventional CEMRA

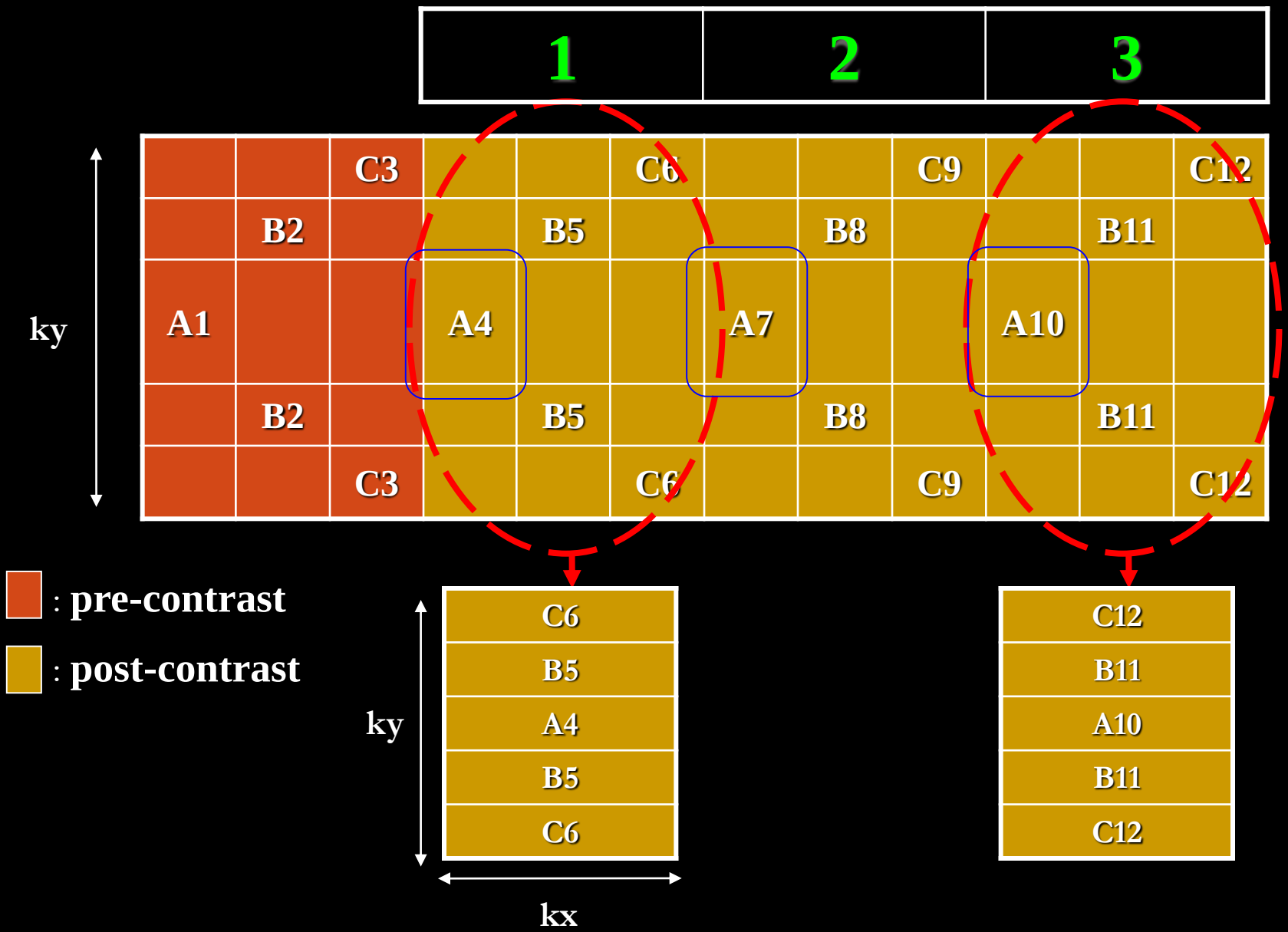


Conventional CEMRA

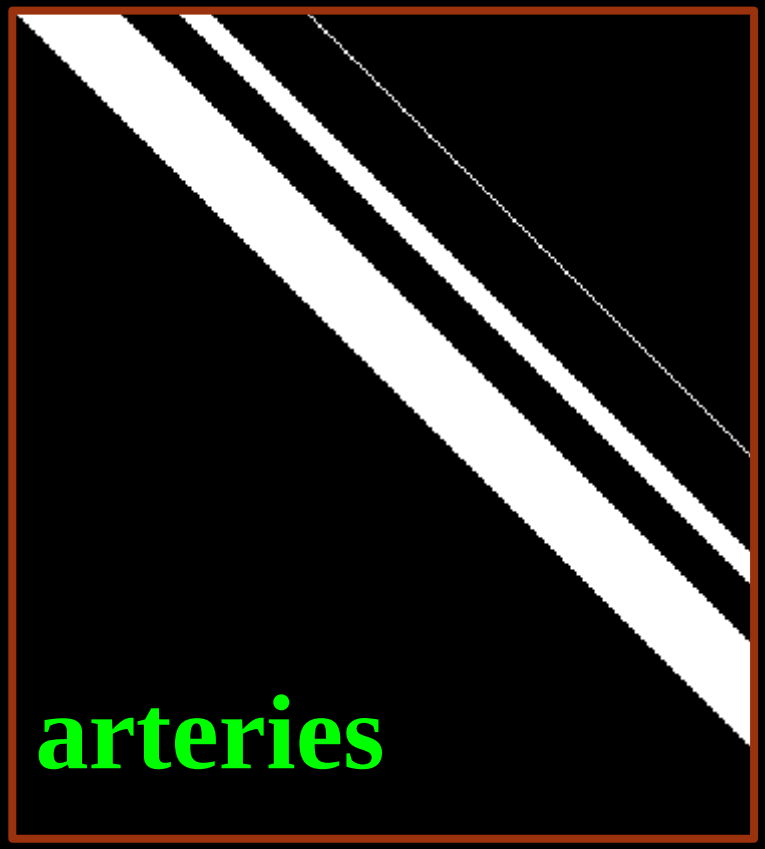


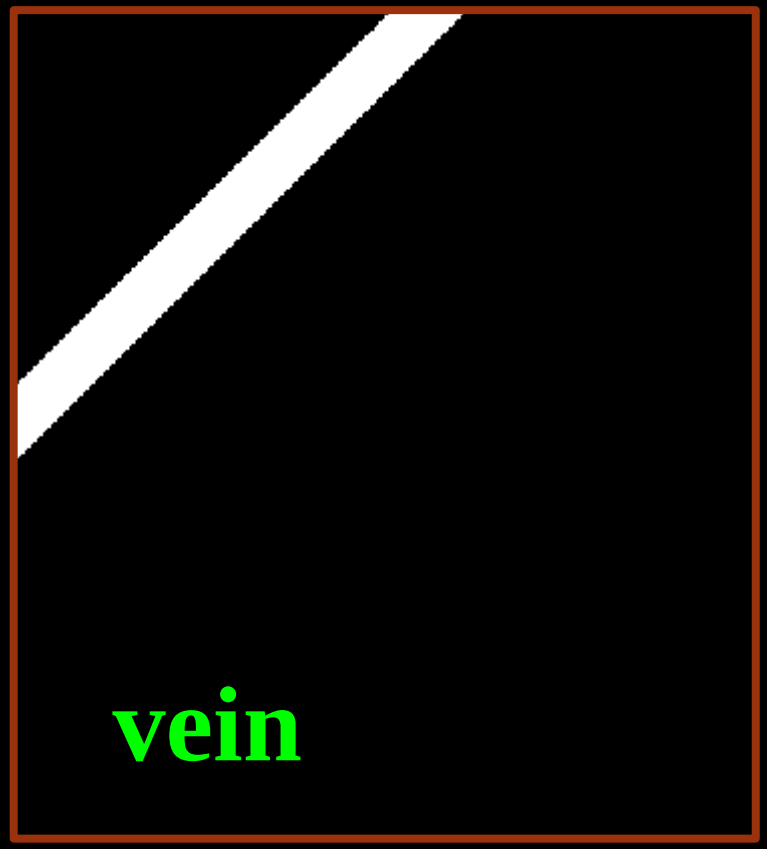
All 3 sections acquired in 10 seconds

Conventional CEMRA (3 sections)

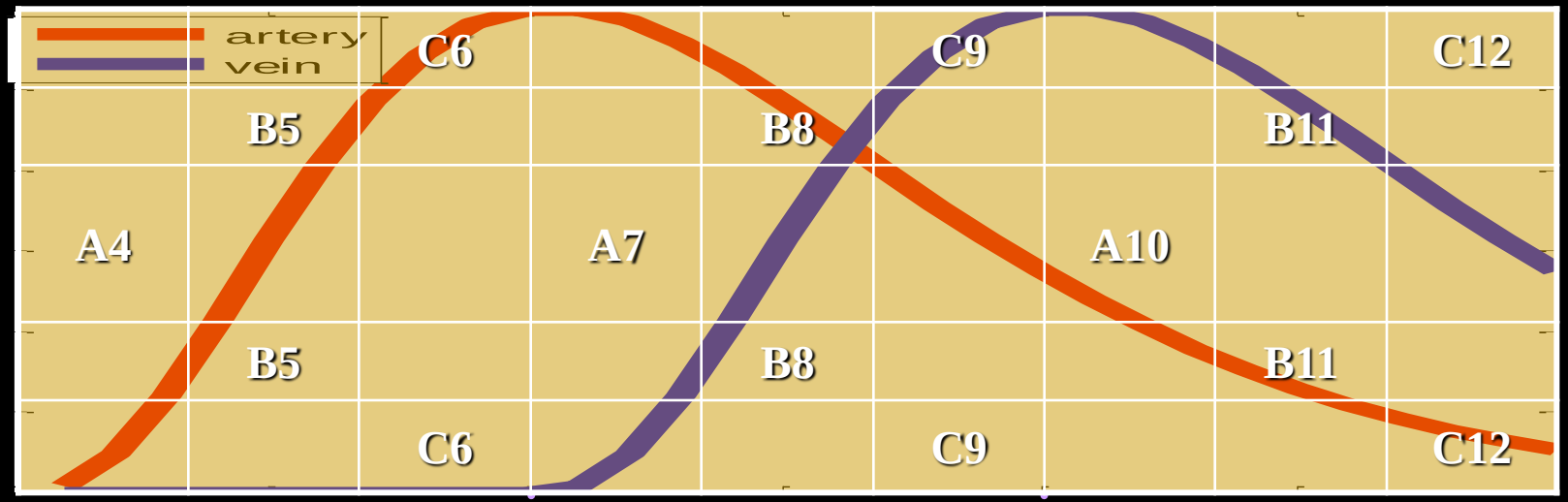


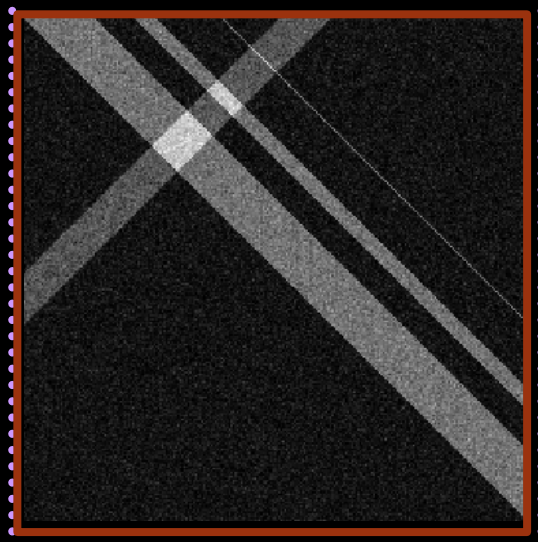
Suppose the image of arteries and veins





Conventional CEMRA

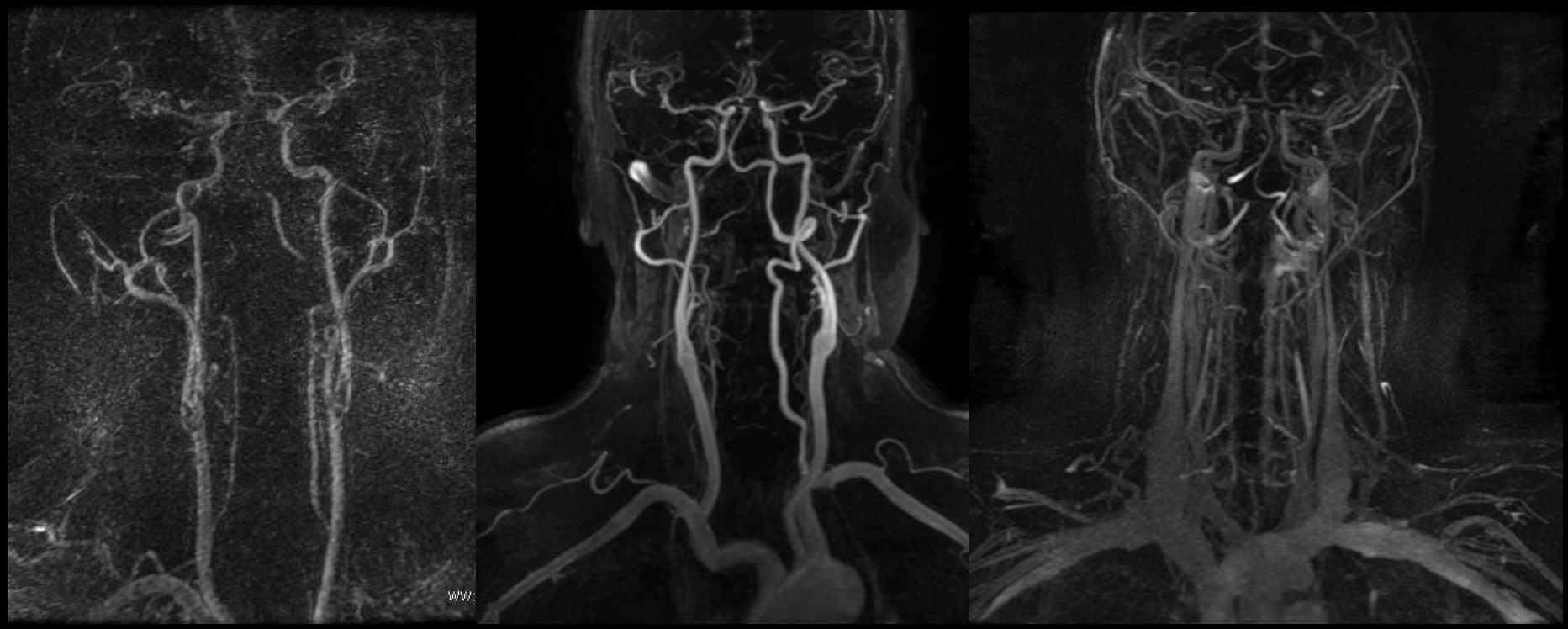




Arterial phase

Venous phase

Fill in the k-space center different timing

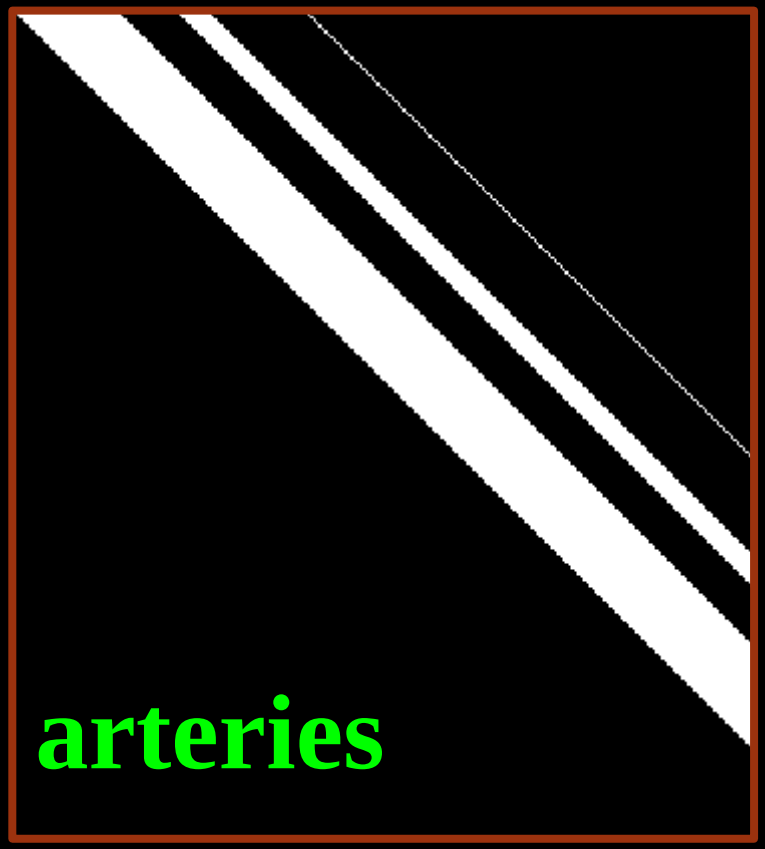


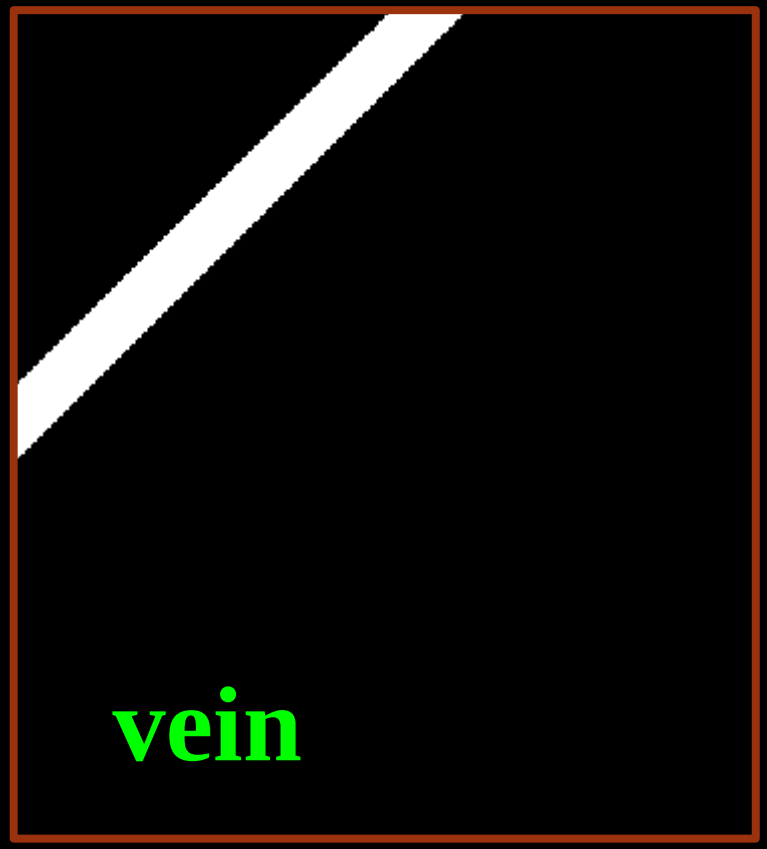
too early exactly too late

From left to right: early to late scanning

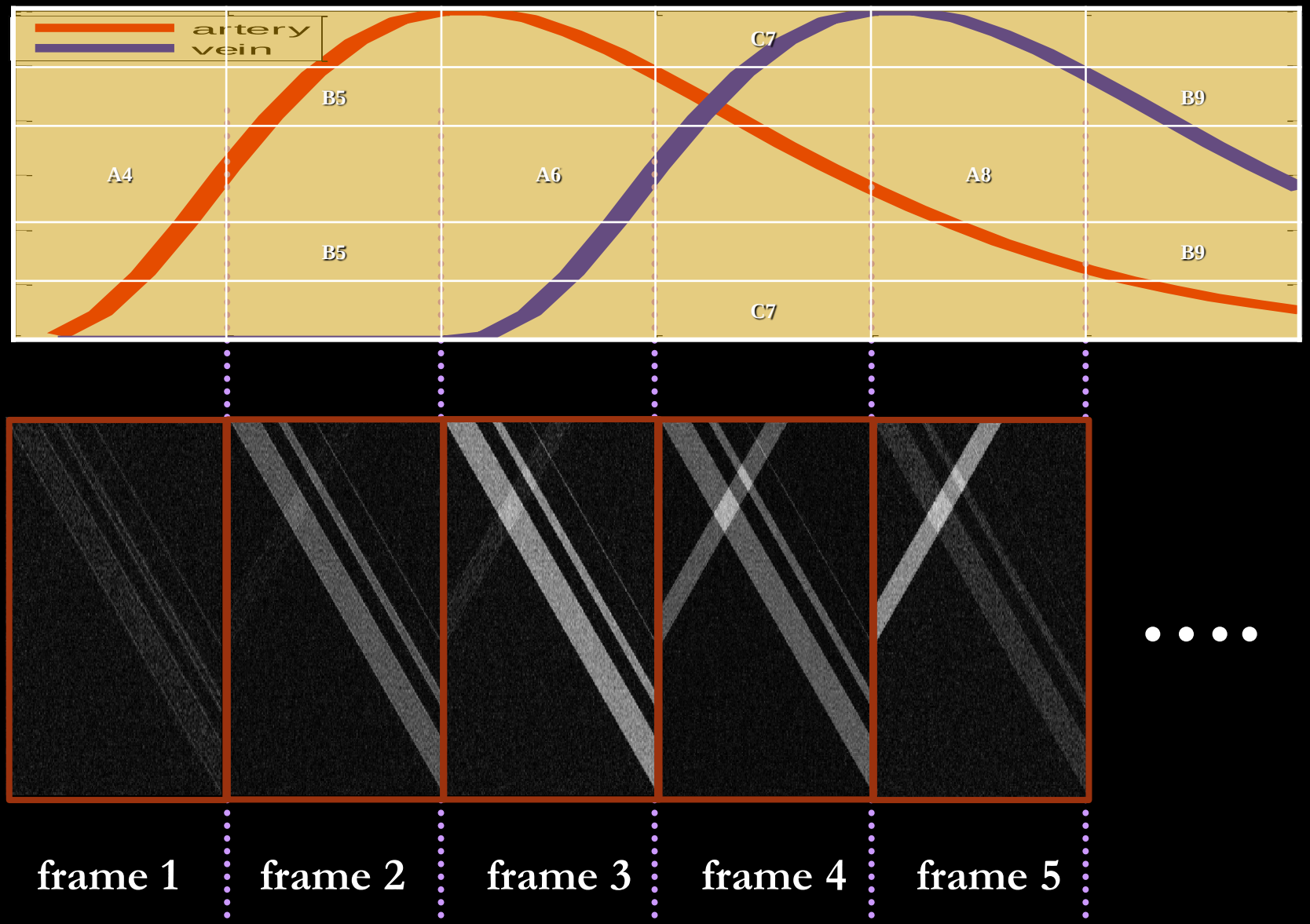
Technique 、patient's (Heart Rate & Blood pressure)

Suppose the image of arteries and veins





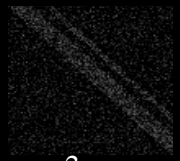
Dynamic Contrast enhanced MRA

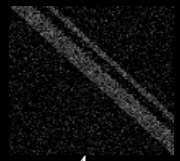


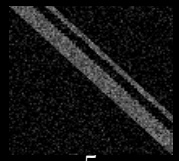
If the signal is received quickly

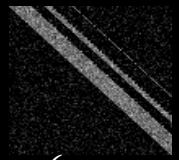

1sec


2sec


3sec


4sec


5sec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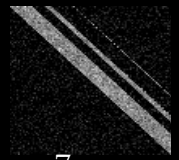
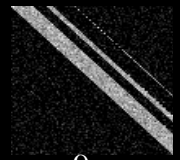
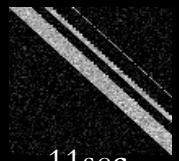

7sec

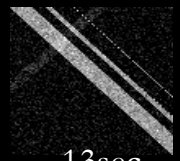

8sec


9sec


10sec


11sec


12sec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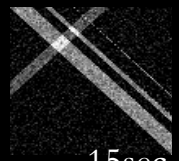
14sec

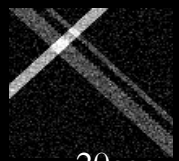

15sec


16sec

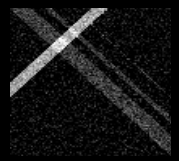

17sec


18sec


19sec


20sec


21sec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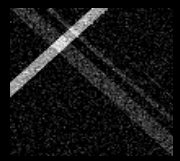
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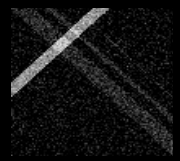
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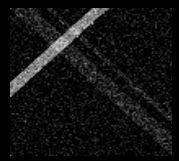
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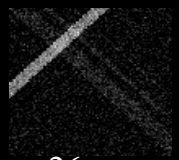
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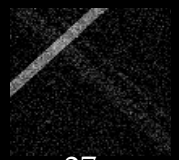
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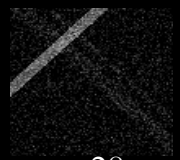
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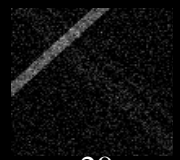
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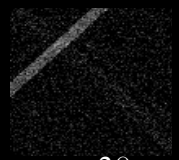
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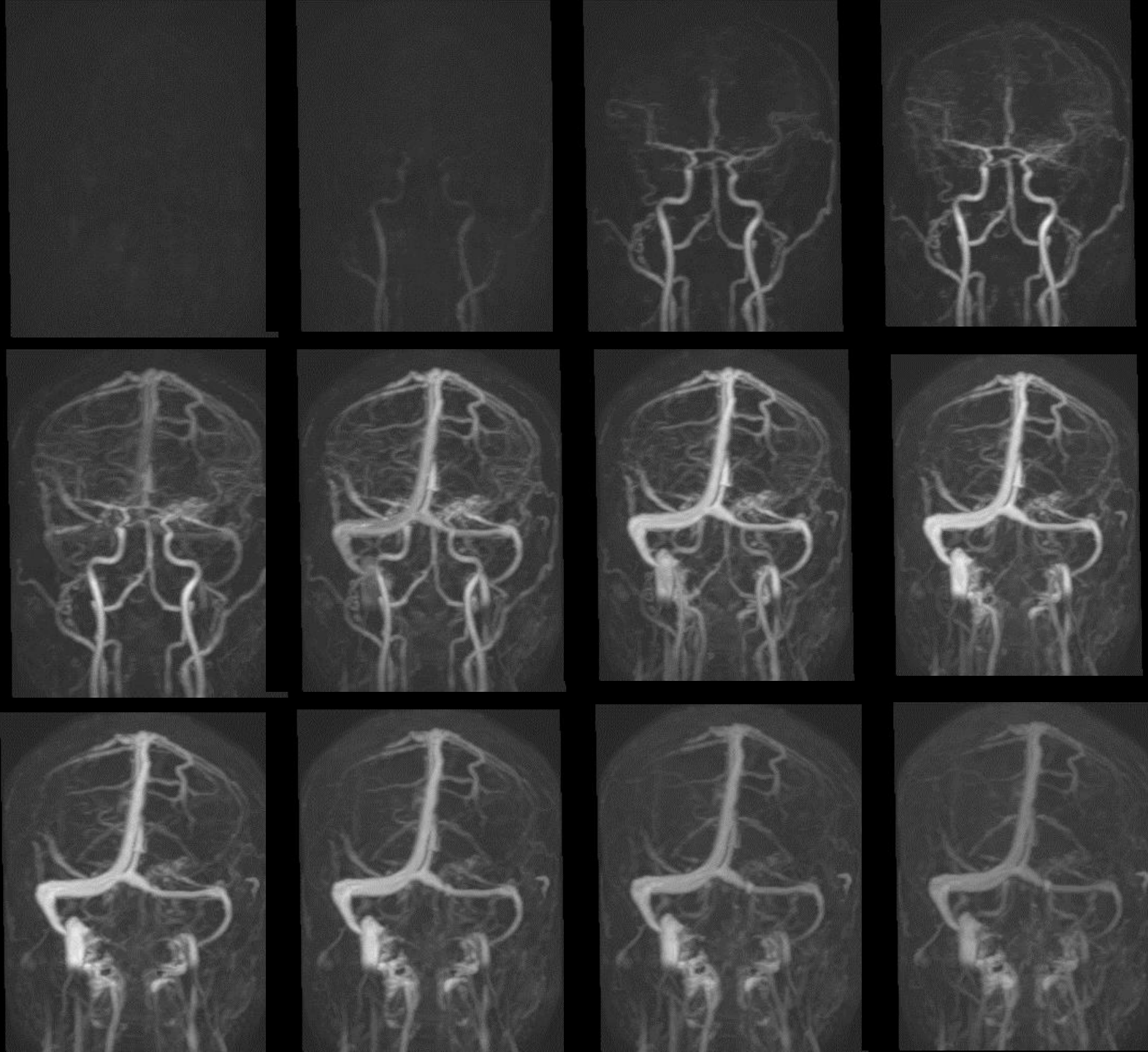
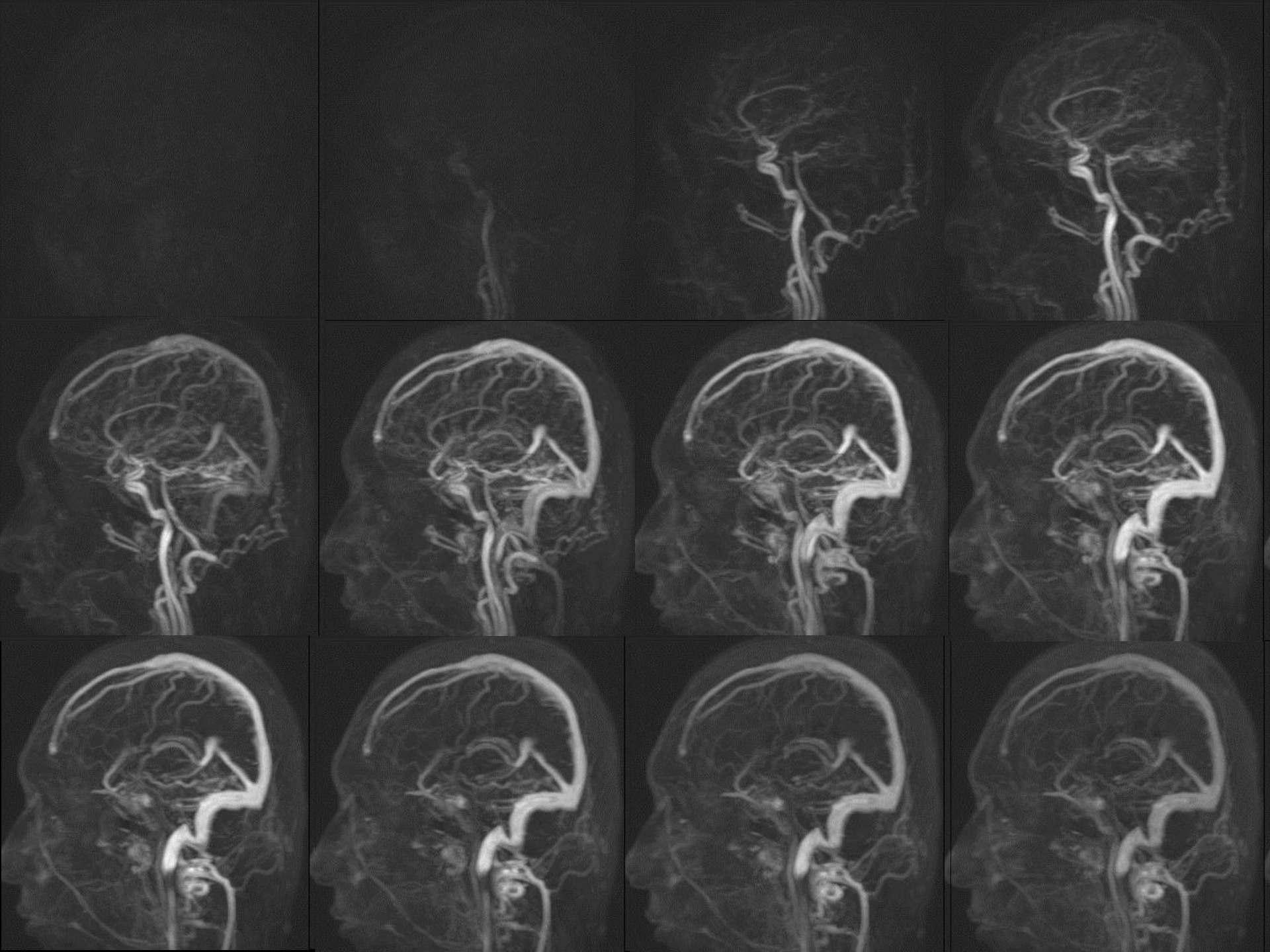
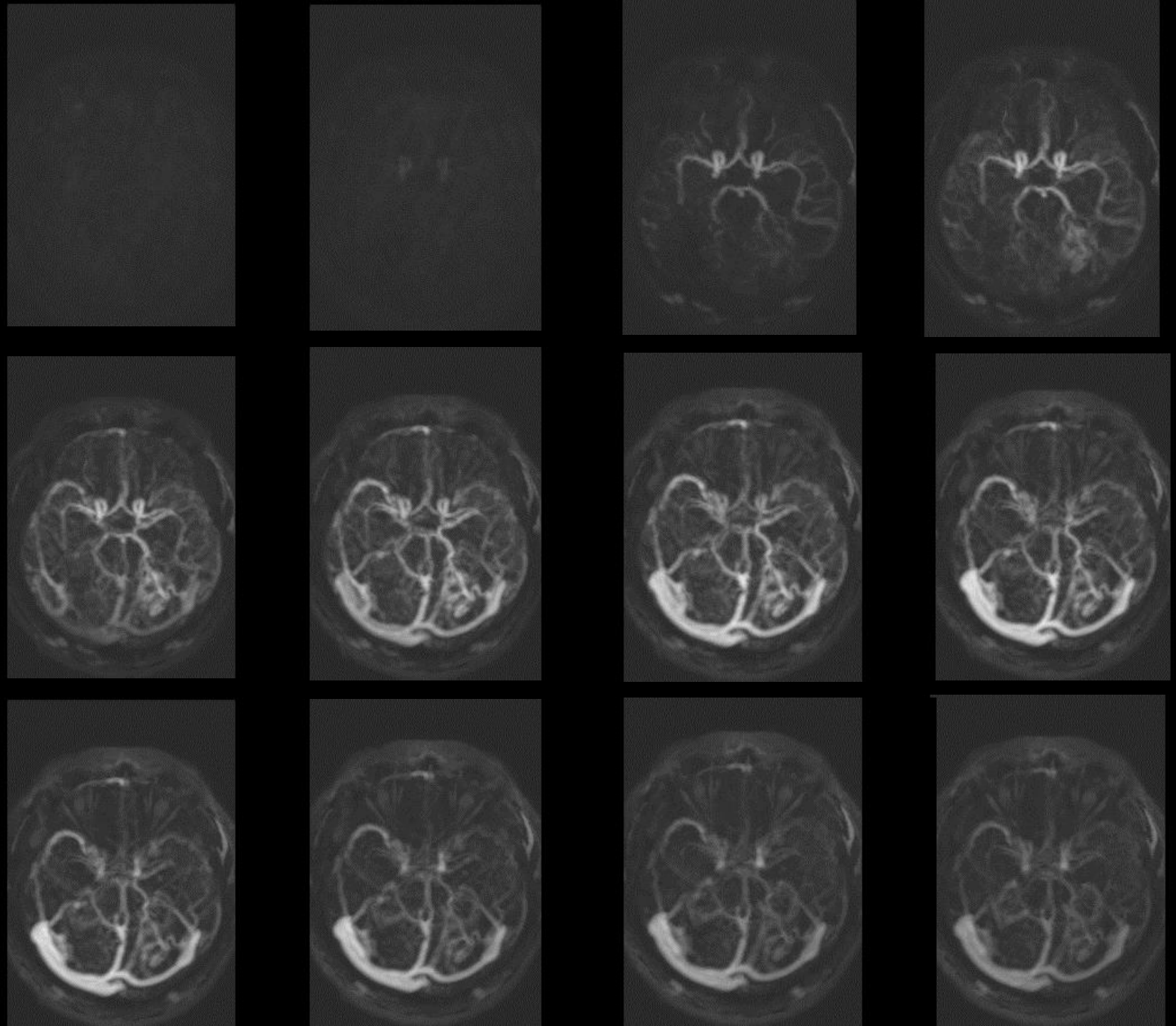
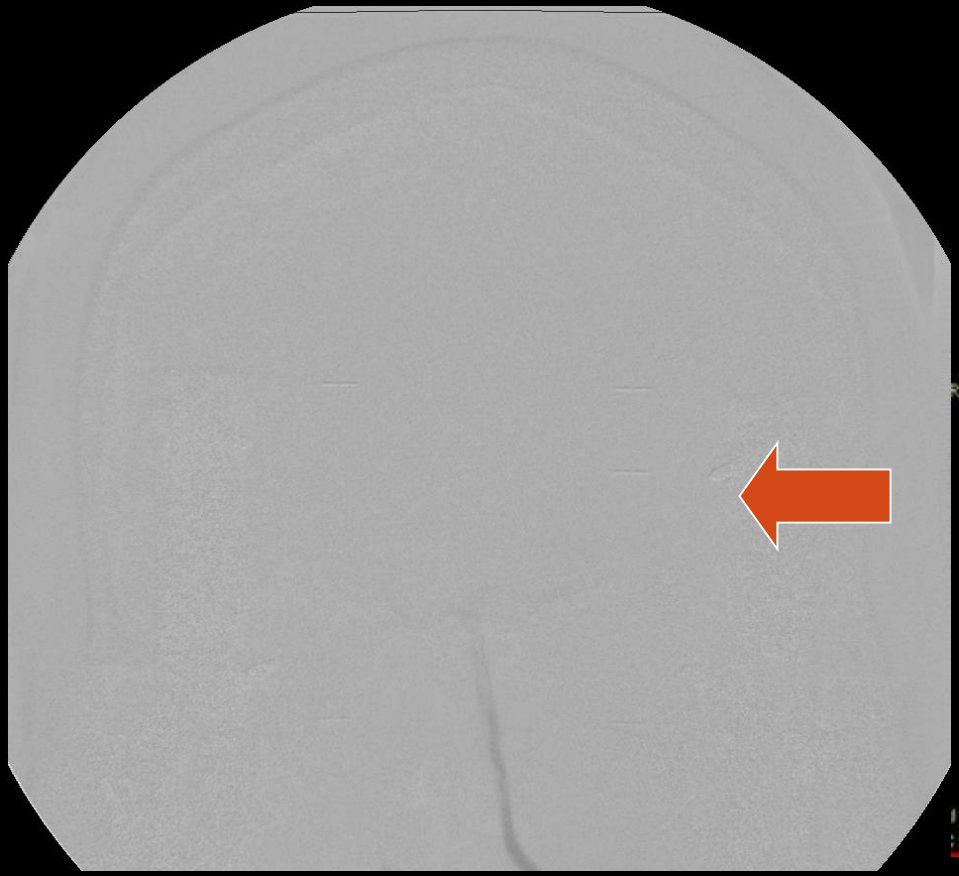






Could we do Dynamic MRA like DSA?



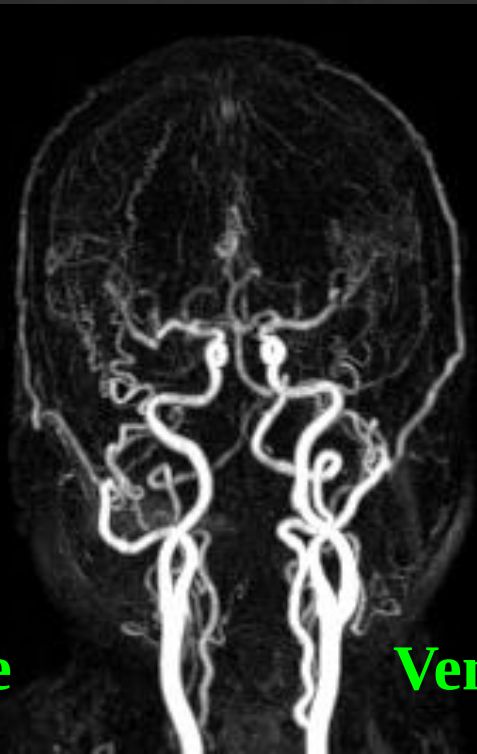
Convential DSA

CEMRA

Dynamic MRA

Conventional

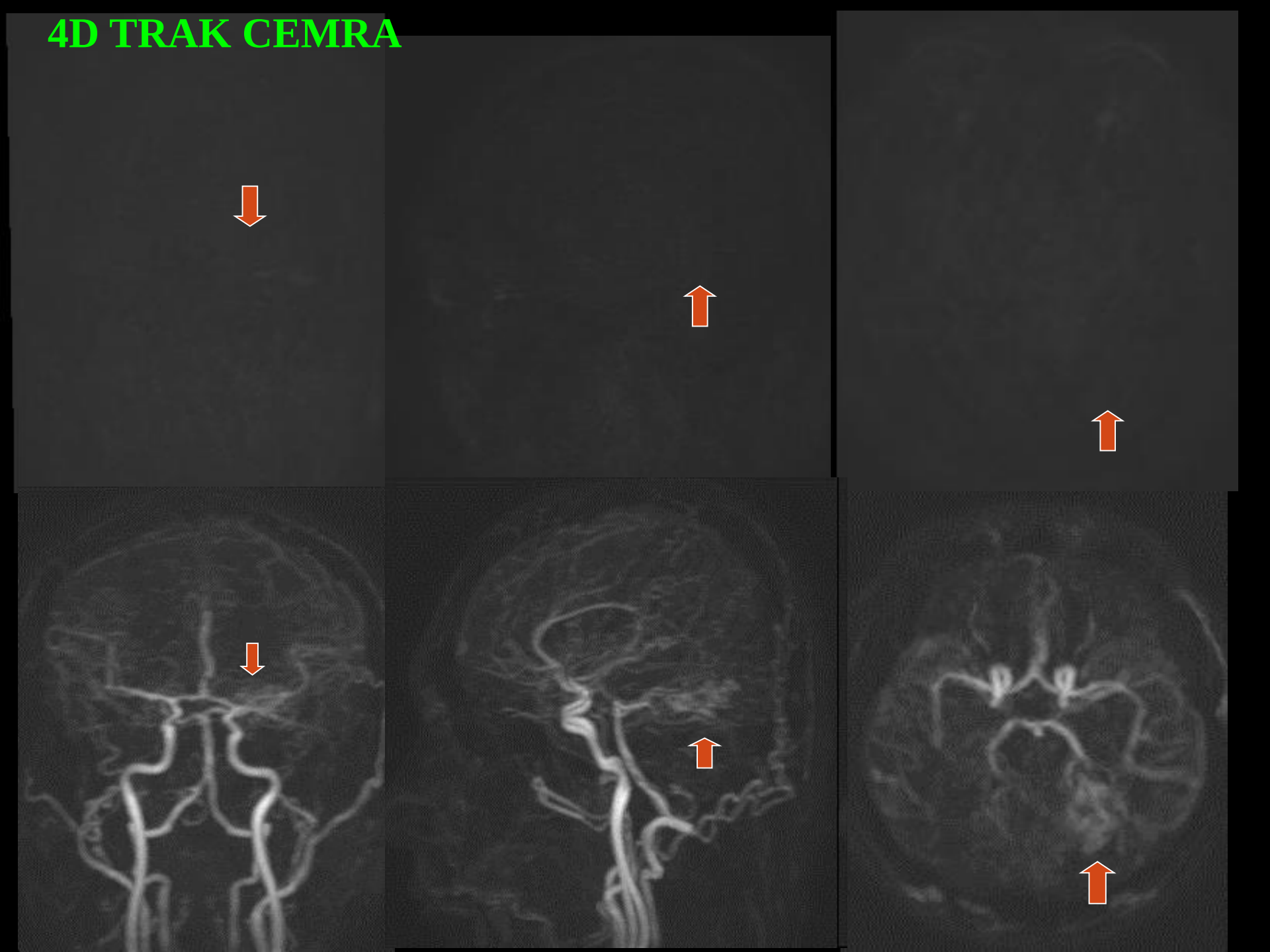
CEMRA



Arterial phase

Venous phase

4D TRAK CEMRA



MRI for Blood vessels

- **None contrast Agent**
  - -Time of flight MRA (3D TOF MRA)
  - -Phase contrast MRA (PC MRA)
- **Contrast Agent**
  - -Contrast-enhanced MRA (CE MRA)
- **Contrast Agent + Acceleration**
  - - 4D-TRAK (Philips)
  - - TWIST (Siemens)
  - - TRICKS (GE)

Why should be accelerated?

- **It avoids the vein interference**

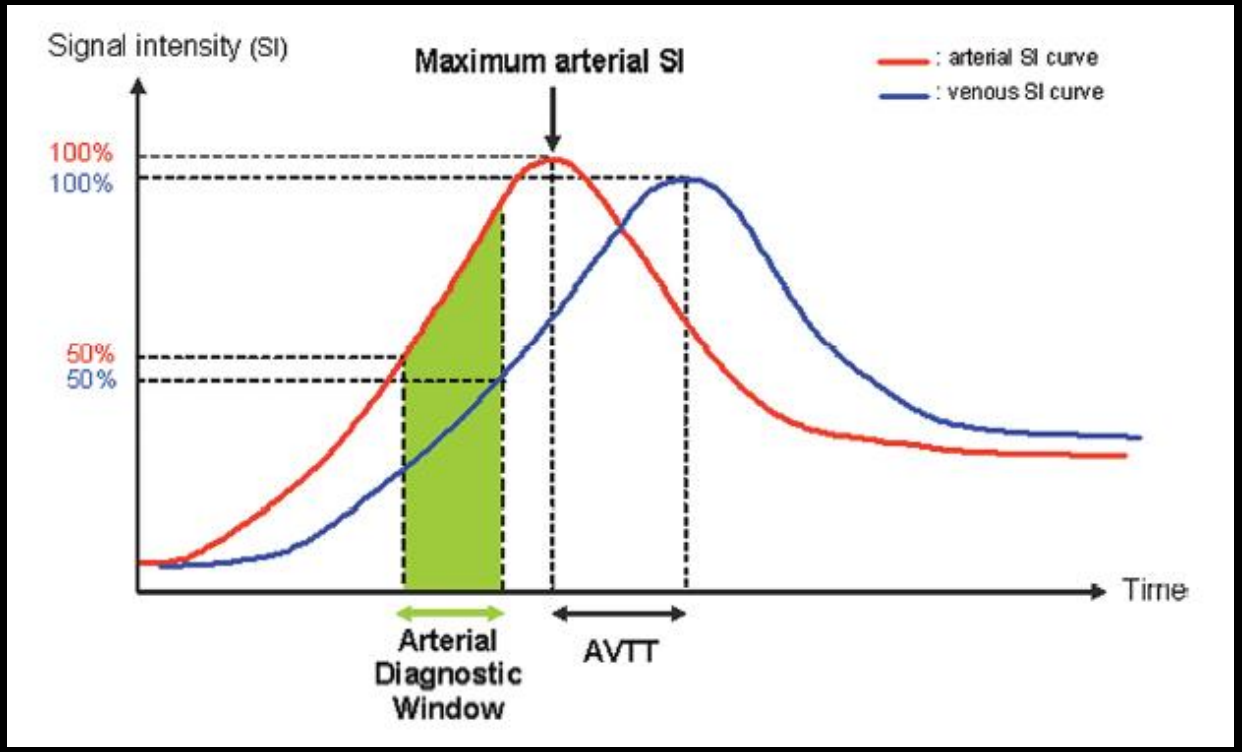
  - Contrast agent flows into vein rapidly from the artery

- **It avoid that can not find arterial phase**

  - Slow flow patient
  - Heart rate (Too slow)
  - Heart rate (Too fast)
  - Carotid artery Short (kids)

How do we avoid that vein is appeared

- **It uses of accelerate scanning technology for reducing scan time**



Parameters Compare (VGHTC)

	3D MRA	4D-Trak
matrix	380x280x150	288x187x160
TR / TE (ms)	3.6/1.3	3.3/1
Flip angle (deg)	25	20
Keyhole	no	yes
dyn scans	2	30
Total scan duration	24	53.5
Dyn. refscan time	-	5.5
Dyn. keyhole scan duration	-	1.6

4D-TRAK (Philips)

4D Time-Resolved Angiography using Keyhole

- **Purpose**
  - Dynamic, high-resolution 4D CE-MRA

- **Combination the speed of**
  - SENSE (parallel imaging with SENSitivity Encoding) ,
  - CENTRA (Contrast-ENhanced Timing Robust Angiography),
  - Keyhole
  - halfscan

4D-TRAK (Philips)

4D Time-Resolved Angiography using Keyhole

- **Purpose**
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- **Combination the speed of**
  - SENSE (parallel imaging with SENSitivity Encoding) ,
  - CENTRA (Contrast-ENhanced Timing Robust Angiography),
  - Keyhole
  - halfscan

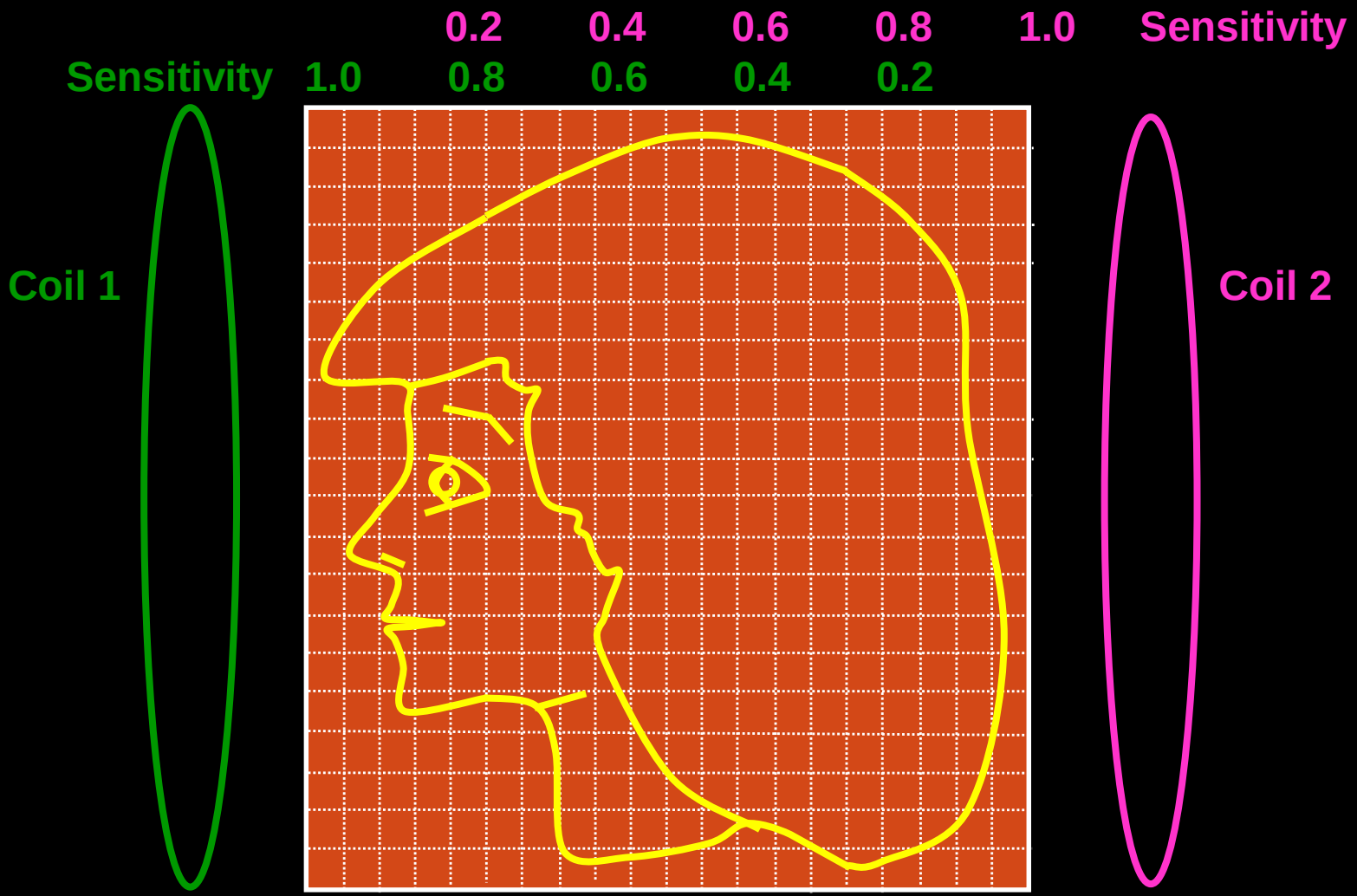
SENSE

SENSitivity Encoding (iPAT,ASSET)

- **Parallel Imaging technique:**
  - multi-element RF coils increase speed using in imaging
- **Preparation:**
  - Determine sensitivity maps of individual RF coil elements
- **Acquisition:**
  - Measure less data (k-profiles), results in faster scan
- **Reconstruction:**
  - Decode images using coil element sensitivity maps

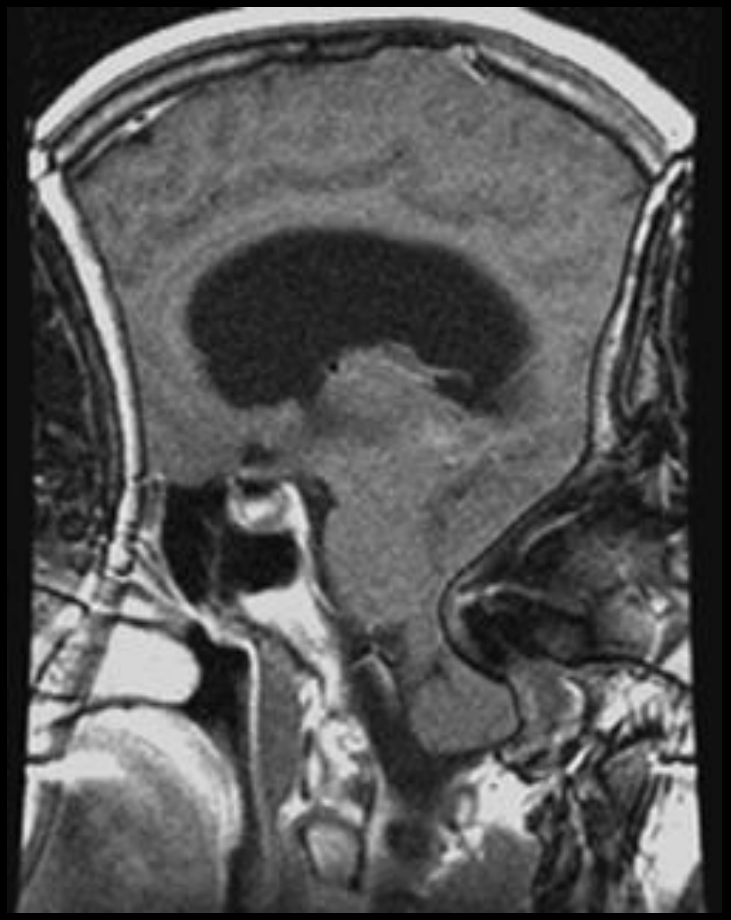
Sensitivity encoding

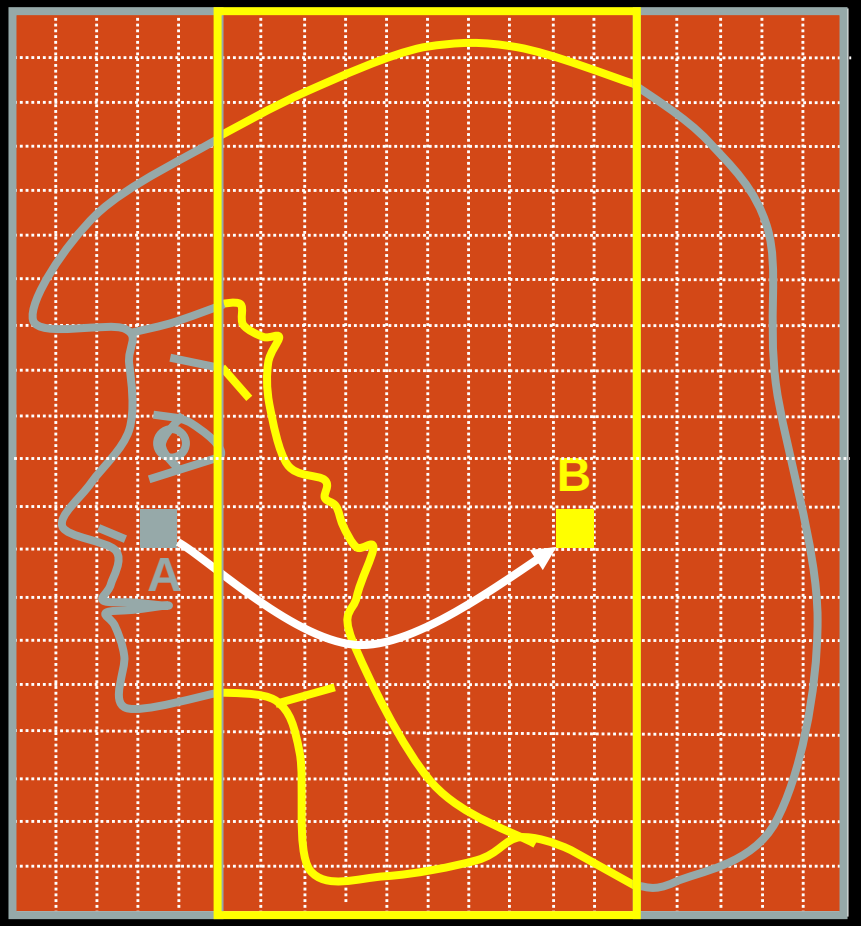
Application with 2-element synergy coil



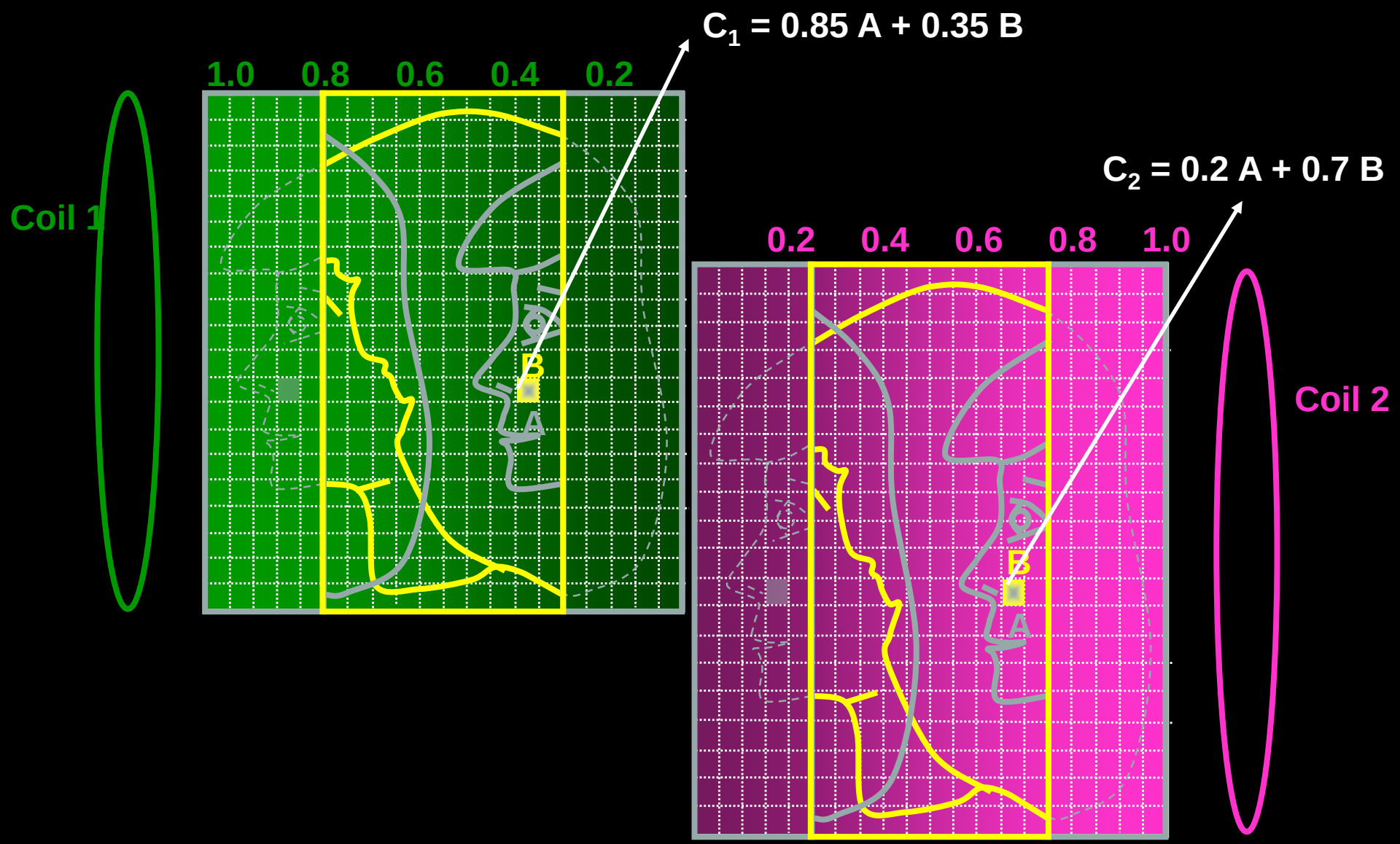
Sensitivity encoding

Scan with sense factor 2 (RFOV of 50%)





Sensitivity encoding

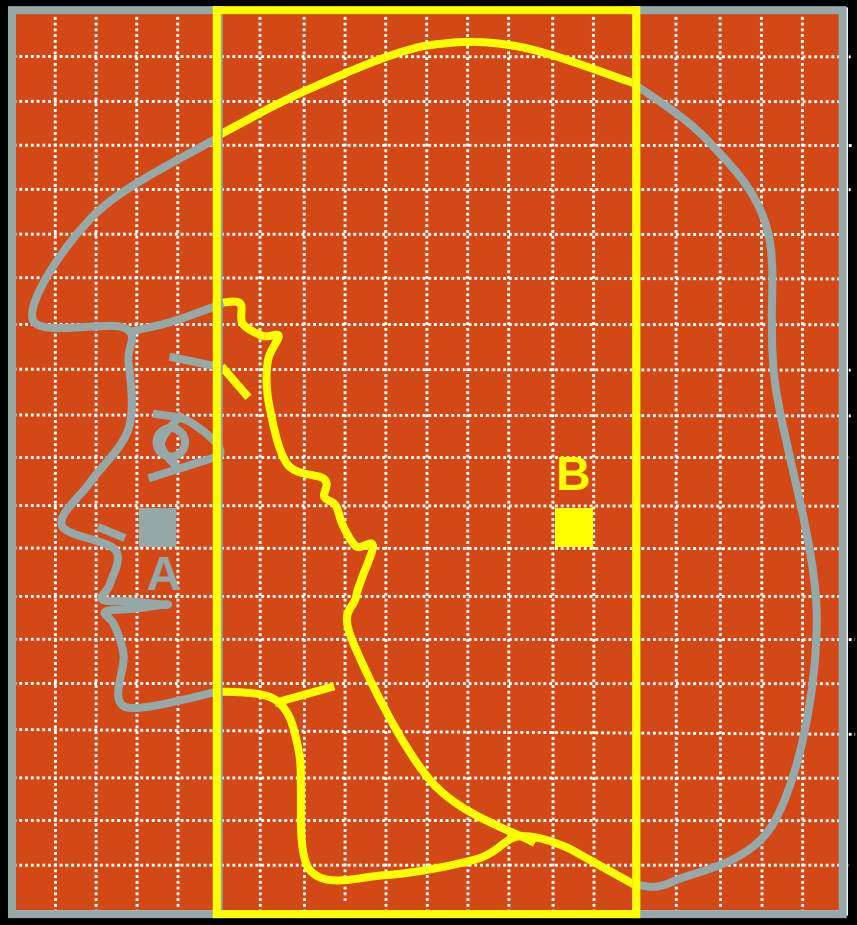


Sensitivity encoding

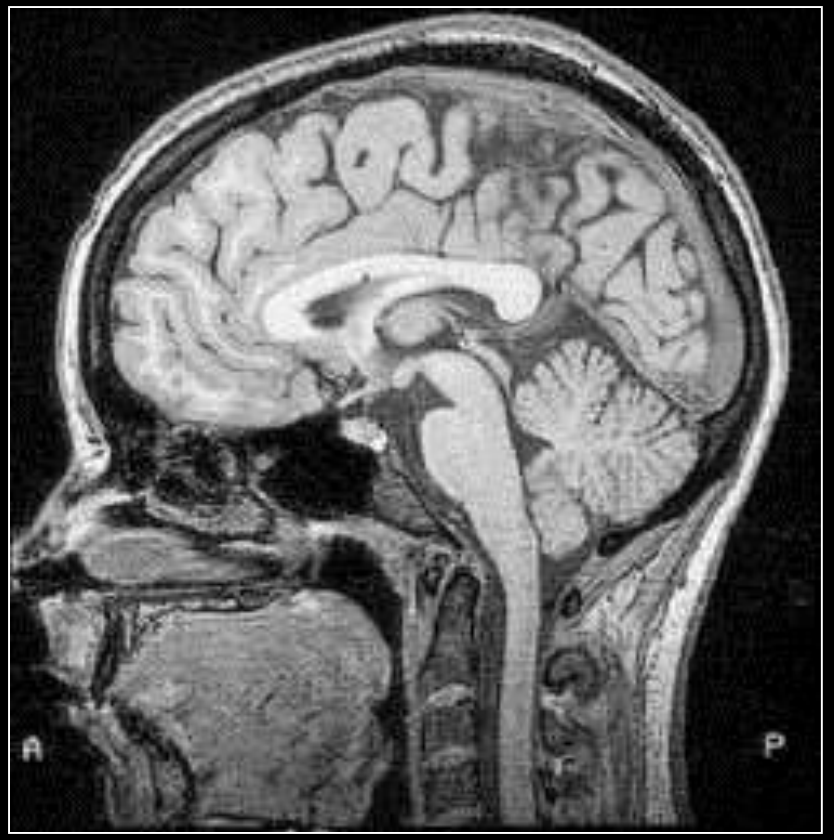
Result -Accelerated Image Acquisition

$C_1 = 0.85\ A + 0.35\ B$

$C_2 = 0.2\ A + 0.7\ B$



A and B



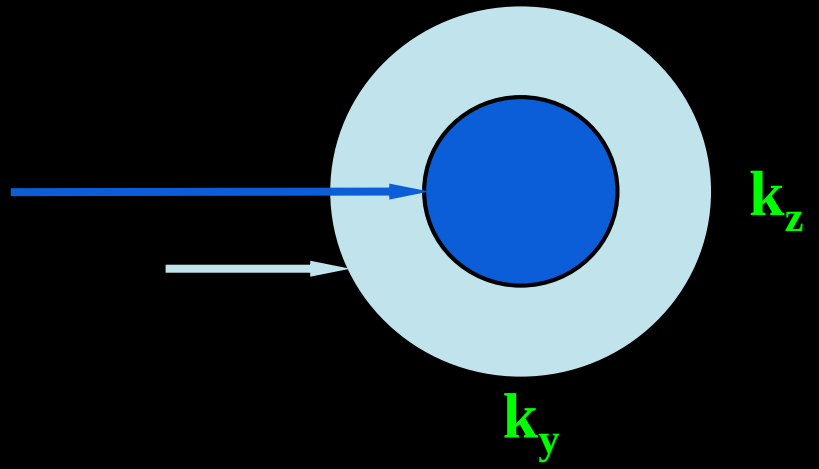
4D-TRAK (Philips)

4D Time-Resolved Angiography using Keyhole

- **Purpose**
  - Dynamic, high-resolution 4D CE-MRA
- **Combination the speed of**
  - SENSE (parallel imaging with SENSitivity Encoding) ,
  - CENTRA (Contrast-ENhanced Timing Robust Angiography),
  - Keyhole
  - halfscan

Contrast-ENhanced Timing Robust Angiography

- Divide k-space in 2 segments:
  - arterial window
  - arterial + venous window
- Benefits:
  - ✓ Optimal venous suppression → longer scan times possible resulting in:
    - Higher resolution
    - High SNR



Contrast-ENhanced Timing Robust Angiography

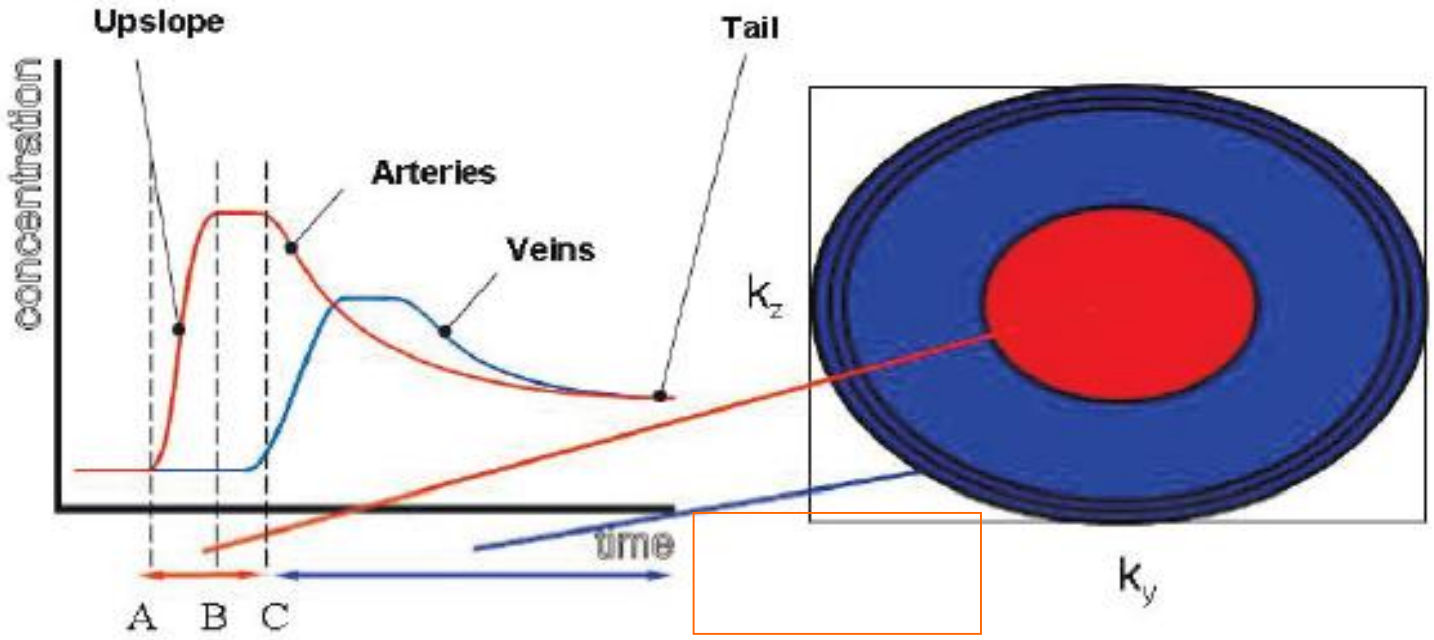


圖.4 Ky與Kz的填寫方法分為內圈與外圈，以橢圓體為中心向外依序填出，不再依賴bolus到達最大濃度，只要到達upslope上昇段即開始取像(A點)控制可以自動化，在C之

Elliptical centric ordering

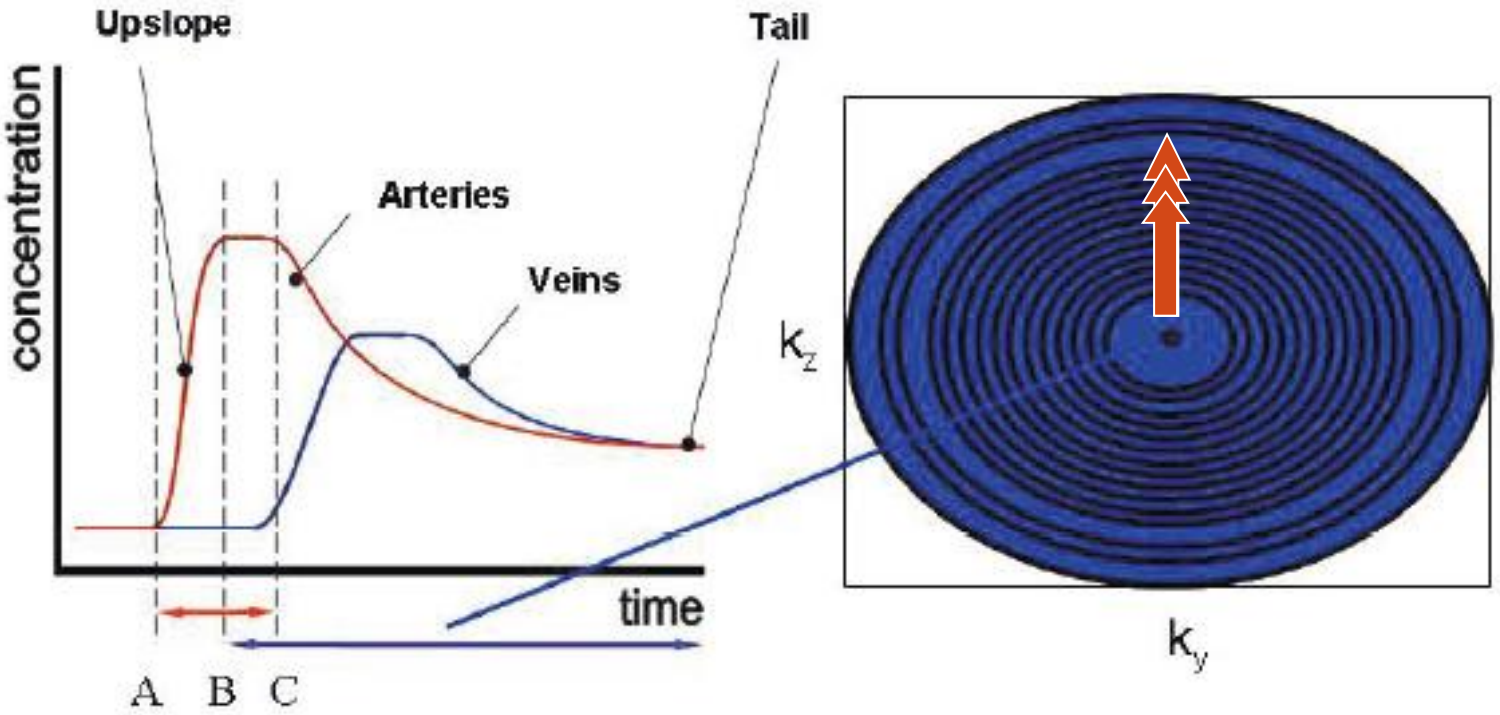
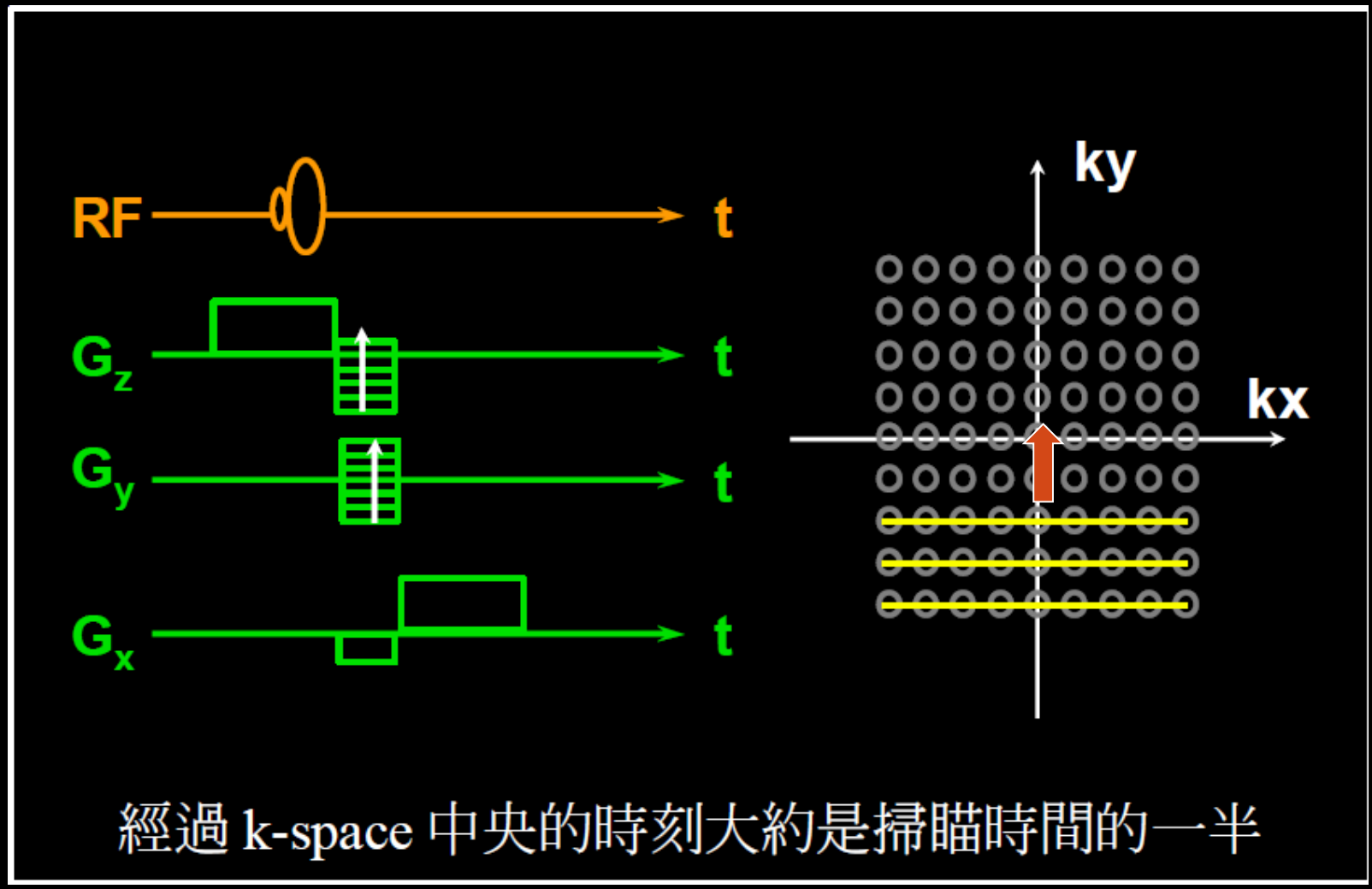


圖.3 Ky與Kz的填寫方法以橢圓體為中心向外依序填出，bolus dealy到A-B段的控制可以自動化，但只在B之後(藍色段)的訊號開始填k空間

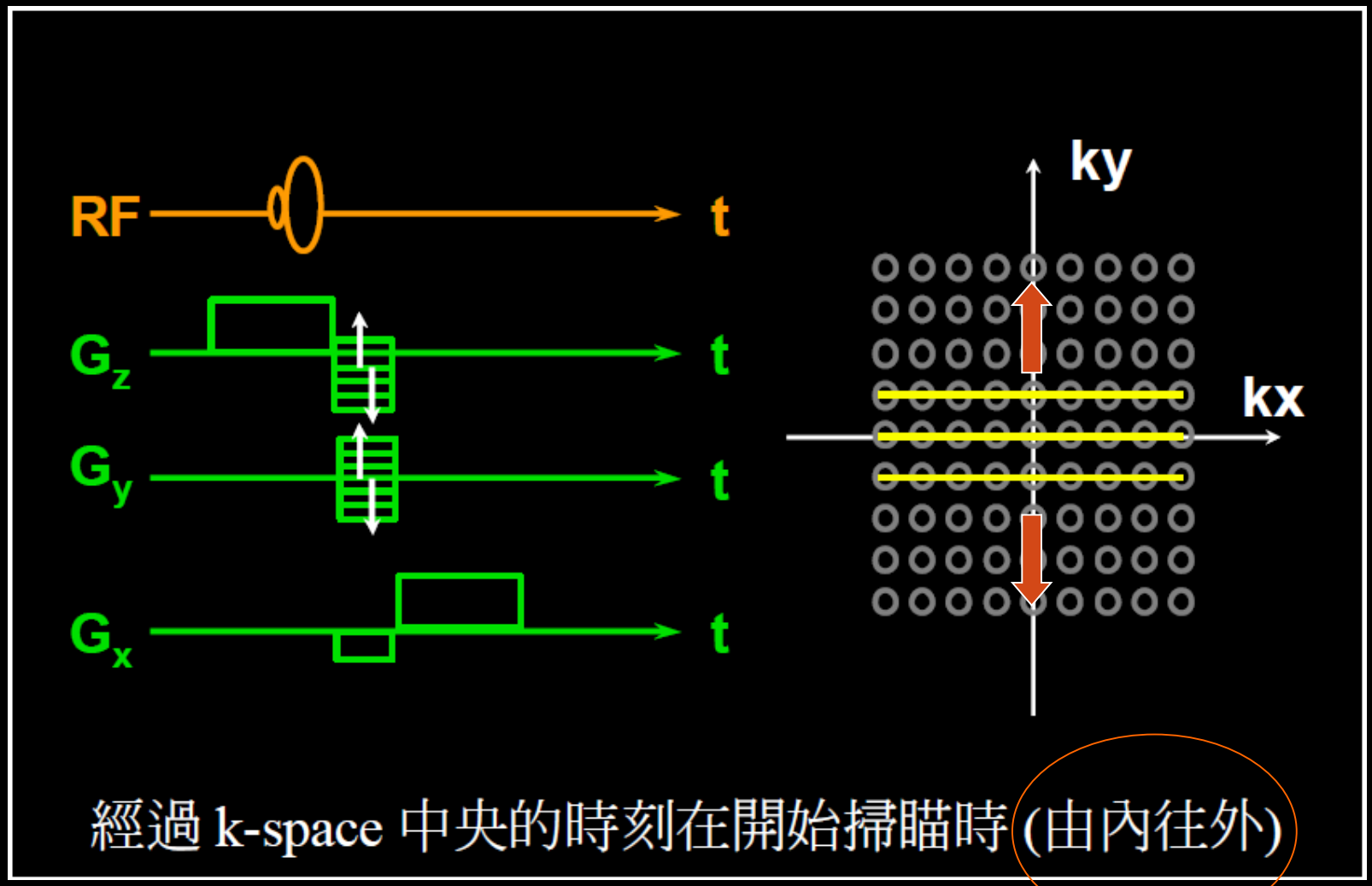
Sequential view order

(Fixed timing, Test bolus timing)



經過 k-space 中央的時刻大約是掃瞄時間的一半

Elliptical centric view order (Real time imaging)

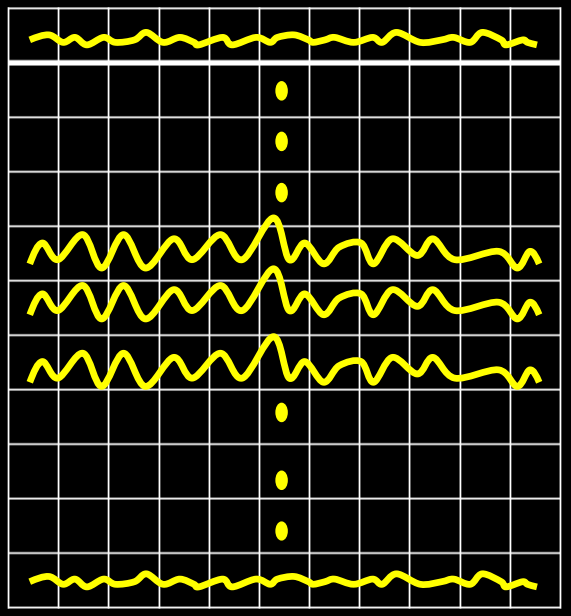


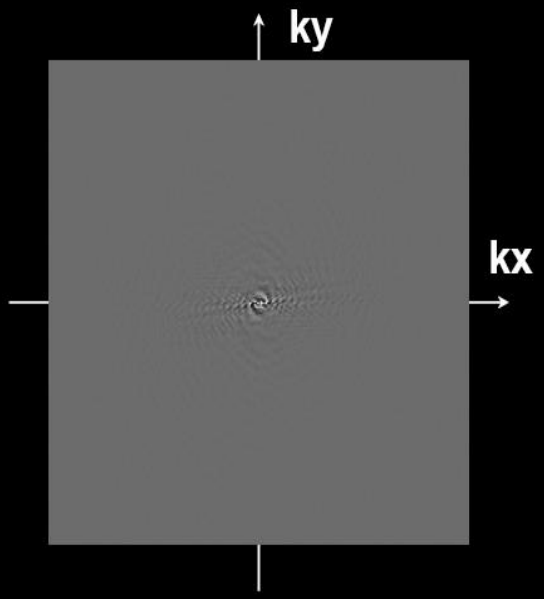
4D-TRAK (Philips)

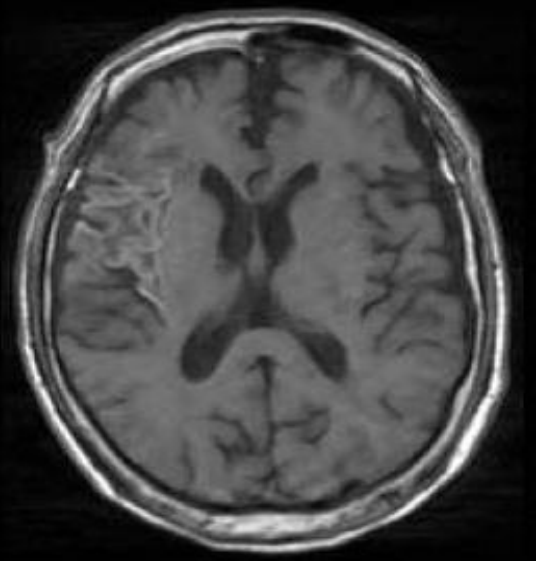
4D Time-Resolved Angiography using Keyhole

- **Purpose**
  - Dynamic, high-resolution 4D CE-MRA
- **Combination the speed of**
  - SENSE (parallel imaging with SENSitivity Encoding) ,
  - CENTRA (Contrast-ENhanced Timing Robust Angiography),
  - Keyhole
  - halfscan

K space





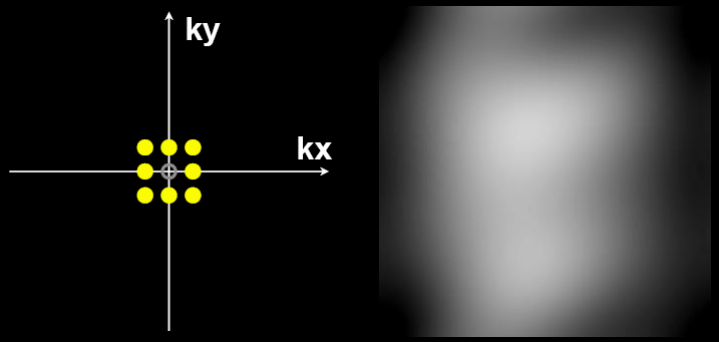


MR sampling → **K space** → **MR image**

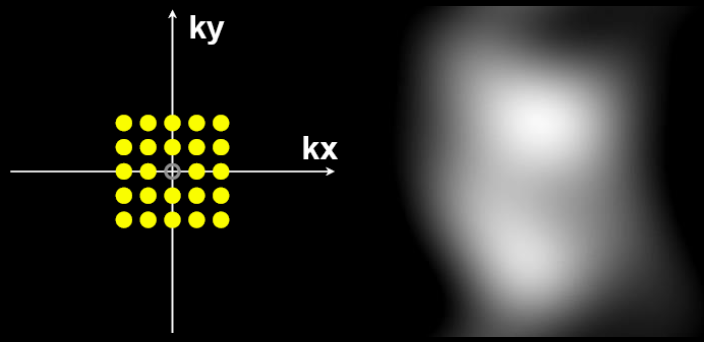
(Analogic signal) (Digital signal) (Digital image)

ADC 2D FT

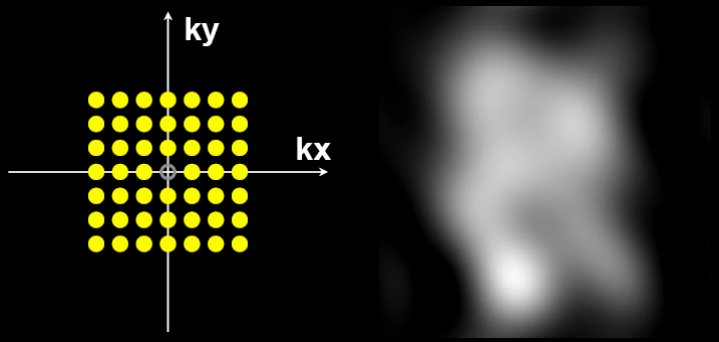
K space



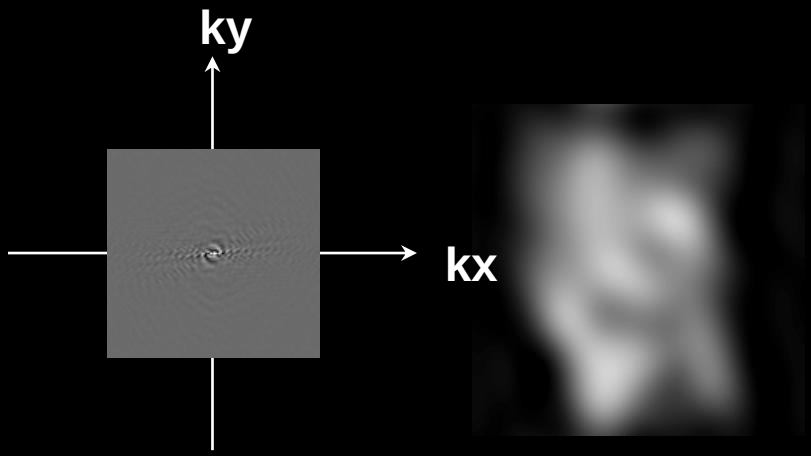
(a) k ≦1



(b) k ≦2

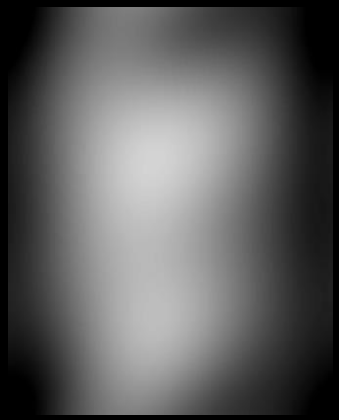


(c) k ≦3

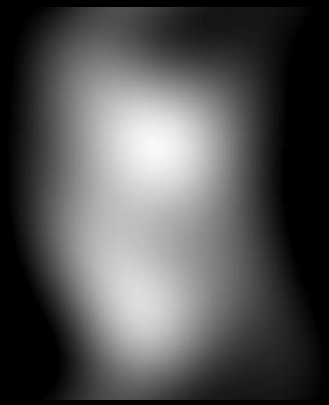


(d) k ≦4

K space

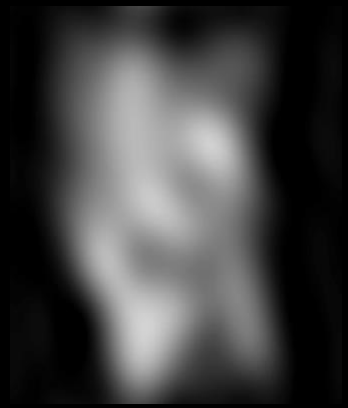


(a) k ≦1



(b) k ≦2

(c) k ≦3



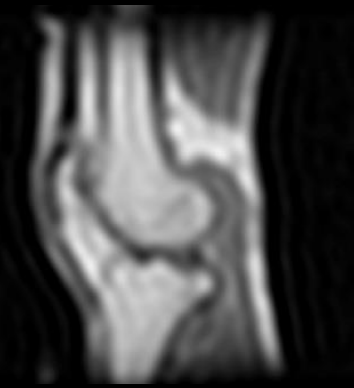
(d) k ≦4

(e) k ≦5

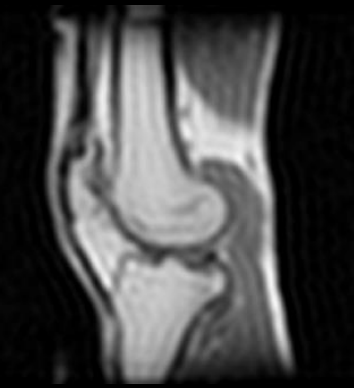
(f) k ≦6

(g) k ≦8

(h) k ≦12

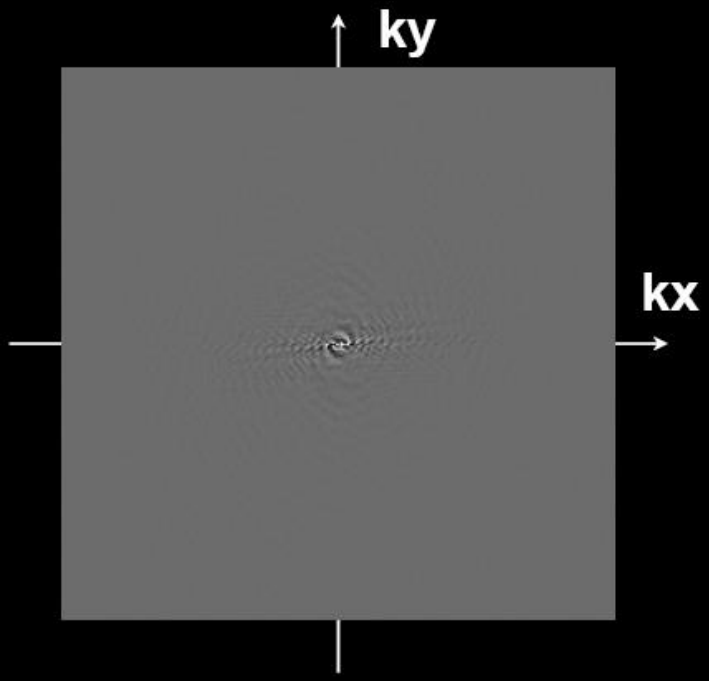


(i) k ≦16



(j) k ≦24

K space



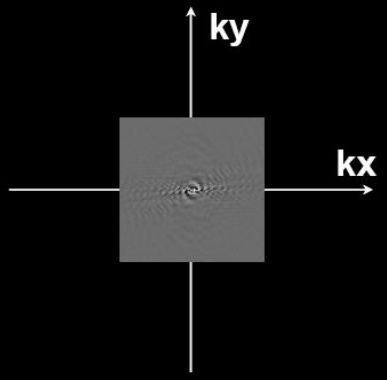
(n) k ≦128

More K number that

1. Resolution will be better

2. Scanning time increases

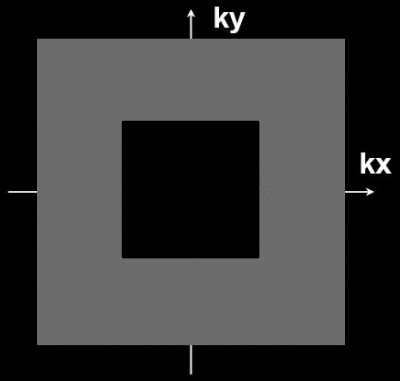
K space

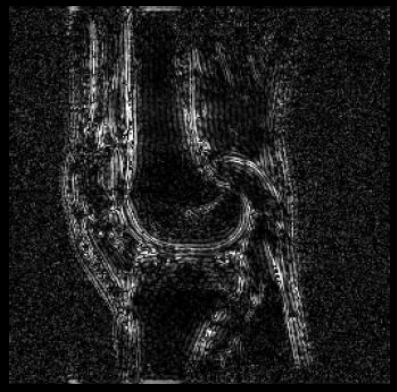


The center of k space

⇨ **SNR and Contrast**

(a) The central 64×64 points of k space



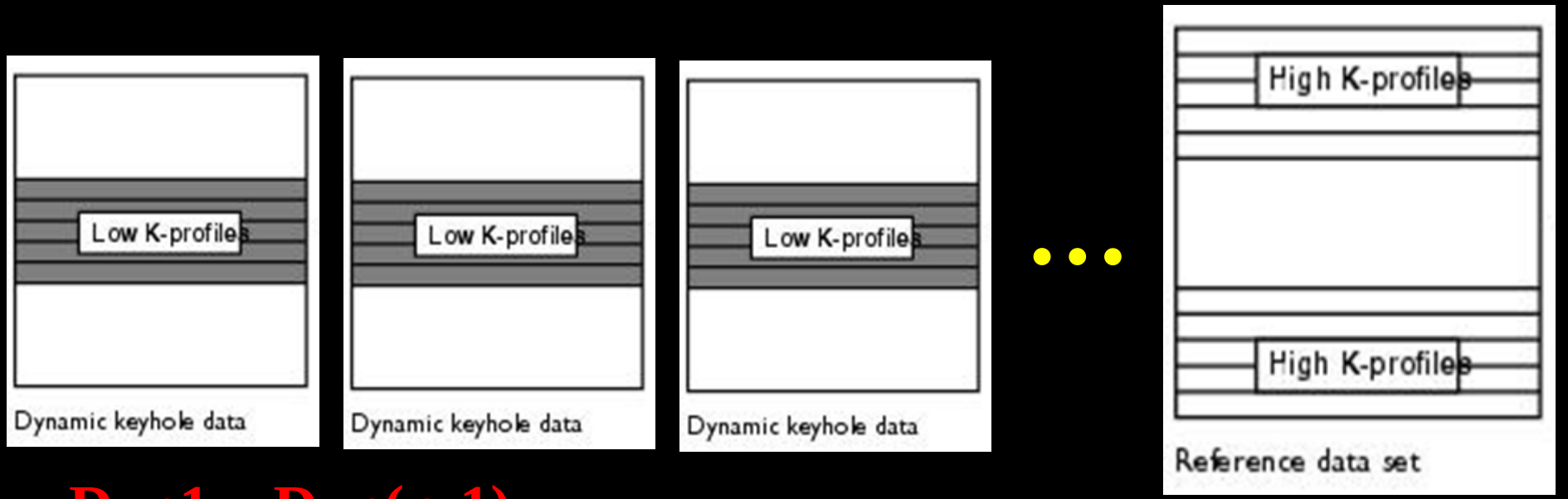


The periphery of k space

⇨ **Resolution**

(b) The central 64×64 points of k space

4D-TRAK (Keyhole)

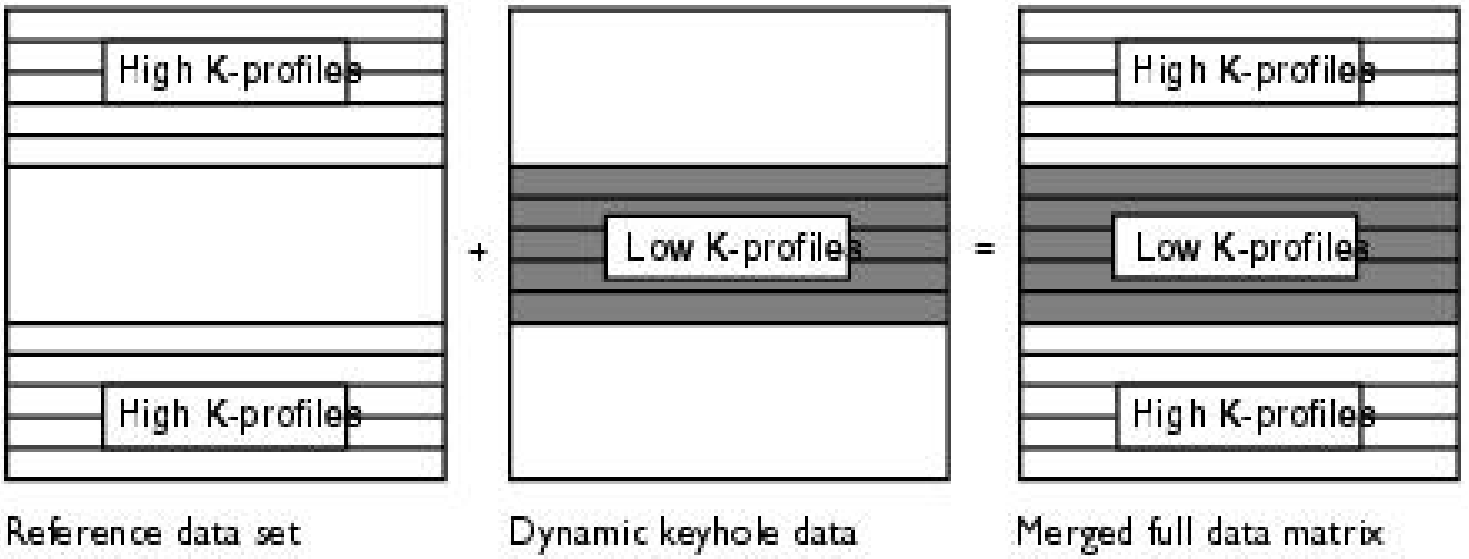


Dyn1 ~ Dyn(n-1)
The center of k space

Nth (Last scanning)
The periphery of k space

Keyhole : copying k-space information from reference scan to other dynamics.

Keyhole

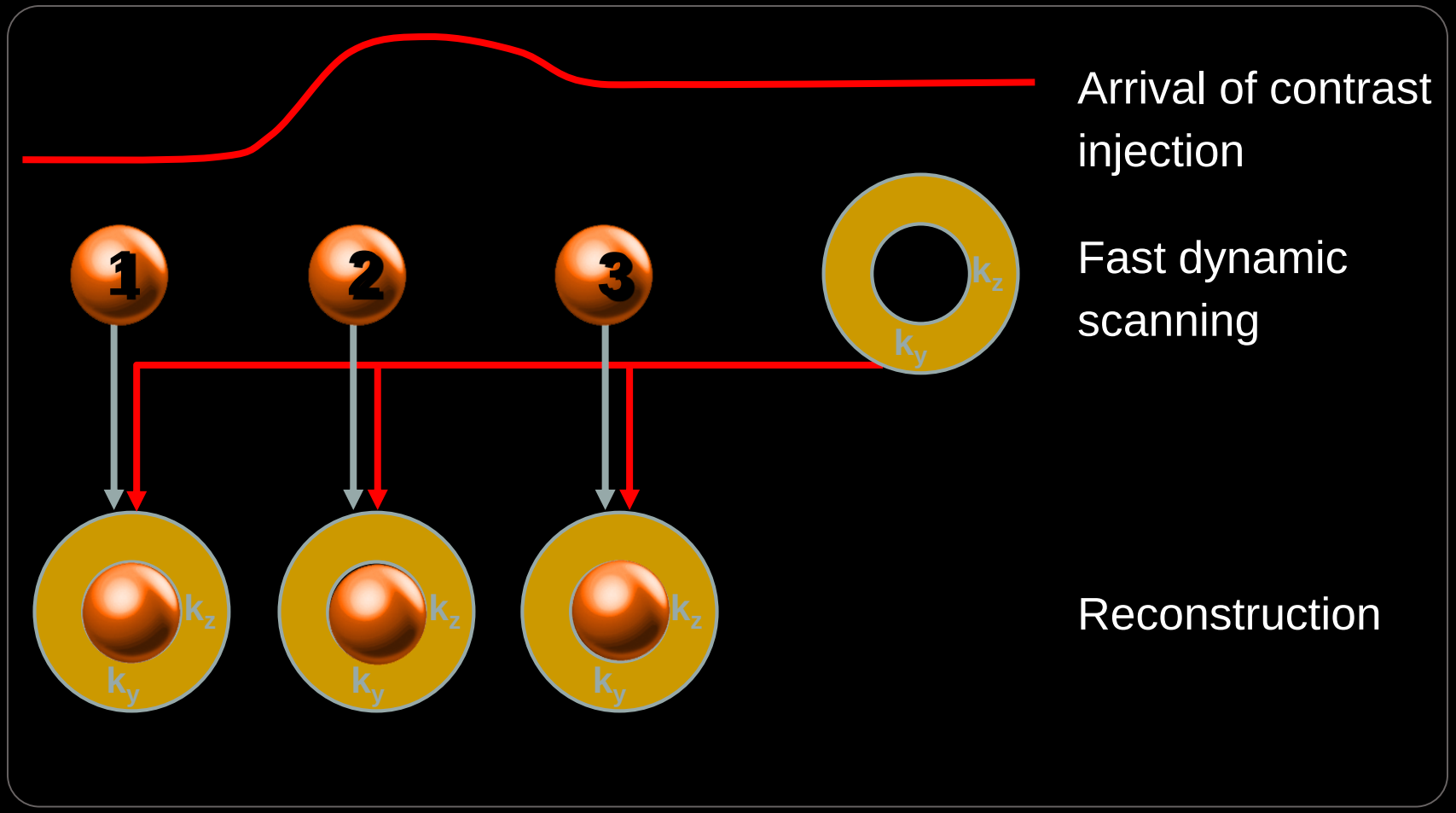


4D-TRAK using keyhole acquisition and reconstruction.

The last dynamic is fully sampled and the peripheral part of the k-space is used to reconstruct the contrast-enhanced timing-robust angiography (CENTRA) keyhole dynamics.

Keyhole

Time-Resolved Angiography using Keyhole



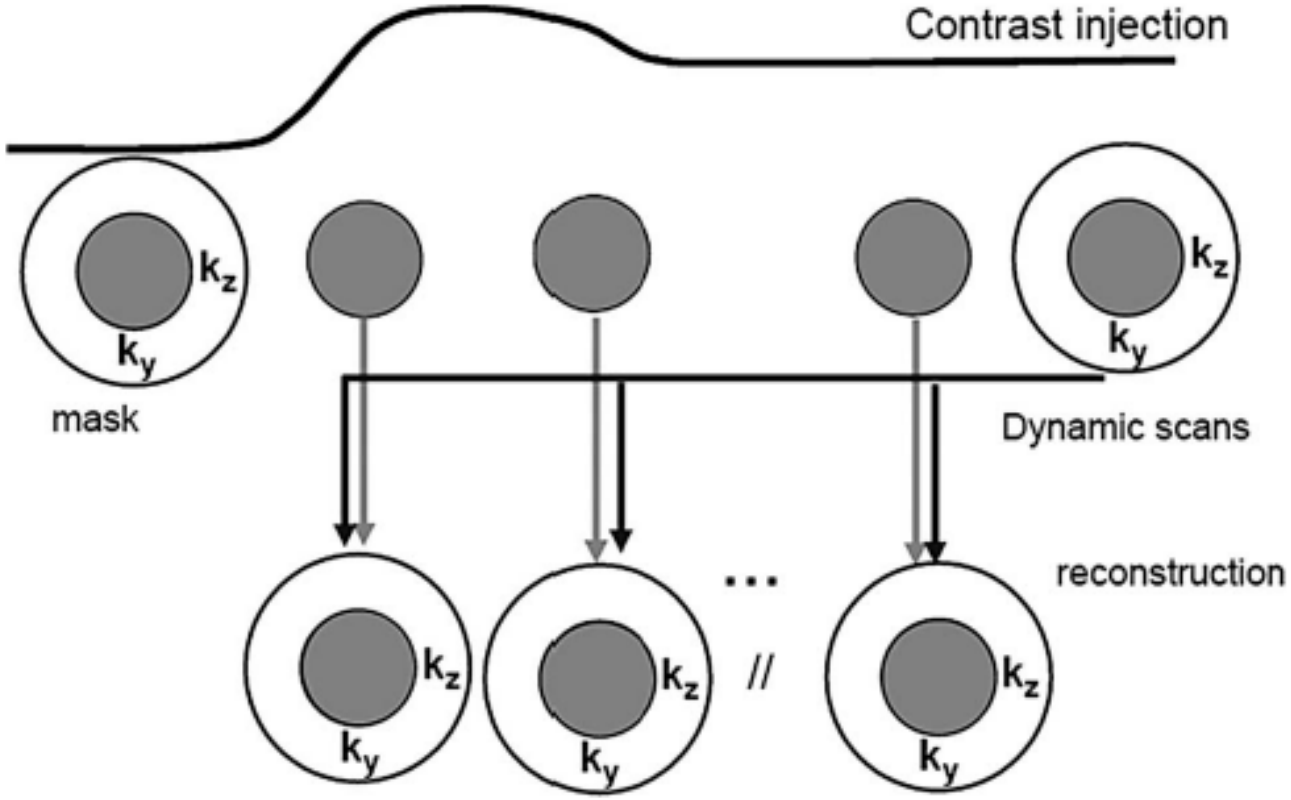
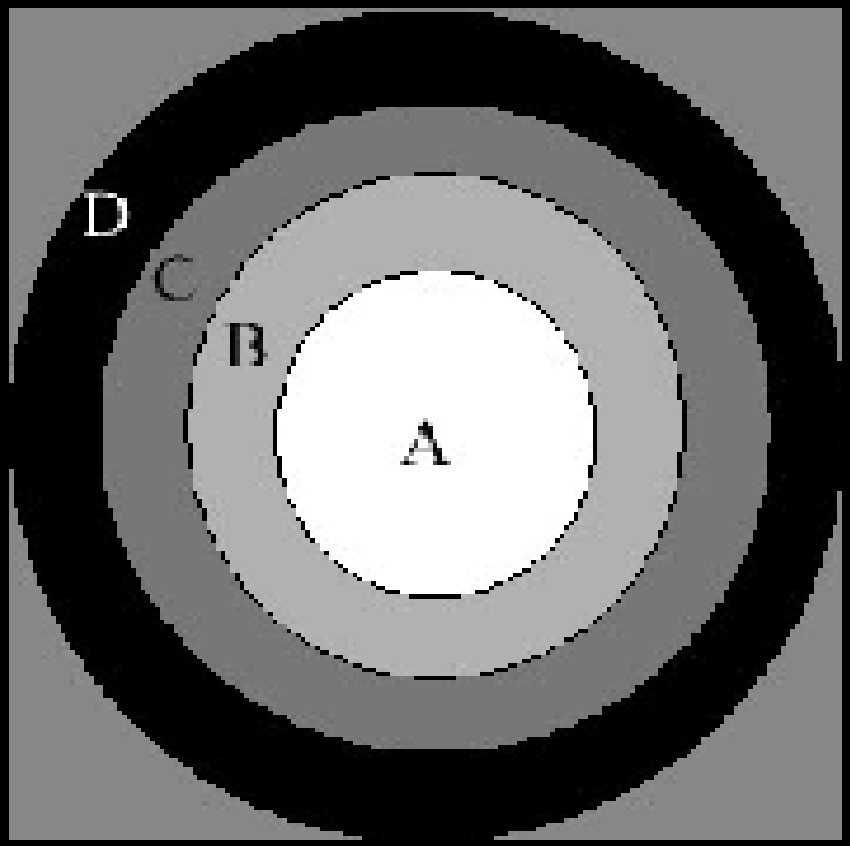
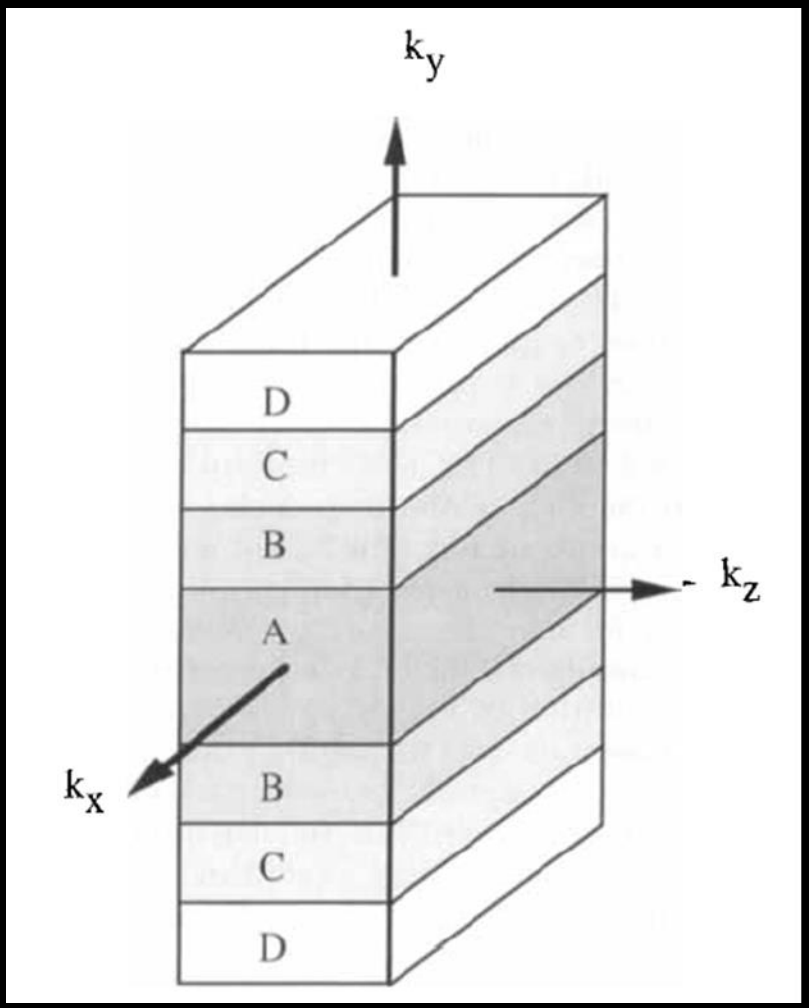


FIG. 1. Schematic representation of four-dimensional time-resolved angiography using keyhole acquisition (4D-TRAK) and reconstruction. The last dynamic is fully sampled and the peripheral part of the k-space is used to reconstruct the contrast-enhanced timing-robust angiography (CENTRA) keyhole dynamics. A precontrast fully sampled mask can be used for post-processing subtractions.

Acquisition Order

Order : ABACAD……





Acquisition Order

ABCD ABACADABACAD..

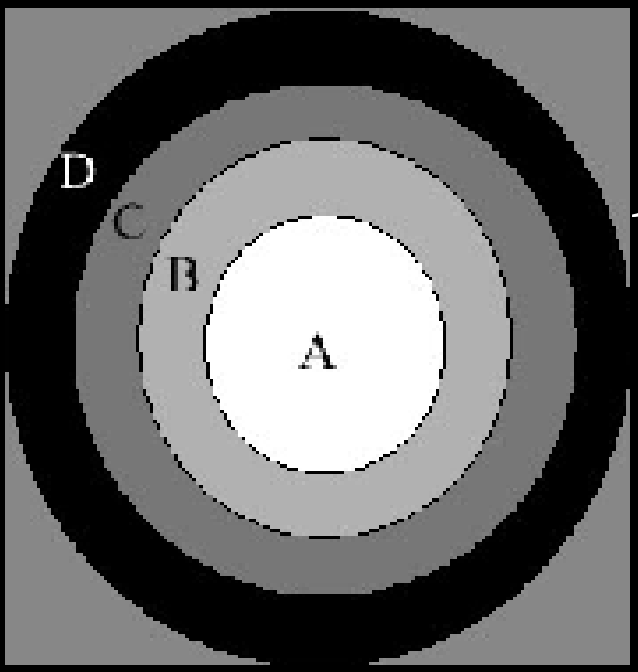
4T

Prior to the contrast injection, k-space is fully sampled.

Posterior to the contrast injection

ABCD ABACADABACAD..

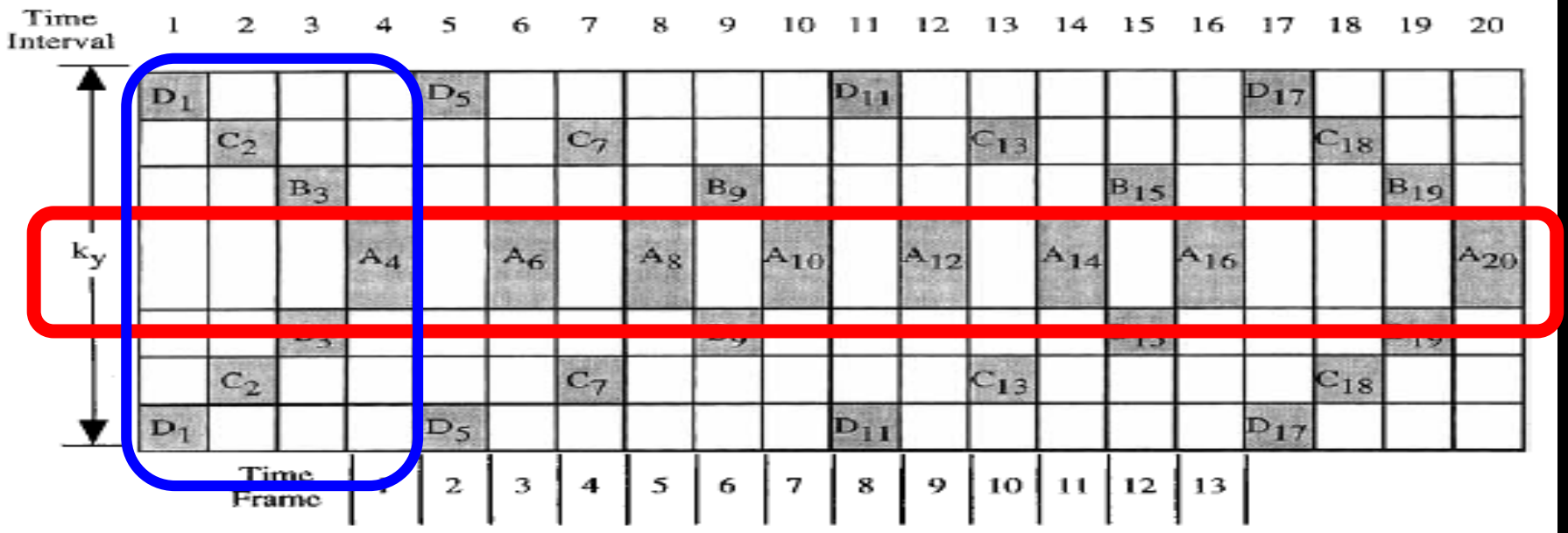
2T



ABCD ABACADABACAD..

6T

Acquisition MRM 36:345-351 (1996)



Reconstruction

(Selected Frames)

Time Frame 5	Time Frame 8	Time Frame 11
$I(D_5,D_{11})$	D_{11}	$I(D_{11},D_{17})$
$I(C_7,C_{13})$	$I(C_7,C_{13})$	$I(C_{13},C_{18})$
$I(B_3,B_9)$	$I(B_9,B_{15})$	$I(B_9,B_{15})$
A_8	$I(A_{10},A_{12})$	A_{14}
$I(B_3,B_9)$	$I(B_9,B_{15})$	$I(B_9,B_{15})$
$I(C_7,C_{13})$	$I(C_7,C_{13})$	$I(C_{13},C_{18})$
$I(D_5,D_{11})$	D_{11}	$I(D_{11},D_{17})$

4D-TRAK

Maximum acceleration

Speedup of keyhole 6
High speedup thanks to simple segmentation in k-space

Speedup of SENSE up to 8

Speedup of halfscan ~1.25

X

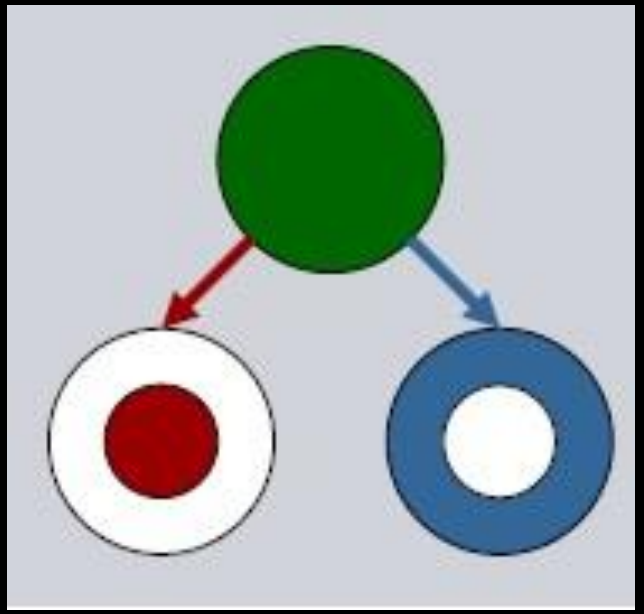
Maximum acceleration: up to 60x

TWIST (Siemens)

- **Time-resolved angiography With Interleaved Stochastic Trajectories**

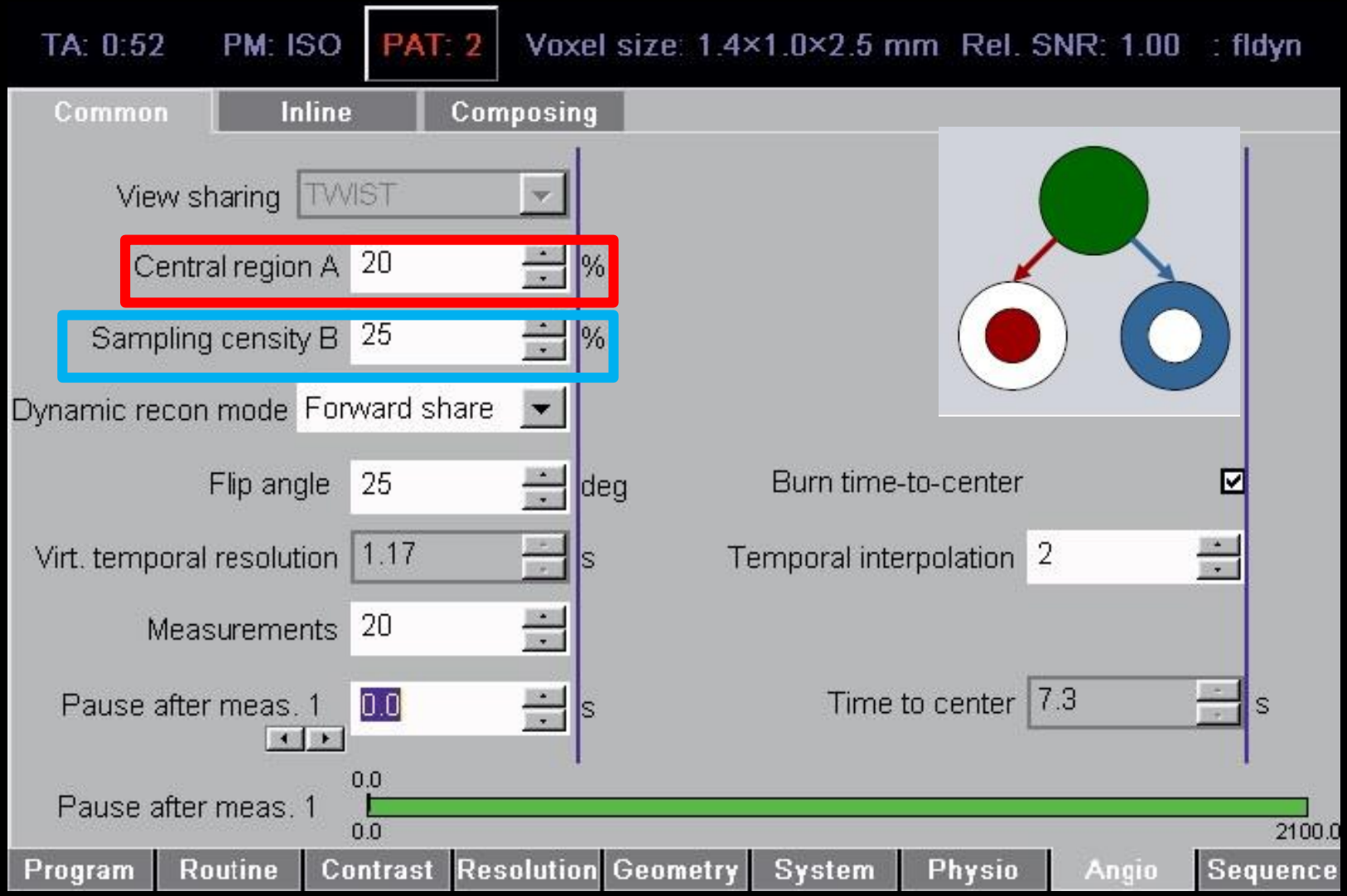
- **Faster Scanning Options:**
- **Short TR**
- **Partial Fourier**
- **Reduction in spatial resolution**
  In-plane resolution
  Slice resolution
- **Parallel imaging (PAT²)**

TWIST



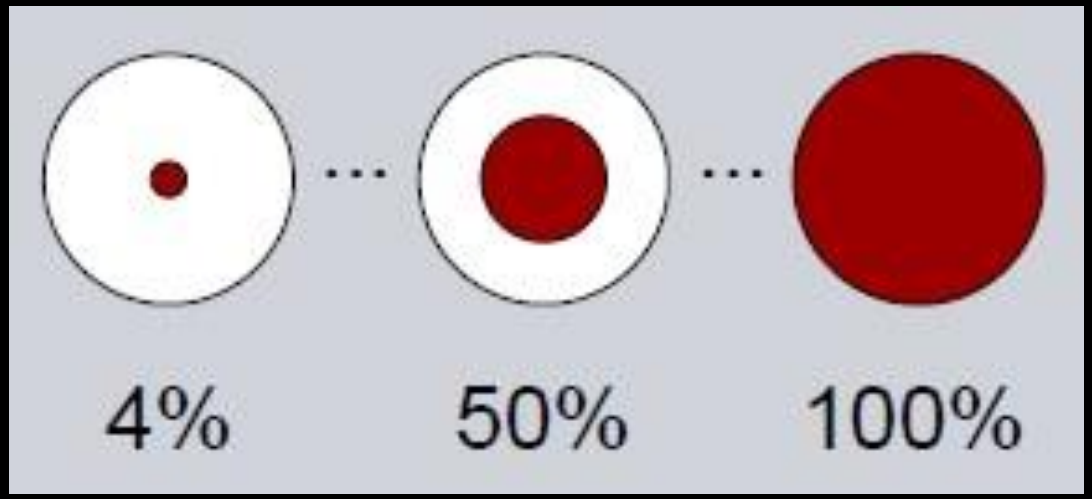
- **Sub-divide k-space into 2 regions:**
- a central region **A**
  (with main information about image contrast)
- a peripheral region **B**
  (with main information about spatial resolution)
- Scan **A** with a higher frequency than **B**, in order to achieve a higher temporal resolution

TWIST

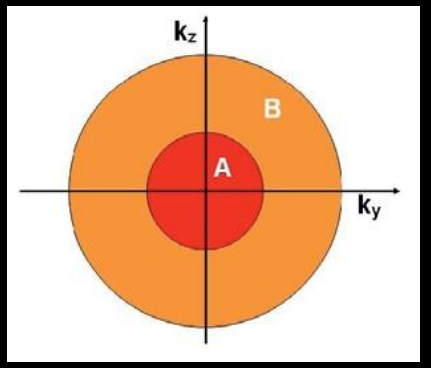

TA: 0:52
PM: ISO
PAT: 2
Voxel size: 1.4×1.0×2.5 mm
Rel. SNR: 1.00
: fldyn
Common
Inline
Composing
View sharing
TWIST
Central region A
20
%
Sampling censity B
25
%
Dynamic recon mode
Forward share
Flip angle
25
deg
Burn time-to-center
Virt. temporal resolution
1.17
s
Temporal interpolation
2
Measurements
20
Pause after meas. 1
0.0
s
Time to center
7.3
s
Pause after meas. 1
0.0
0.0
2100.0
Program
Routine
Contrast
Resolution
Geometry
System
Physio
Angio
Sequence

TWIST

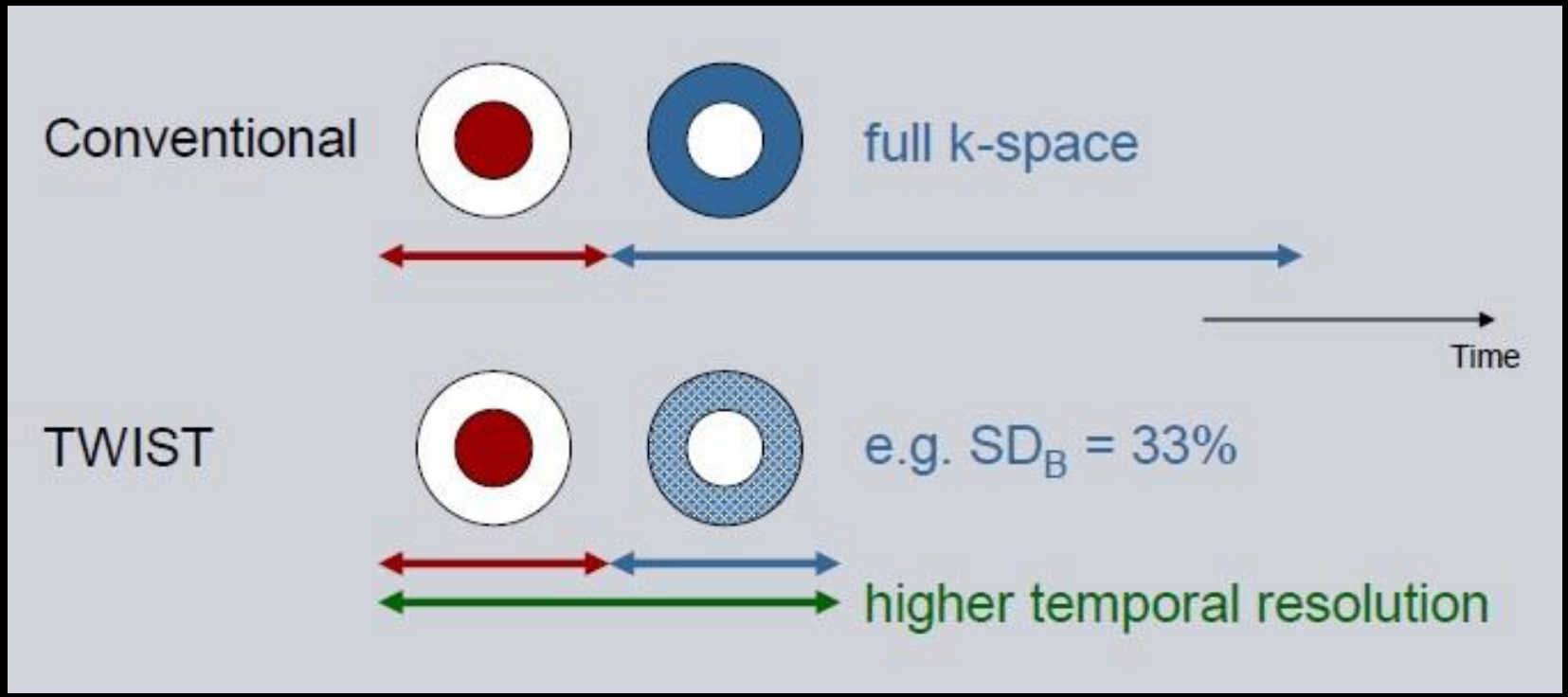
- Region **A** is the center of k-space, determining the **image contrast**
- The size of Region **A** can be flexibly chosen, between 4% and 100% of total k-space



TWIST



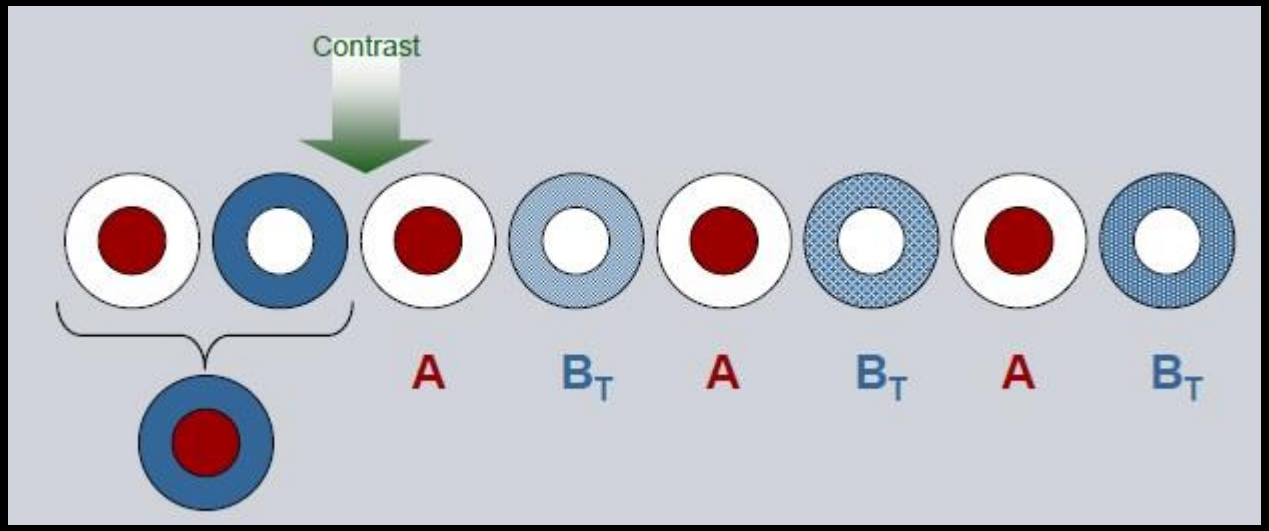
- The key is to use a **reduced sampling density** of **B** (= **SD$_B$**),

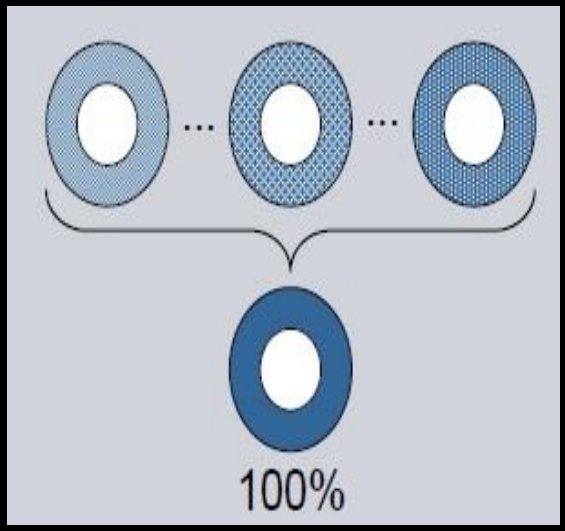


TWIST

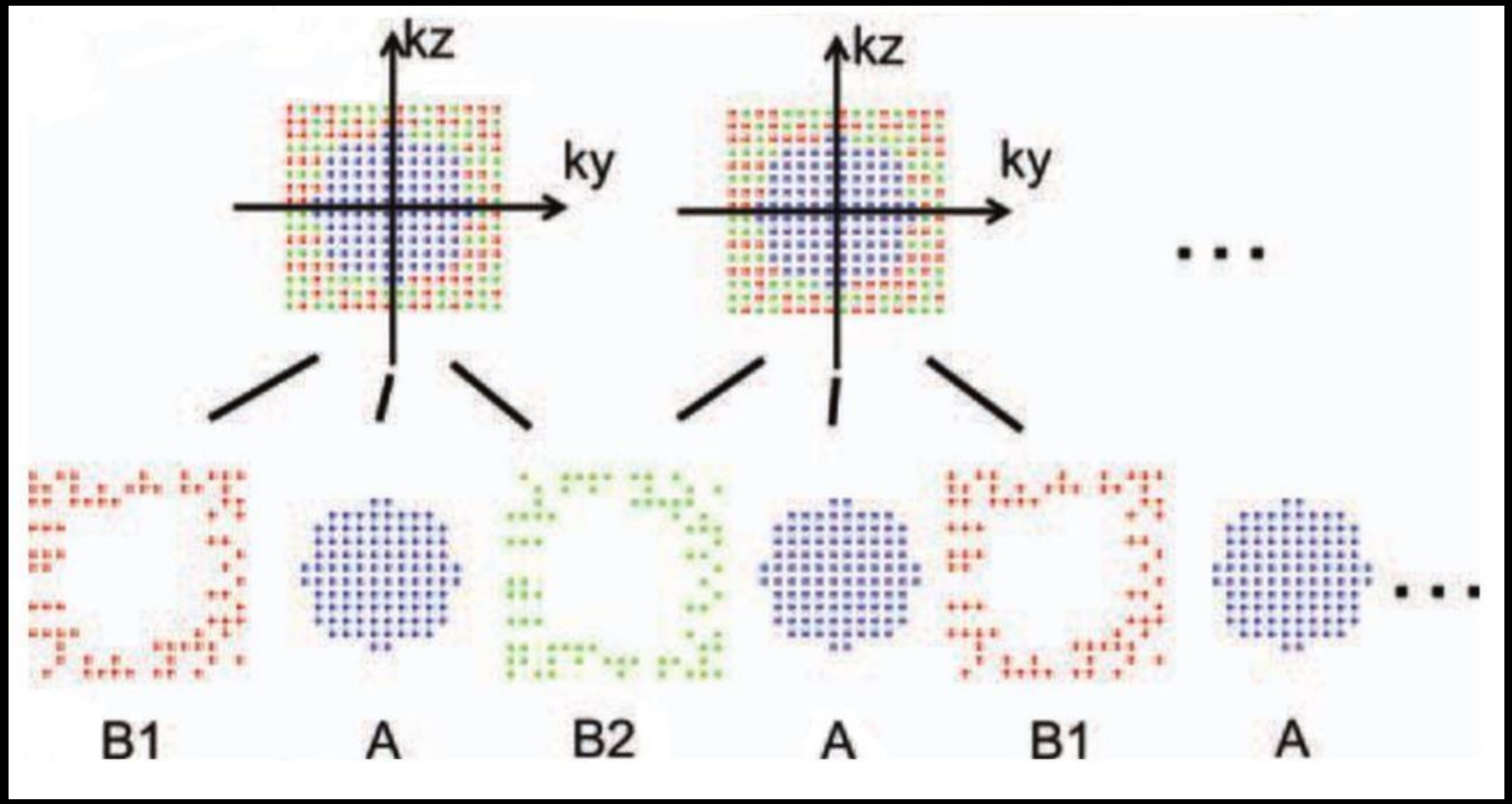
- Sub-divide k-space into 2 regions and scan them in the alternating scheme

  A B_T A B_T A B_T ...



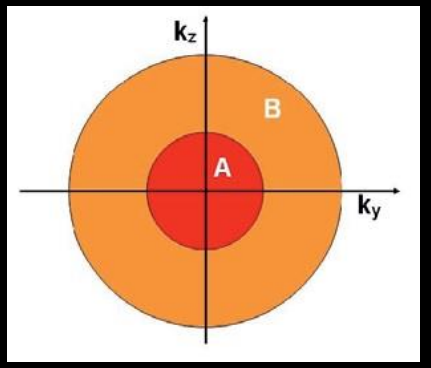


TWIST



- The diagram of TWIST k-space sampling strategy. In the dots show the ky kz plane of k-space, each dot represents onereadout line of k space data. Blue dots shows the center k space views that are acquired for each timepoint.

TWIST



- Higher (nominal) frame rate than conventional imaging: With the flexibility of
- Size of **A**
- Sampling Density of **B** the reconstructed temporal resolution can be set **flexibly**,

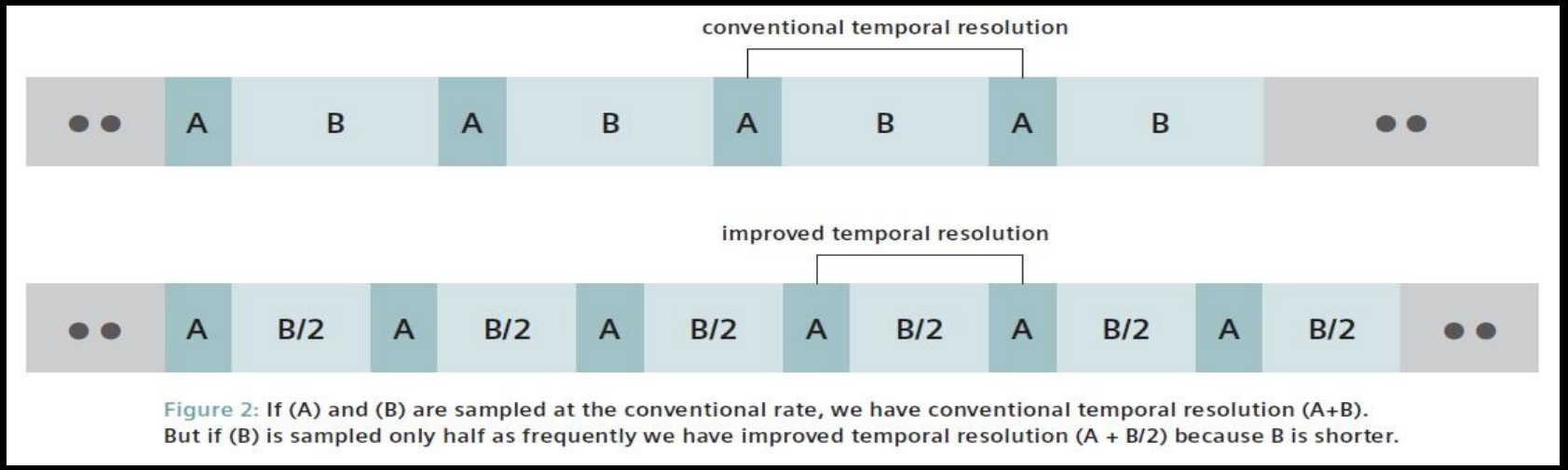
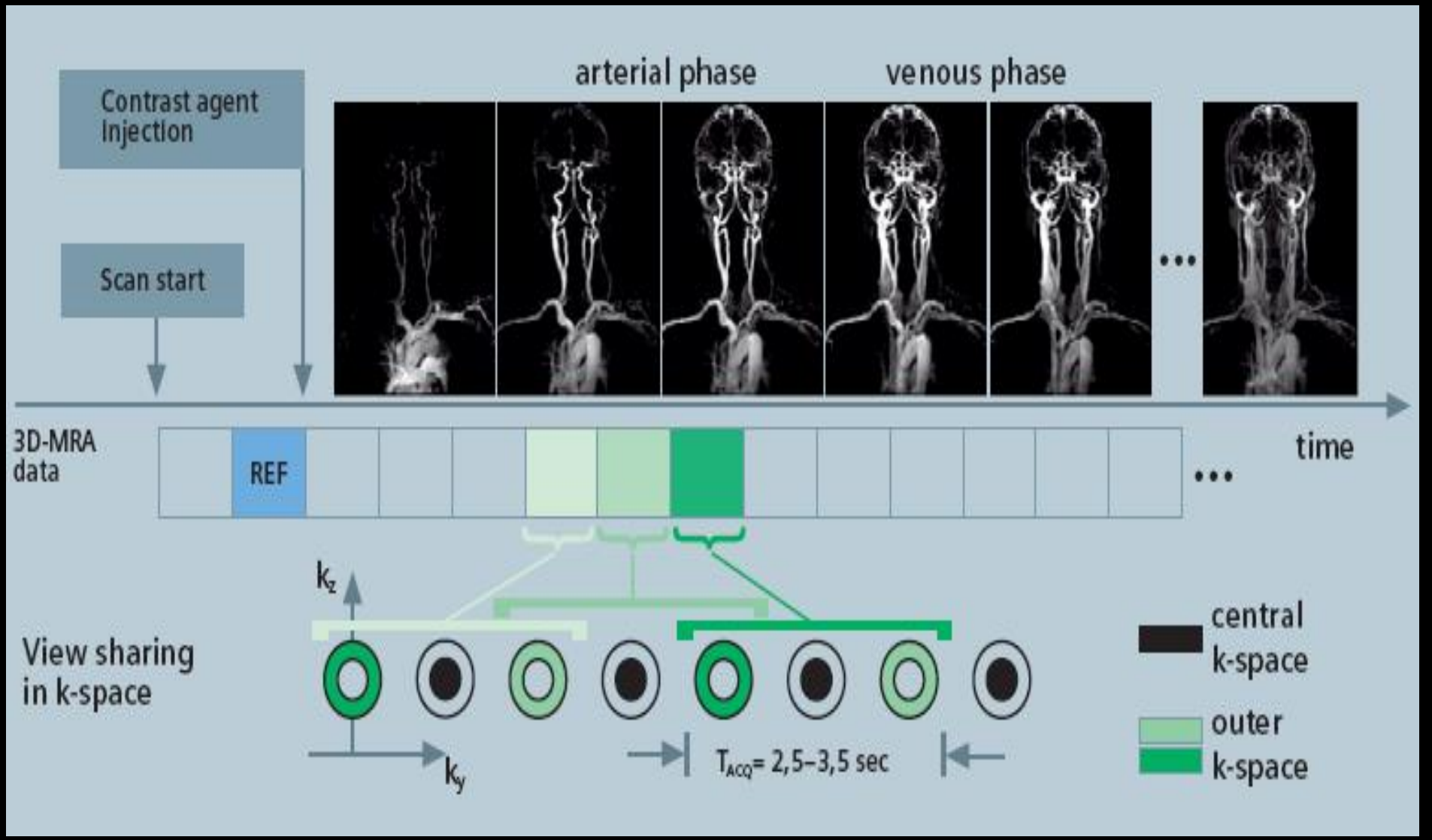


Figure 2: If (A) and (B) are sampled at the conventional rate, we have conventional temporal resolution (A+B). But if (B) is sampled only half as frequently we have improved temporal resolution (A + B/2) because B is shorter.

TWIST


Contrast agent injection
Scan start
arterial phase
venous phase
3D-MRA data
REF
time
View sharing in k-space
k_z
k_y
T_{ACQ}= 2,5–3,5 sec
central k-space
outer k-space

3D TOF

Image quality is good, but can not see.....

4D CEMRA

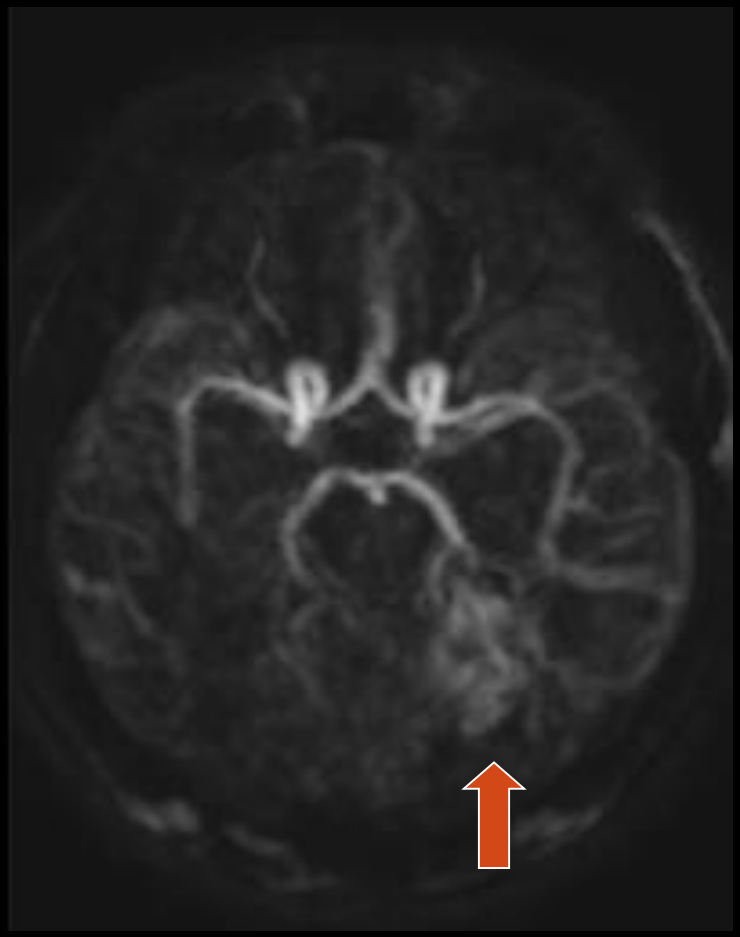
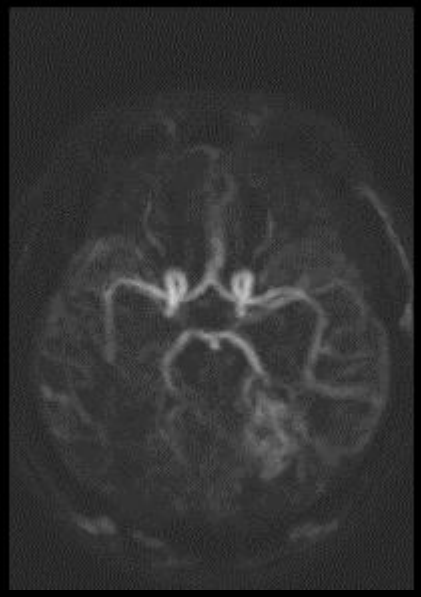
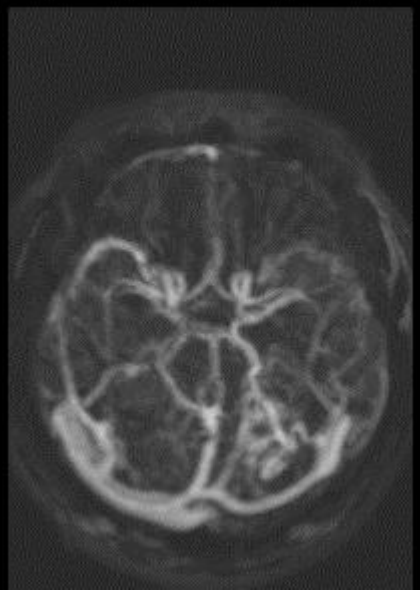
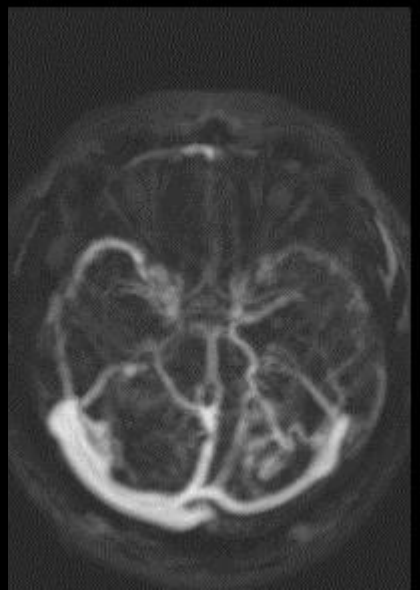


Image is poor, but can see





4D Time-Resolved MR Angiography With Keyhole (4D-TRAK): More Than 60 Times Accelerated MRA Using a Combination of CENTRA, Keyhole, and SENSE at 3.0T

Winfried A. Willinek, MD,[1*] Dariusch R. Hadizadeh, MD,[1] Marcus von Falkenhausen, MD,[1] Horst Urbach, MD,[1] R. Hoogeveen, MD, PhD,[2] Hans H. Schild, MD,[1] and Jürgen Gieseke, PhD[1,2]

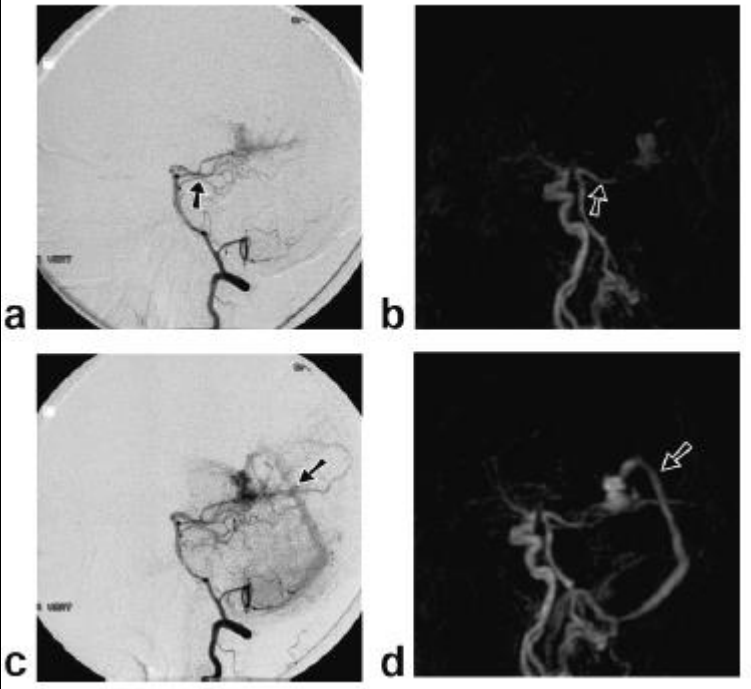


Table 1
Spatial and Temporal Resolution of 4D Time-Resolved MRA With Keyhole, CENTRA, and SENSE

Study	*n*	FS	Spatial Resolution	T
4D-TRAK	5	3.0T	(1.1 x 1.4 x 1.1) mm^3	0.608 s

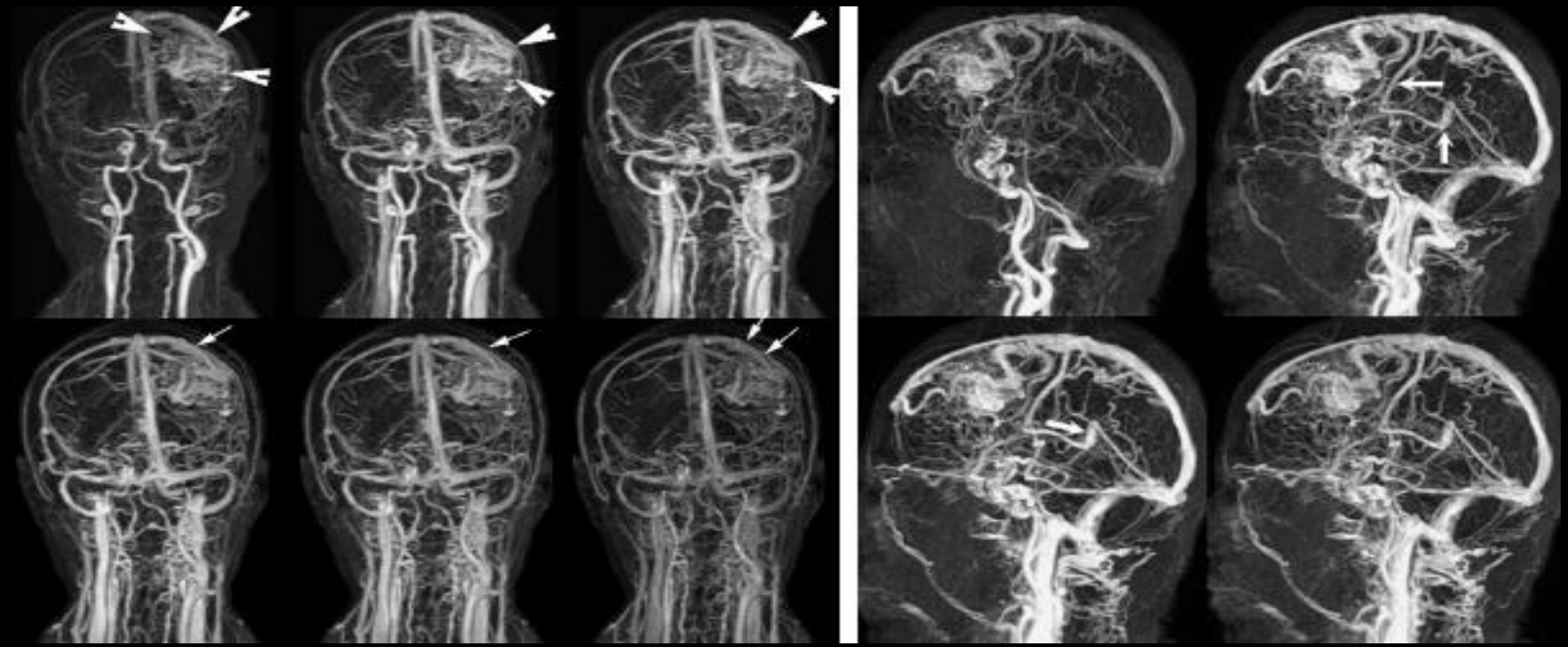
n = number of individuals examined in the study; FS = field strength of magnet used for imaging; t = temporal resolution as time needed for each dynamic scan.

MR Imaging

Contrast-enhanced MR angiography was performed on a 32-channel 3.0T Achieva system (Philips Medical Systems, Best, The Netherlands) equipped with a commercially available eight-channel SENSE capable head coil. The gradient system of the MR unit allows a maximal achievable gradient amplitude of 80 mT/m with a rise time of 0.2 msec and a slew rate of 200 T/m/s.

Dynamic MRA With Four-Dimensional Time-Resolved Angiography Using Keyhole at 3 Tesla in Head and Neck Vascular Lesions

Hemant Parmar, MD, Marko K. Ivancevic, PhD, Nancy Dudek, BS, Dheeraj Gandhi, MD, and Suresh K. Mukherji, MD



Vascular malformation

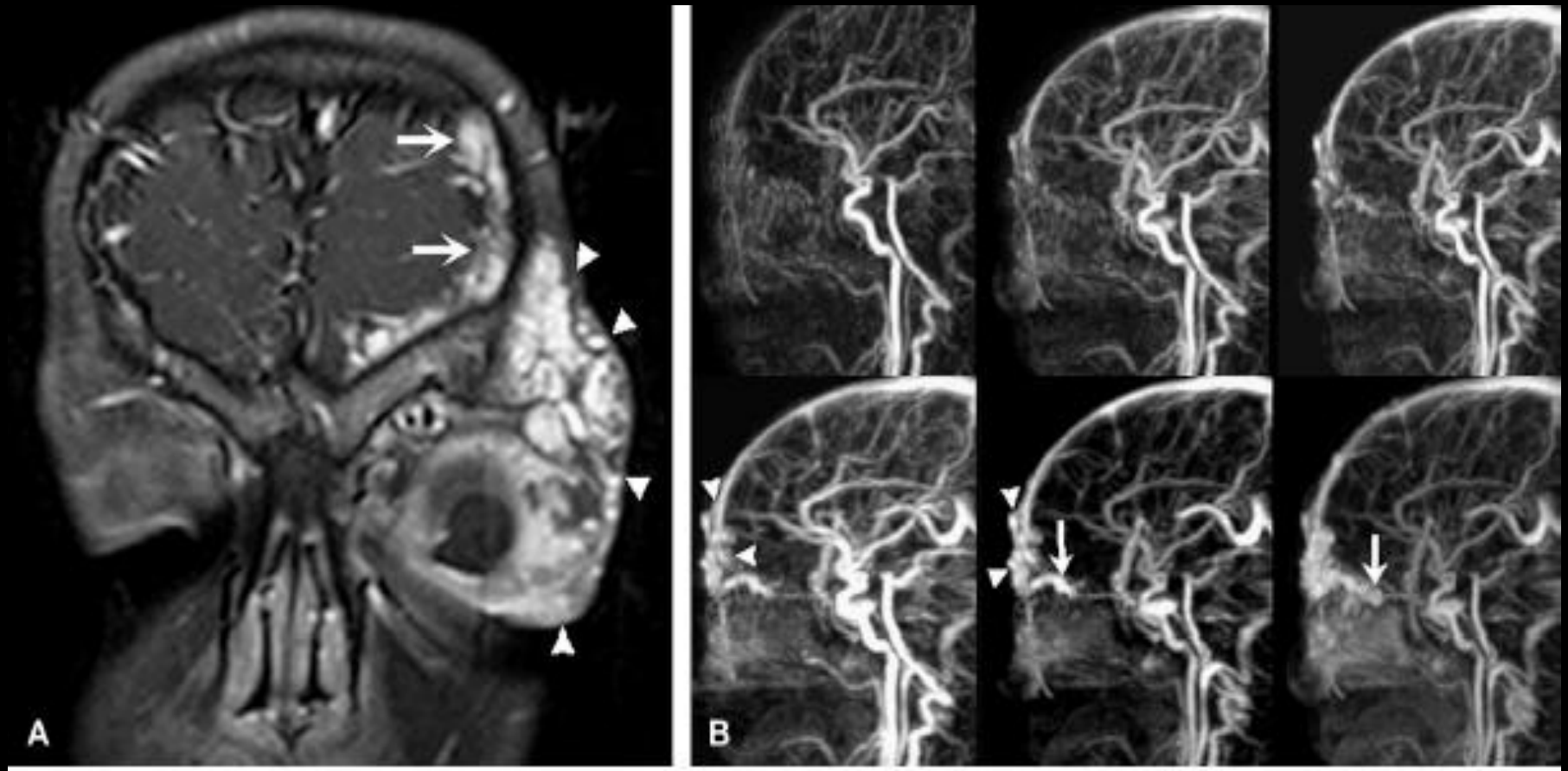
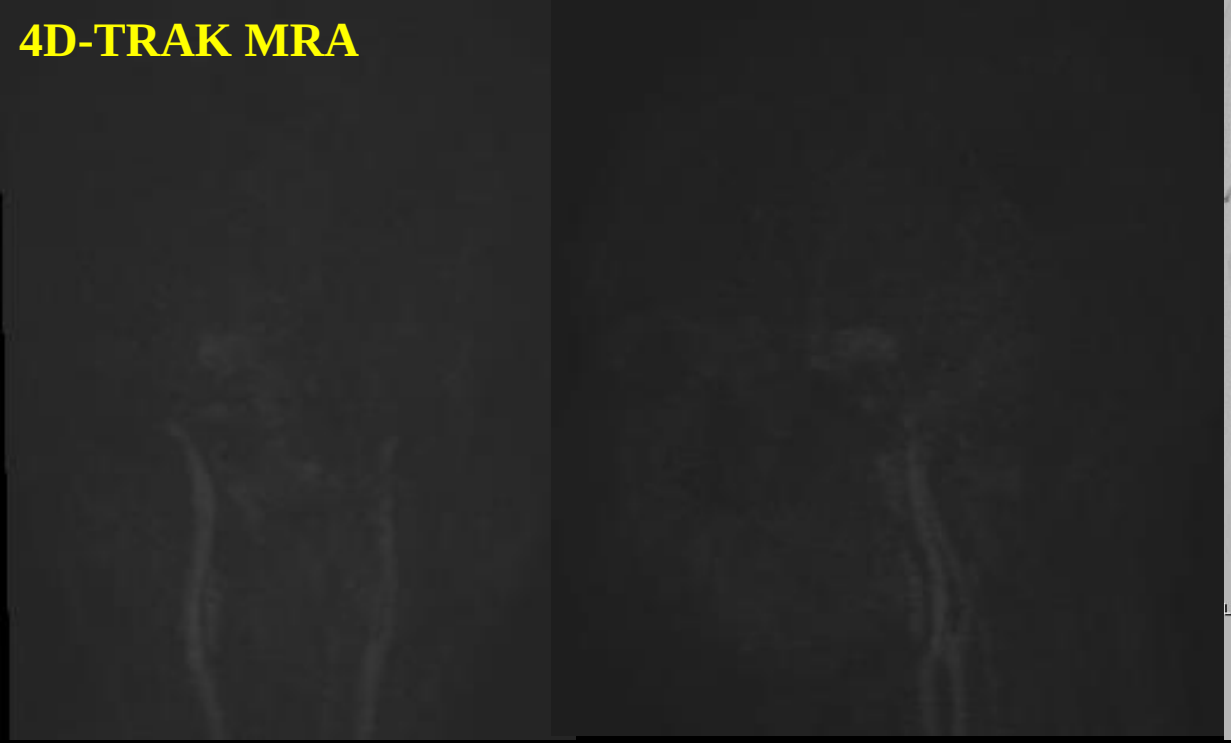
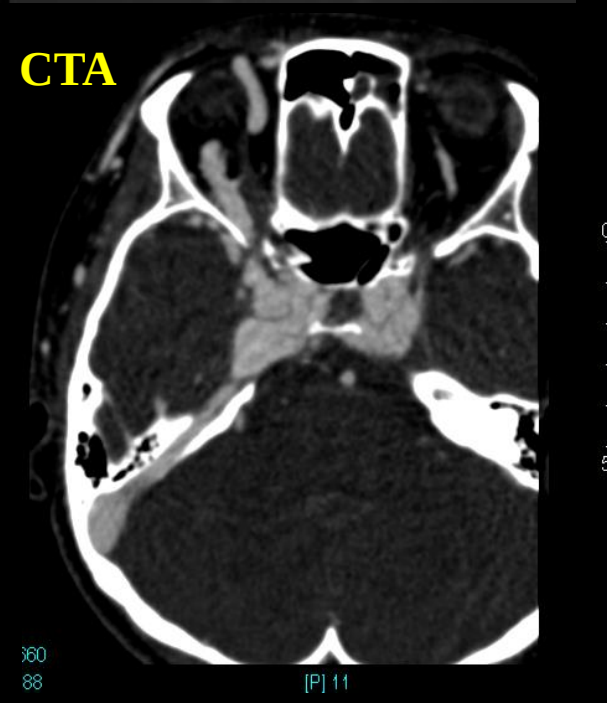


FIG. 8. Four-dimensional time-resolved angiography using keyhole (4D-TRAK) of an orbital venolymphatic malformation. **A.** Postcontrast T1 coronal MRI shows a mass (*arrowheads*) with a small intracranial component (*arrows*). **B.** Sagittal MIP images show it as a large vascular malformation (*arrowheads*) with a small apical varix (*arrows*).

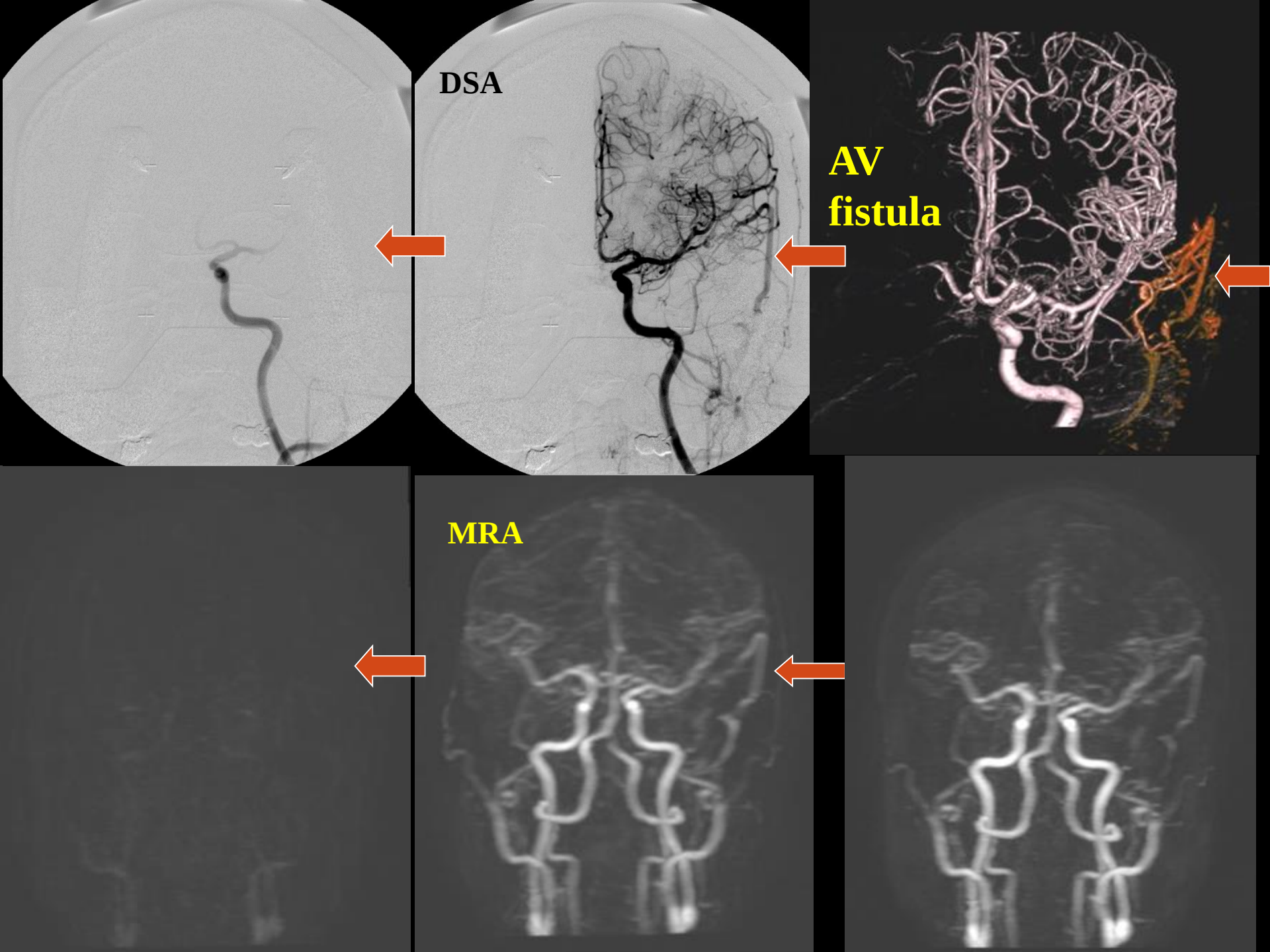
4D-TRAK MRA

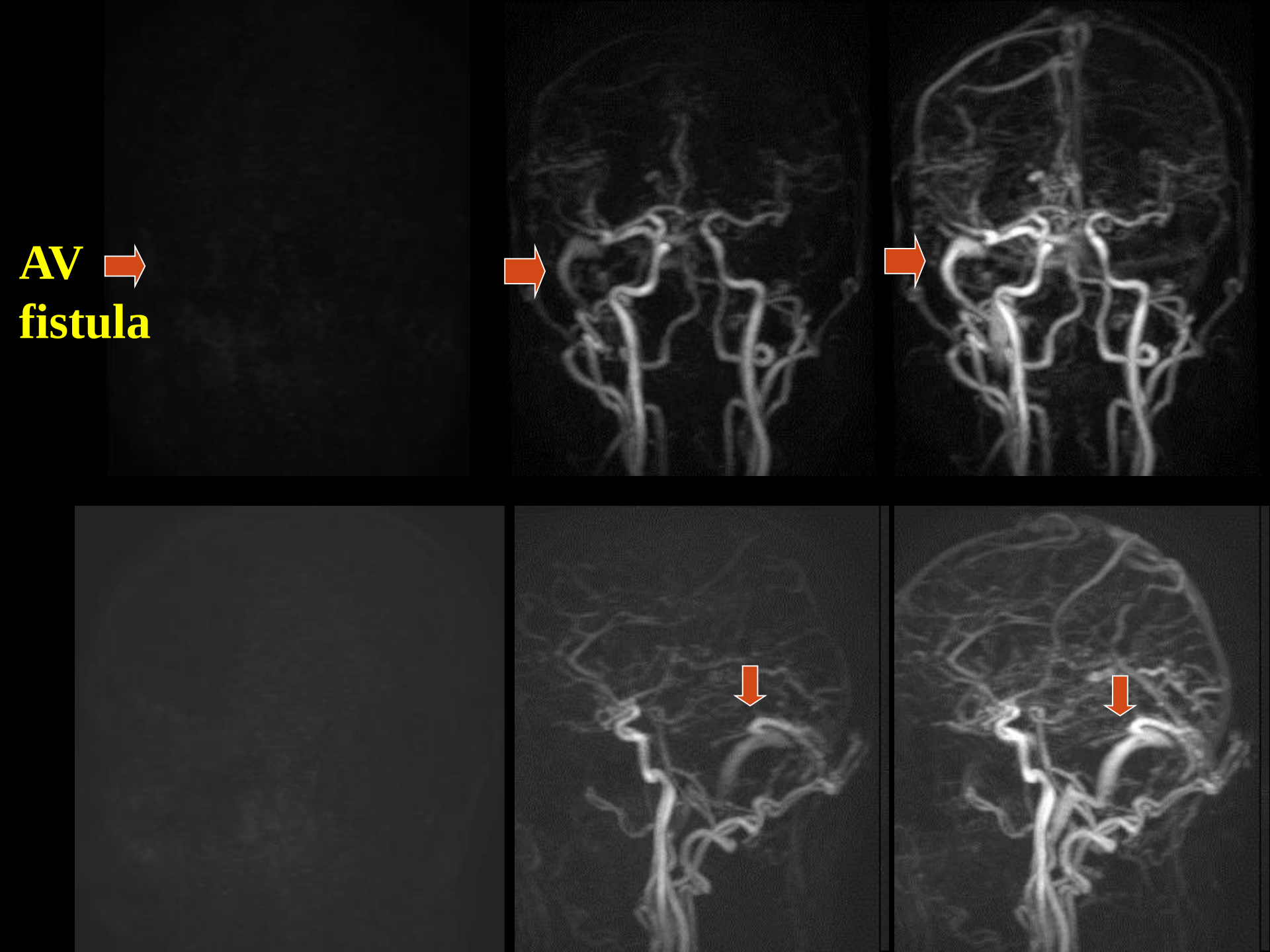


CTA



Direct type CCF


DSA
AV
fistula
MRA


AV
fistula

4D-TRAK

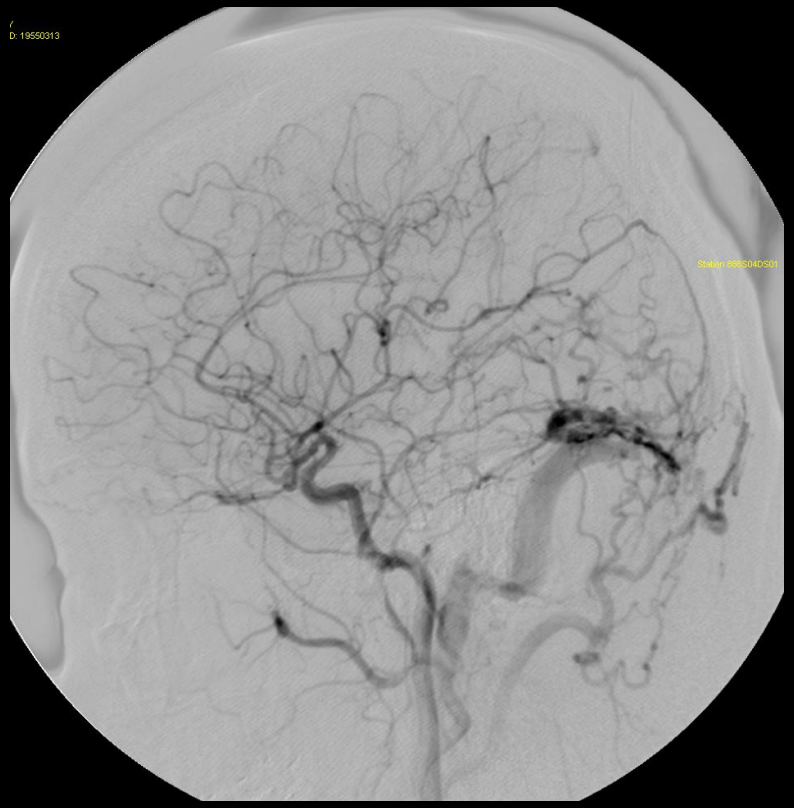
IV bolus injection

One hour at the hospital

DSA

Arterial puncture (high risk)

2~3 days at the hospital



Conclusion

- **4D-TRAK (Philips)** is combined the speed of keyhole , SENSE and halfscan that increases for high temporal resolution (Dynamic imaging).

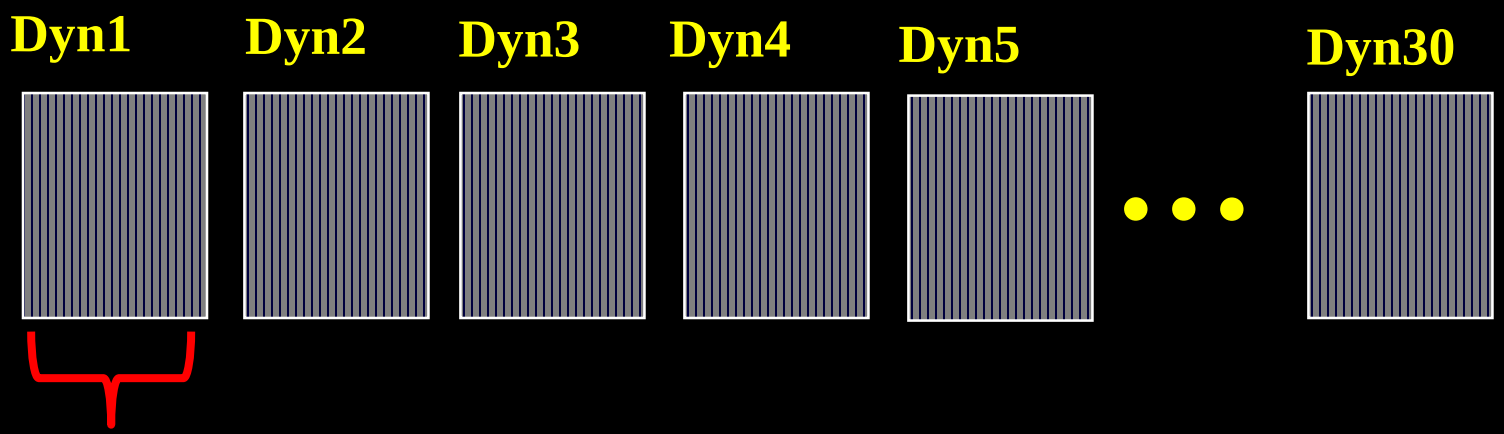
- **TWIST (Siemens)** Time-resolved angiography With Interleaved Stochastic Trajectories,
  It is to use a **reduced sampling density** of **B …** that increases for high temporal resolution

- For applications such as intracranial arteriovenous malformation (AVM),intracranial arteriovenous fistula (AVF) and intracranial venous thrombosis.

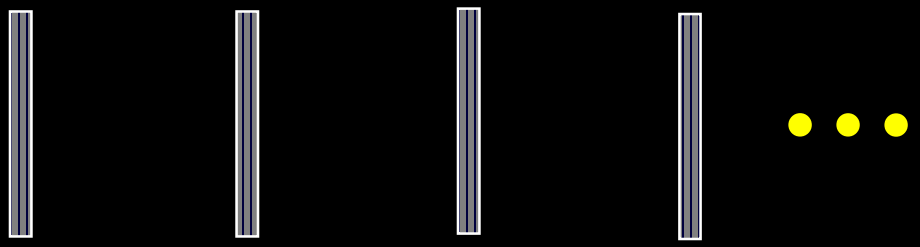
Thank you for your attention

4D-TRAK

Reconstruction Methods (VGHTC)



Maximum intensity projection (MIP)



We will Obtain the Dynamic MRA images