L Muller.
CHU Nîmes

Doppler transcrânien en urgence :

Technique et intérêt clinique

RÉ.PRÉ.LA.R
RÉSEAU DE PRÉLÈVEMENT LANGUEDOC - ROUSSILLON

UM1 Université Montpellier I

JE SUIS CHARLIE

AZUREA

Université Montpellier I
FACULTÉ DE MÉDECINE
Montpellier - Nîmes

CHU NÎMES

Transcranial color coded duplex sonography (TCCD)

In contrast to "blind" conventional transcranial Doppler sonography (TCD)

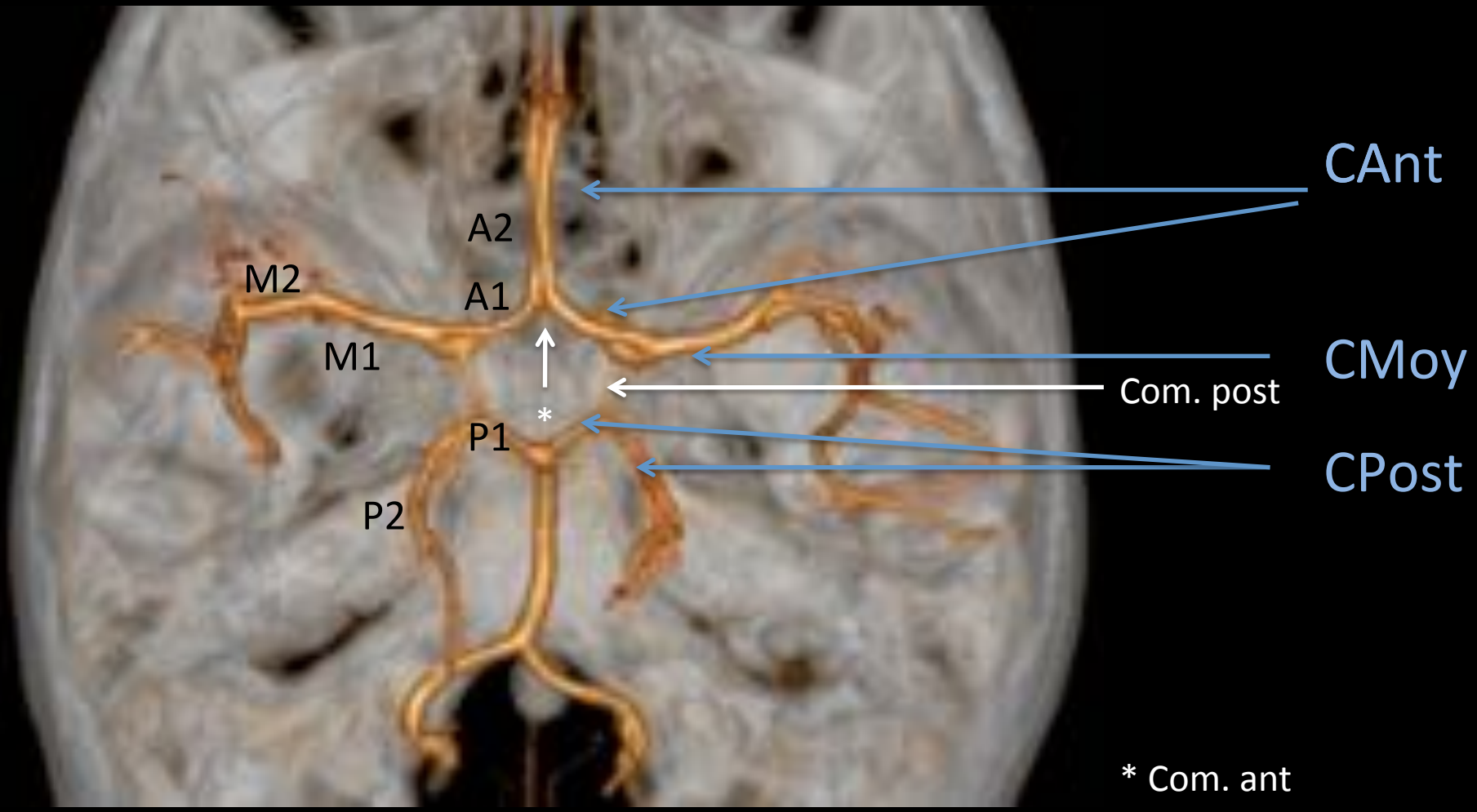
1. TCCD enables a sonographer to outline the intracranial bony and parenchymal structures
2. Visualize the basal cerebral arteries in color
3. Measure angle-corrected blood flow velocities in a specific site of the artery in question.

Krejza et al J Neuroimaging 2004

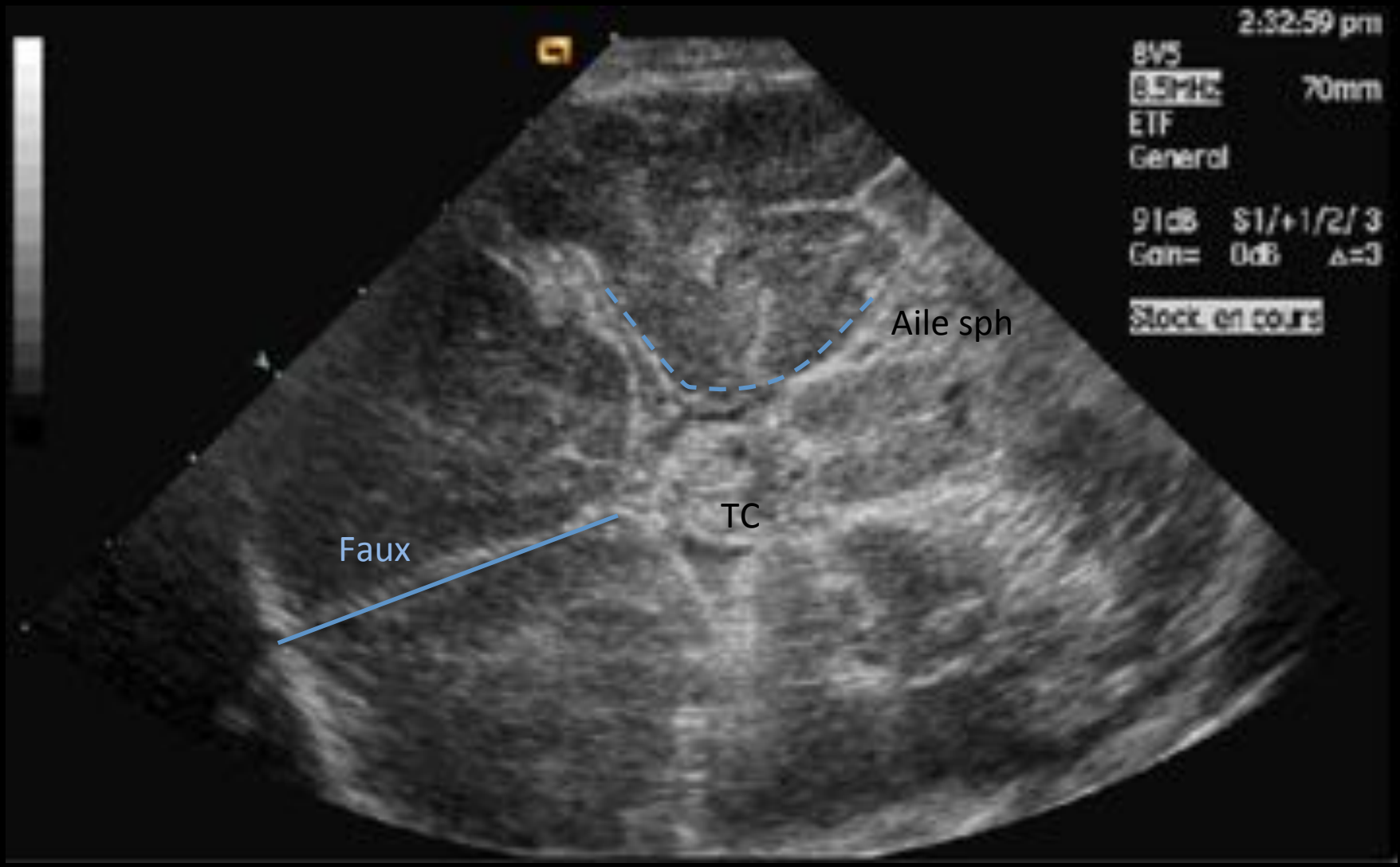
1. Principes

Doppler intra crânien *: anatomie du polygone de Willis*

Doppler intra crânien *: anatomie du tronc cérébral*

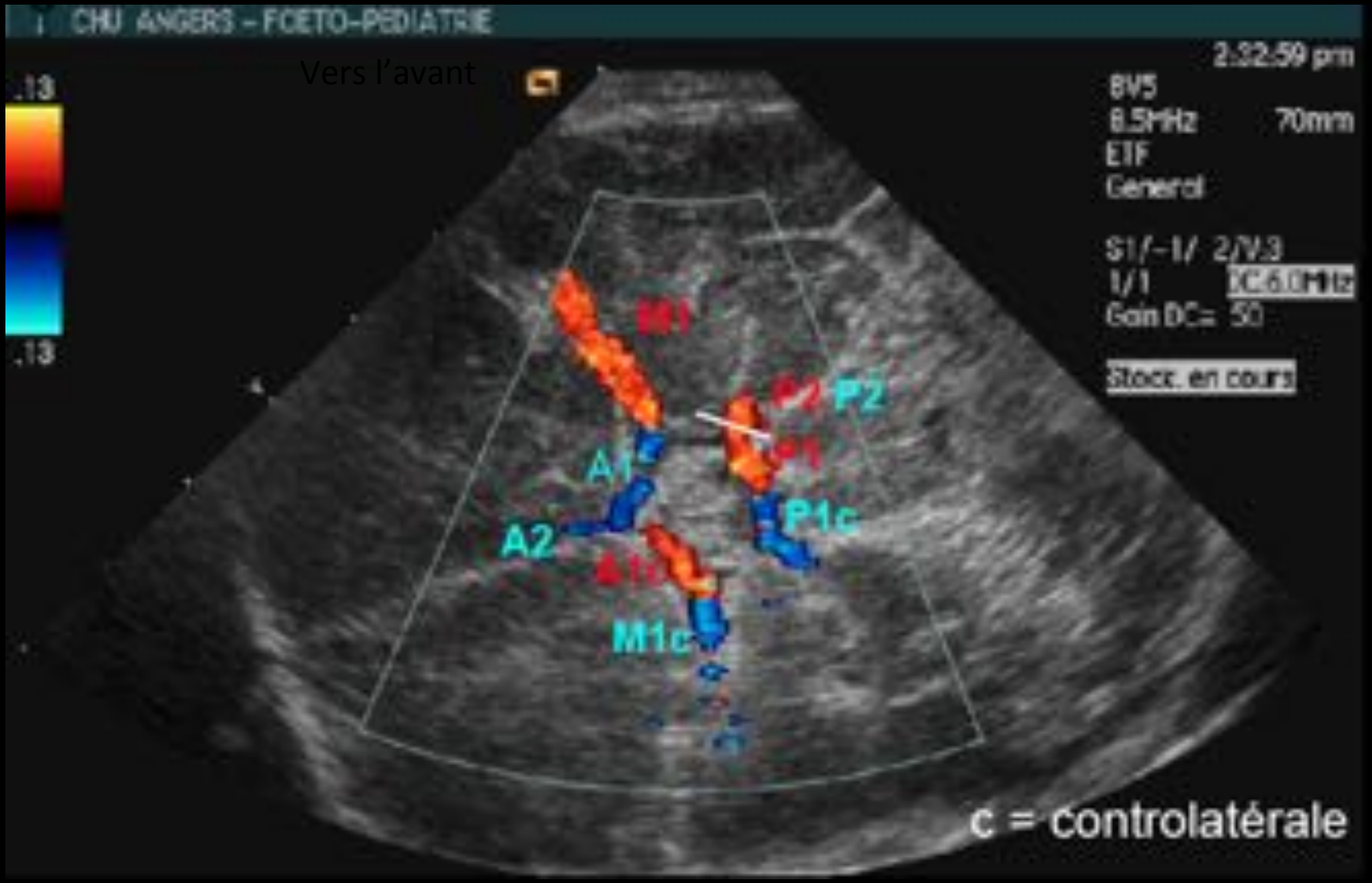


Echographie - Doppler intra crânien *: principe*

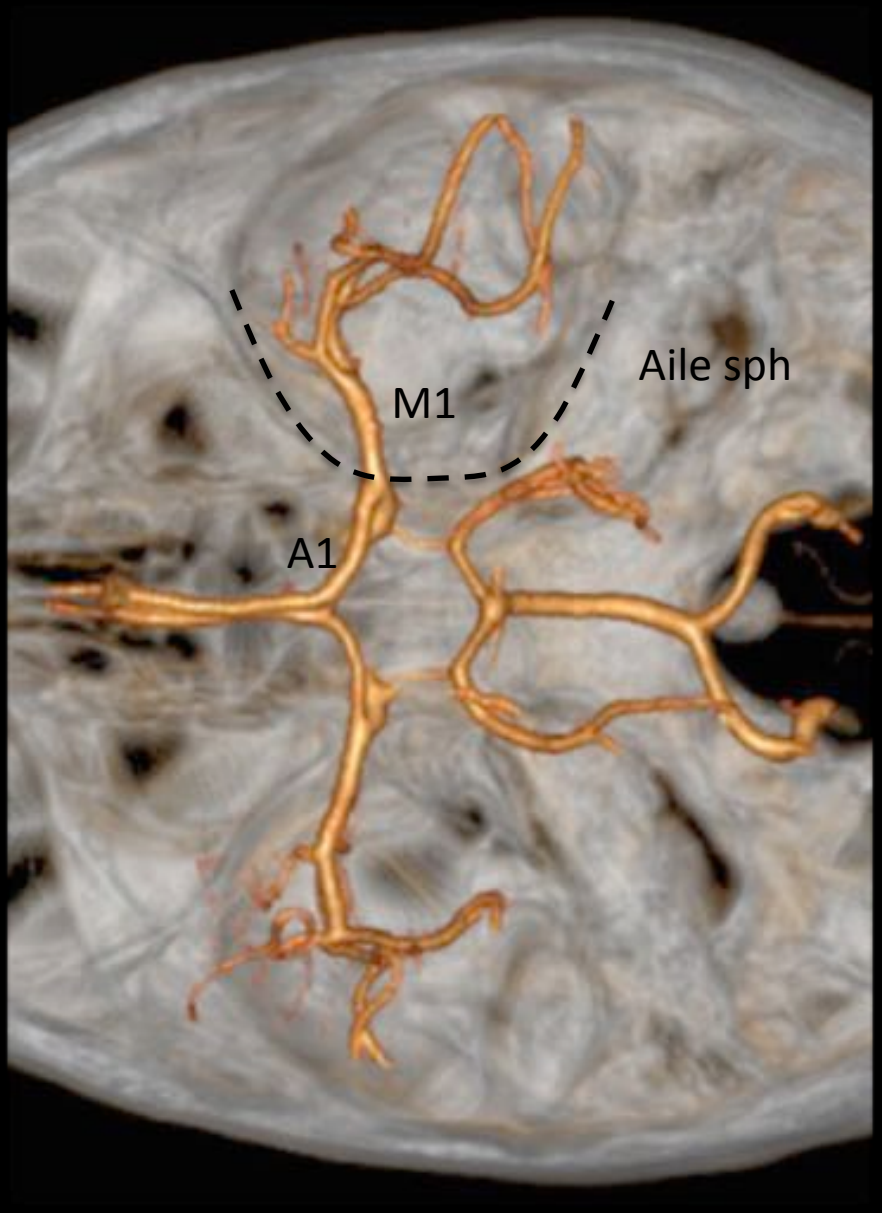


Echographie - Doppler intra crânien *: principe*

Doppler intra crânien : principe

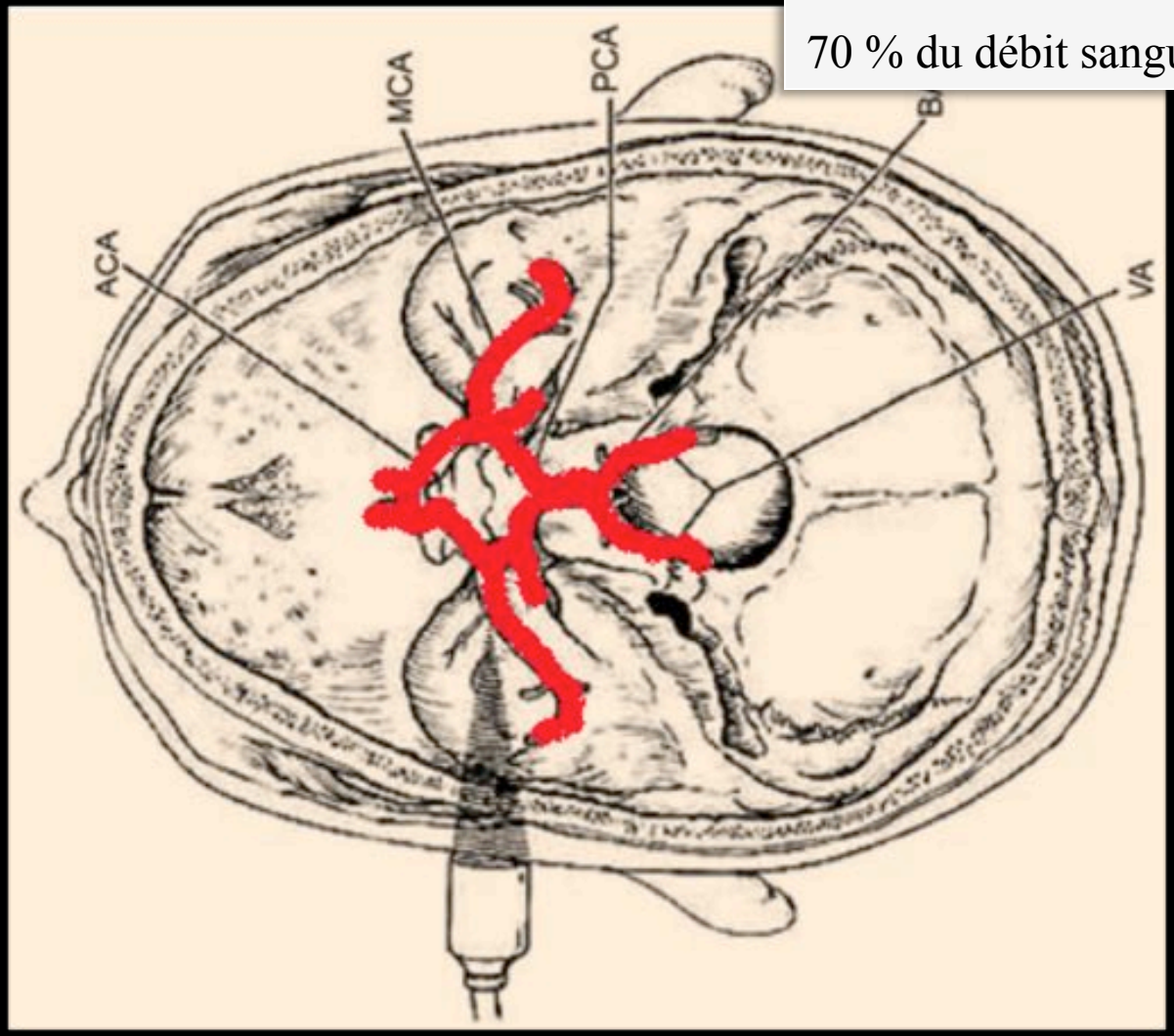


Doppler intra crânien : *reconnaître les reliefs osseux*



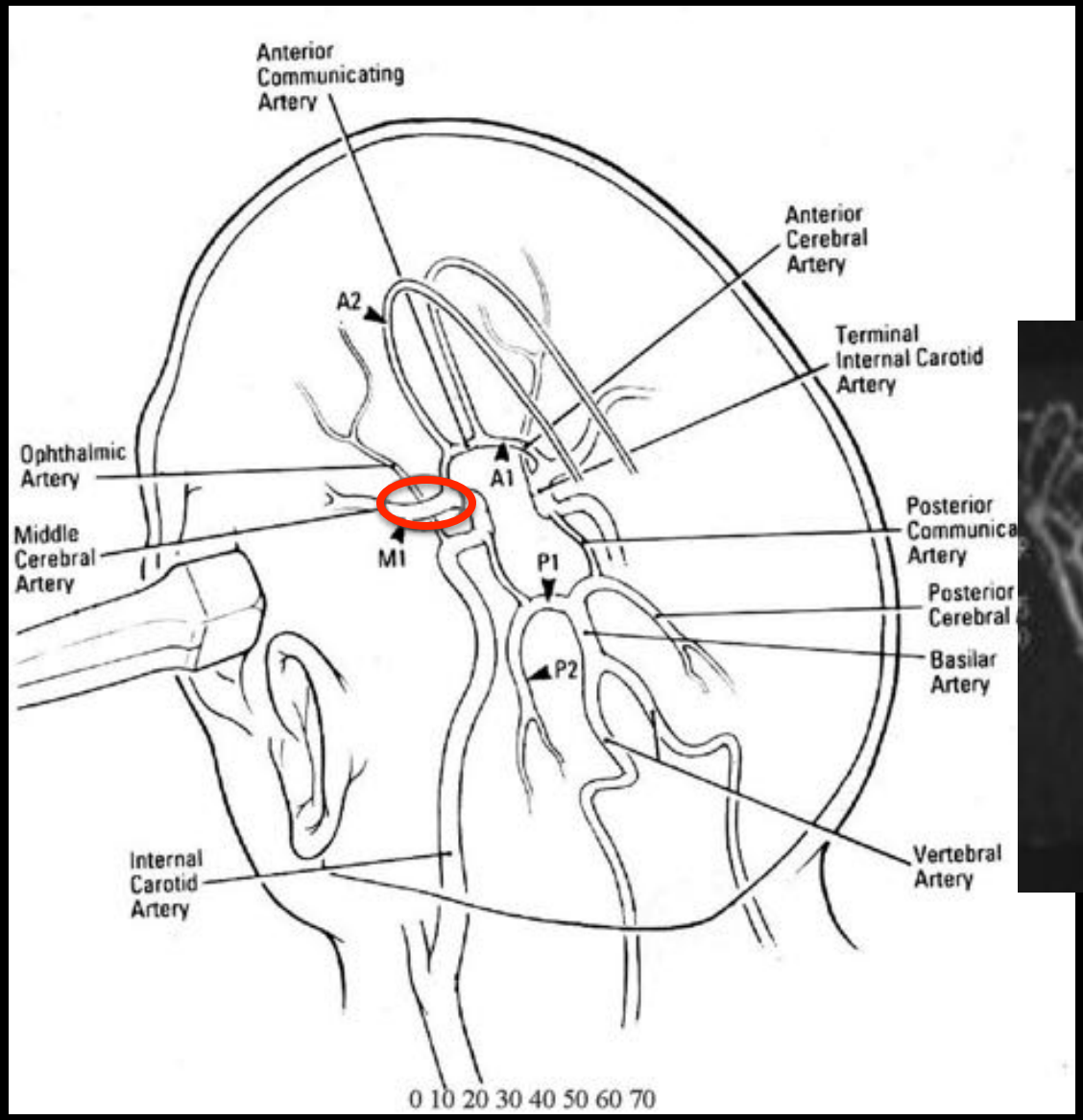
Doppler intra crânien : *anatomie, physiologie*

Flux sylvien (ACM)
=
70 % du débit sanguin cérébral



White et al Intensive Care Med 2006

Doppler intra crânien *: principe*

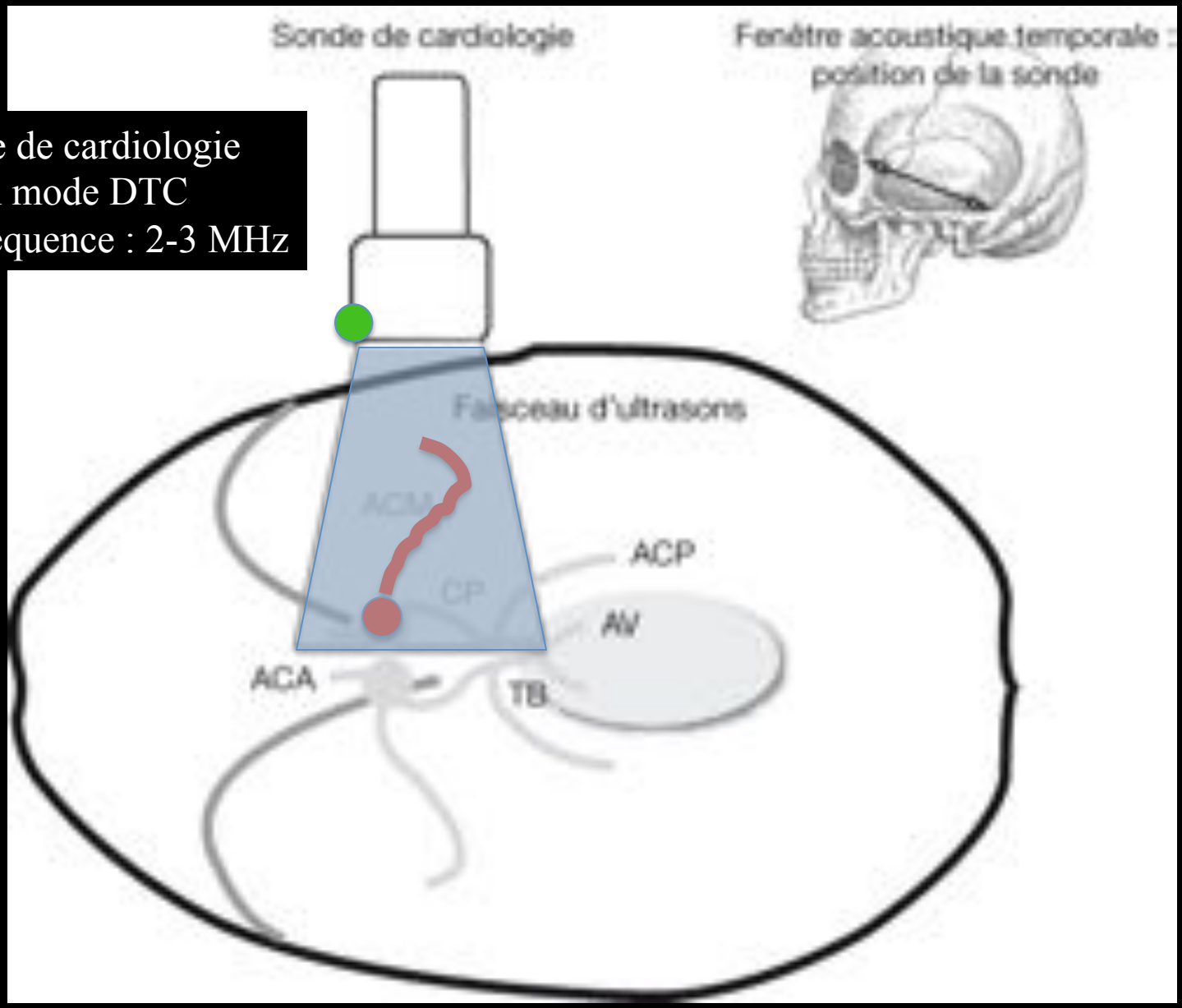


Flux sylvien (ACM)
=
Segment M1

Saqqur et al CCM 2007

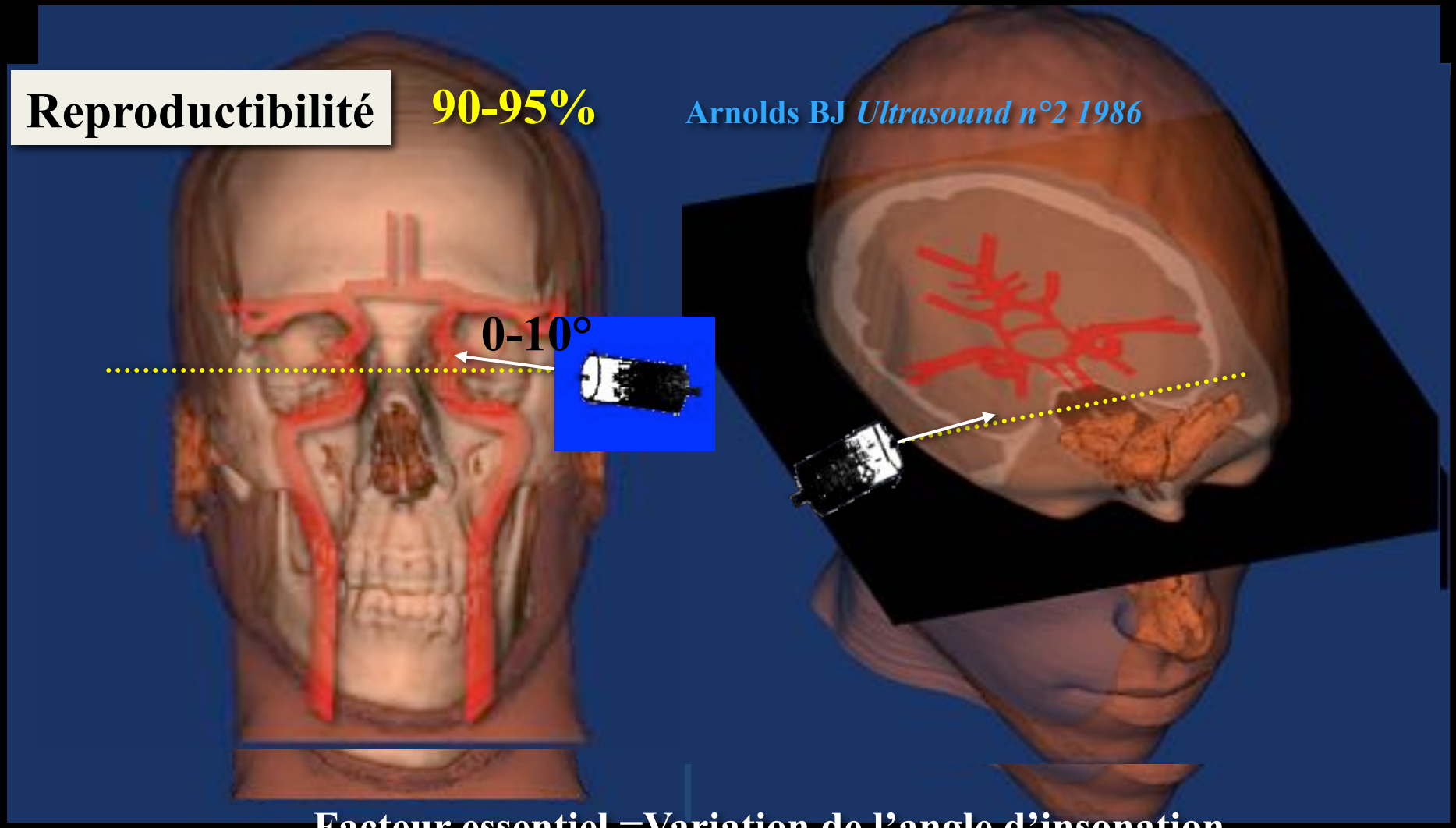
Doppler intra crânien : principe

Sonde de cardiologie
En mode DTC
Basse fréquence : 2-3 MHz



Doppler transcrânien de l'artère cérébrale moyenne : une bonne reproductibilité

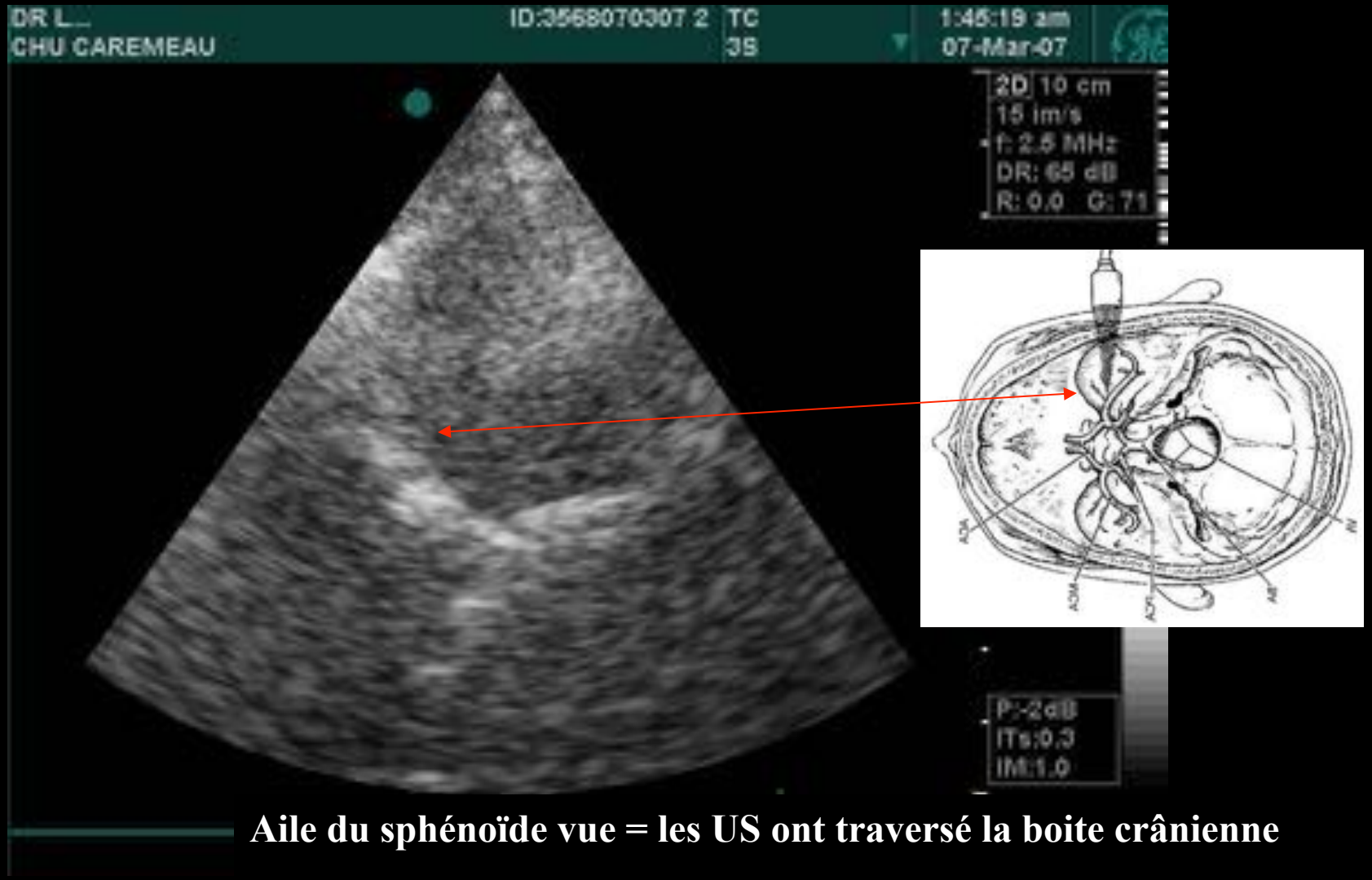
Reproductibilité **90-95%** Arnolds BJ *Ultrasound n°2 1986*



Facteur essentiel =Variation de l'angle d'insonation

Maeda & coll *Ultrasound n° 1991*

Echo-Doppler intra crânien : 1. voir l'aile du sphénoïde



Aile du sphénoïde vue = les US ont traversé la boite crânienne

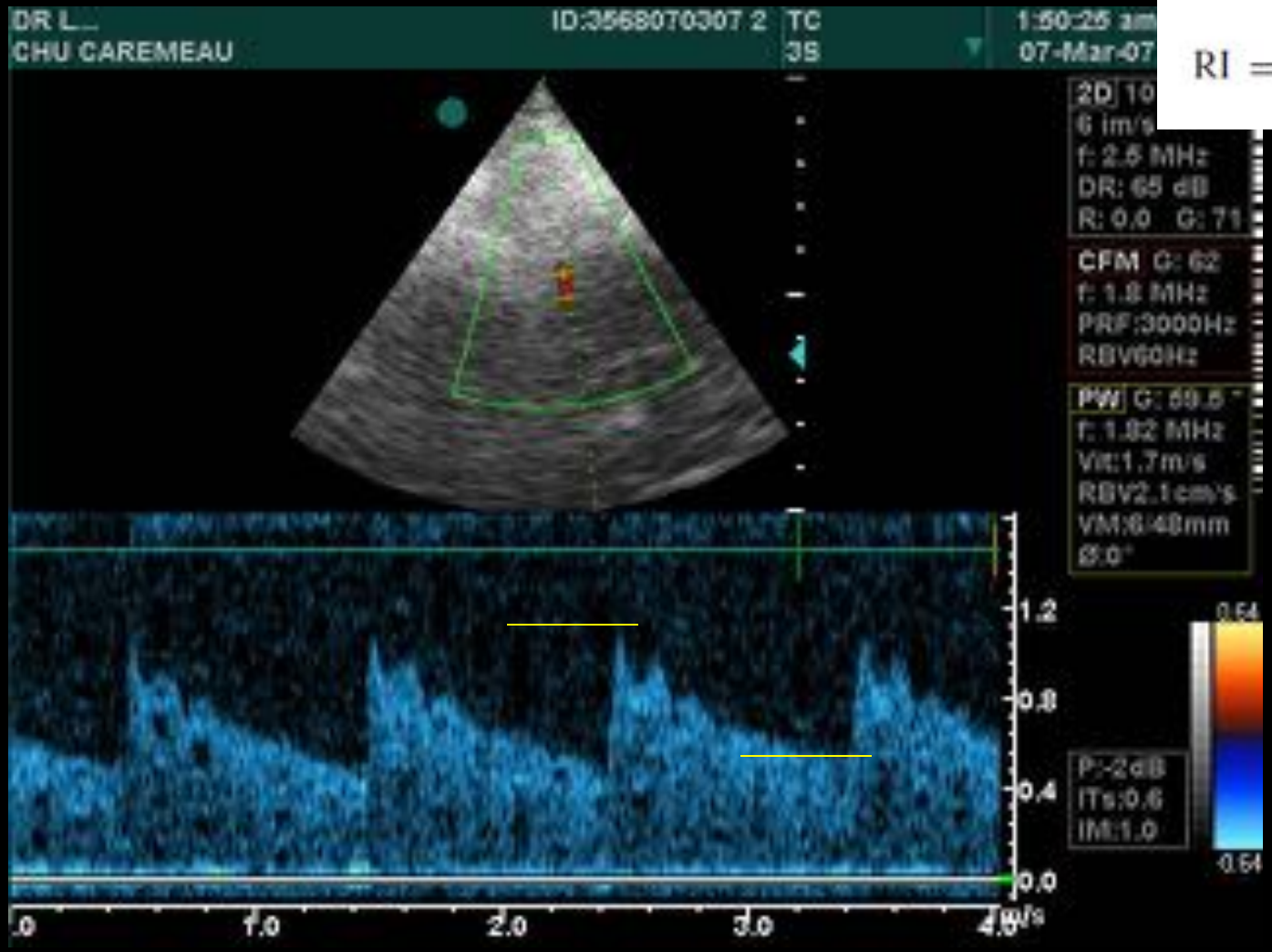
Doppler intra crânien : 2. Repérage par Doppler couleur

Doppler intra crânien : 3. Doppler pulsé

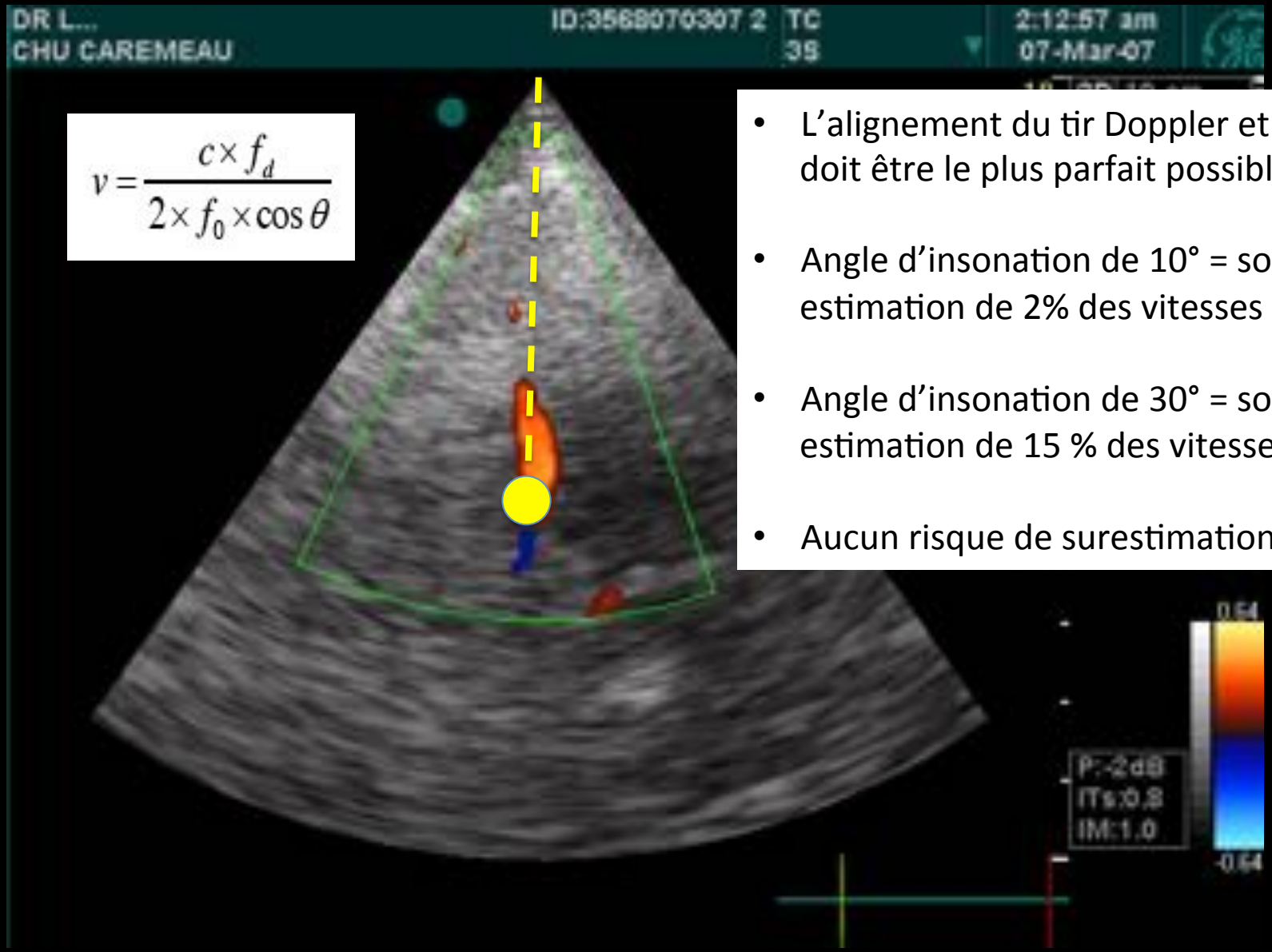
$$MV = \frac{PSV + (EDV \times 2)}{3}$$

$$PI = \left(\frac{PSV - EDV}{MV}\right)$$

$$RI = \left(\frac{PSV - EDV}{PV}\right)$$



Doppler intra crânien : 3. Doppler pulsé sur le segment M1 (ACM)



- L'alignement du tir Doppler et du flux doit être le plus parfait possible
- Angle d'insonation de 10° = sous estimation de 2% des vitesses
- Angle d'insonation de 30° = sous estimation de 15 % des vitesses
- Aucun risque de surestimation

Doppler intra crânien de l'ACM : *valeurs normales*

	Formule	Normale adulte < 60 ans	Normale adulte > 60 ans
Paramètres mesurés			
Vitesse systolique (Vs) (cm/s)	-	75 – 105, max 200	60 – 100
Vitesse diastolique (Vd) (cm/s)	-	35 – 55	35 – 55
Paramètres calculés			
Vitesse moyenne (Vm)	(Vs + (Vd x 2)) / 3	45 – 70	35 – 55
Index de pulsatilté (IP)	(Vs – Vd) / Vm	0,8 – 1,4	0,8 – 1,2
Index de Lindegaard (IL)	Vitesse ACM/ACI	< 3	< 3

Doppler intra crânien de l'ACM : valeurs pathologiques

Doppler transcrânien : valeurs d'alarme	
Vd < 20 – 25 cm/s	2 des 3 critères présents : Hypoperfusion cérébrale grave appelant une manœuvre thérapeutique en urgence.
Vm < 30 – 35 cm/s	
IP > 1,2 – 1,4	

Doppler transcrânien : profils classiques	
Vs basse, Vd basse, IP normal	Hypoperfusion d'origine systémique
Vs basse, Vd basse, IP élevé	Hypoperfusion d'origine cérébrale
Vs élevée, IP normal, IL < 3	Hyperhémie
Vs élevée, IP normal, IL > 3	Vasospasme

Muller et al SFAR 2008

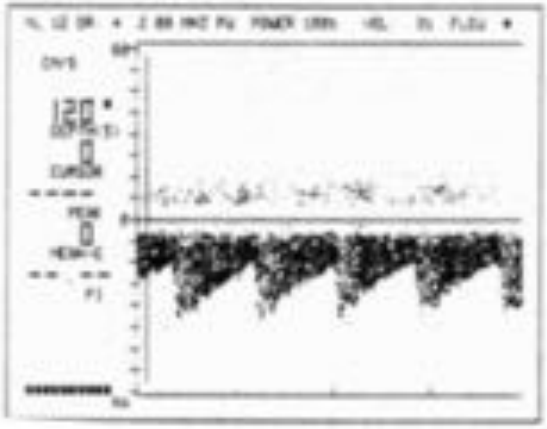
Doppler intra crânien : *autres artères*

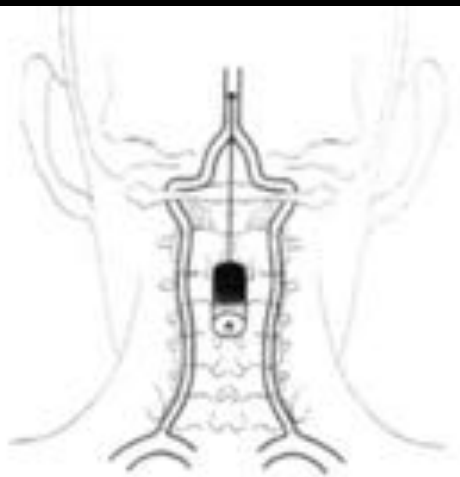
...Peu utile en milieu non spécialisé

	Profondeur (mm)	Vm cm/s	Vs cm/s	Vd cm/s
ACM	45 - 60	60 ± 10	90 ± 15	40 ± 10
ACA	60 - 70	50 ± 13	75 ± 20	35 ± 10
ACP	60 - 70	40 ± 10	55 ± 12	26 ± 7
AV	60 – 85	35 ± 8	60 ± 15	25 ± 6
TB	75 – 110	40 ± 10	60 ± 15	25 ± 6

Doppler intra crânien : *autres artères*

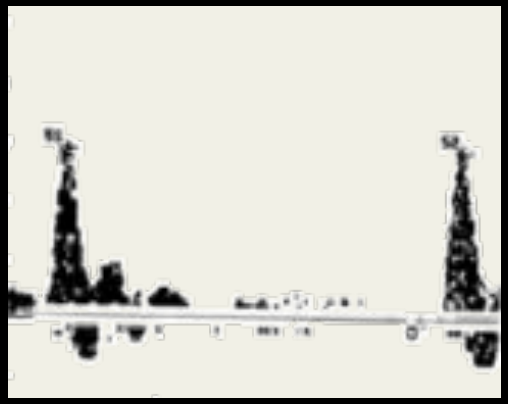
2 cm au-dessous de la bosse occipitale





Profondeur : 80 - 120 mm
Direction: Centrifuge
VM: 40 +/- 10 cm/s
Compression VA: Diminué

Doppler intra crânien de l'ACM : *une artère à basses résistances*



Artère musculaire

IP = 10

Artère mixte : carotide externe

IP = 5

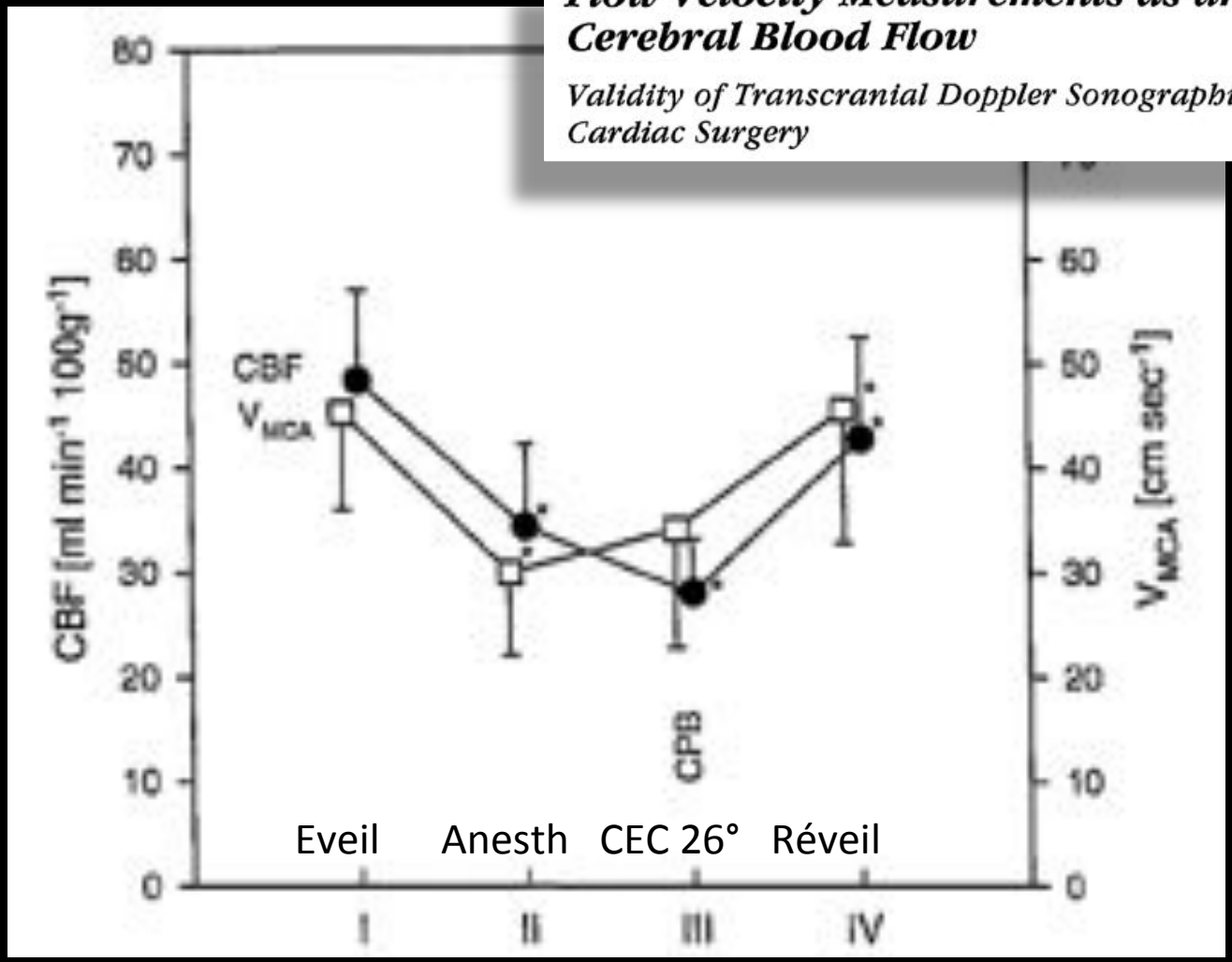
Artère cérébrale moyenne
ou carotide interne

IP = 1

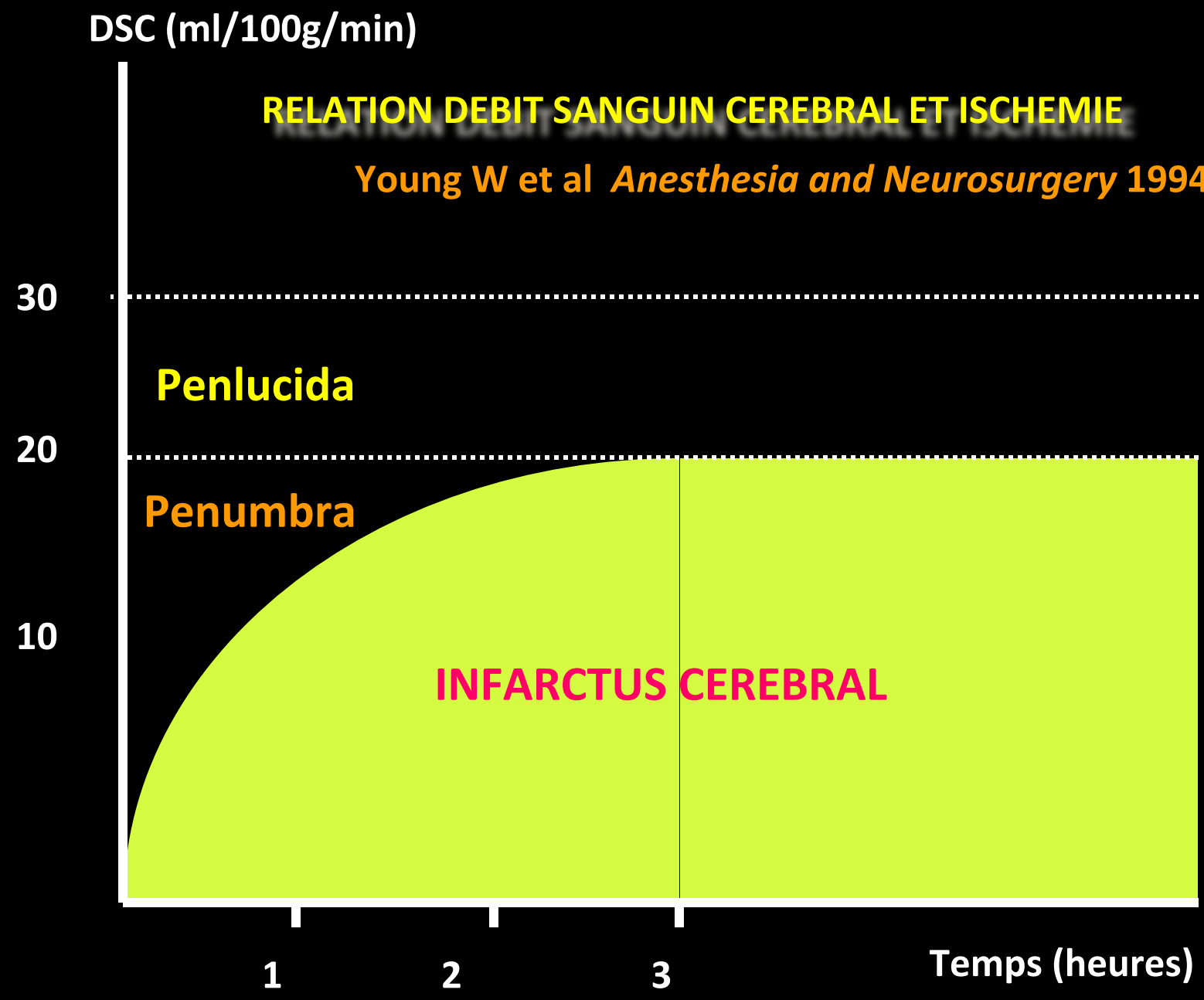
Doppler transcrânien : *bonne correspondance Vm et DSC*

Flow Velocity Measurements as an Index of Cerebral Blood Flow

Validity of Transcranial Doppler Sonographic Monitoring during Cardiac Surgery



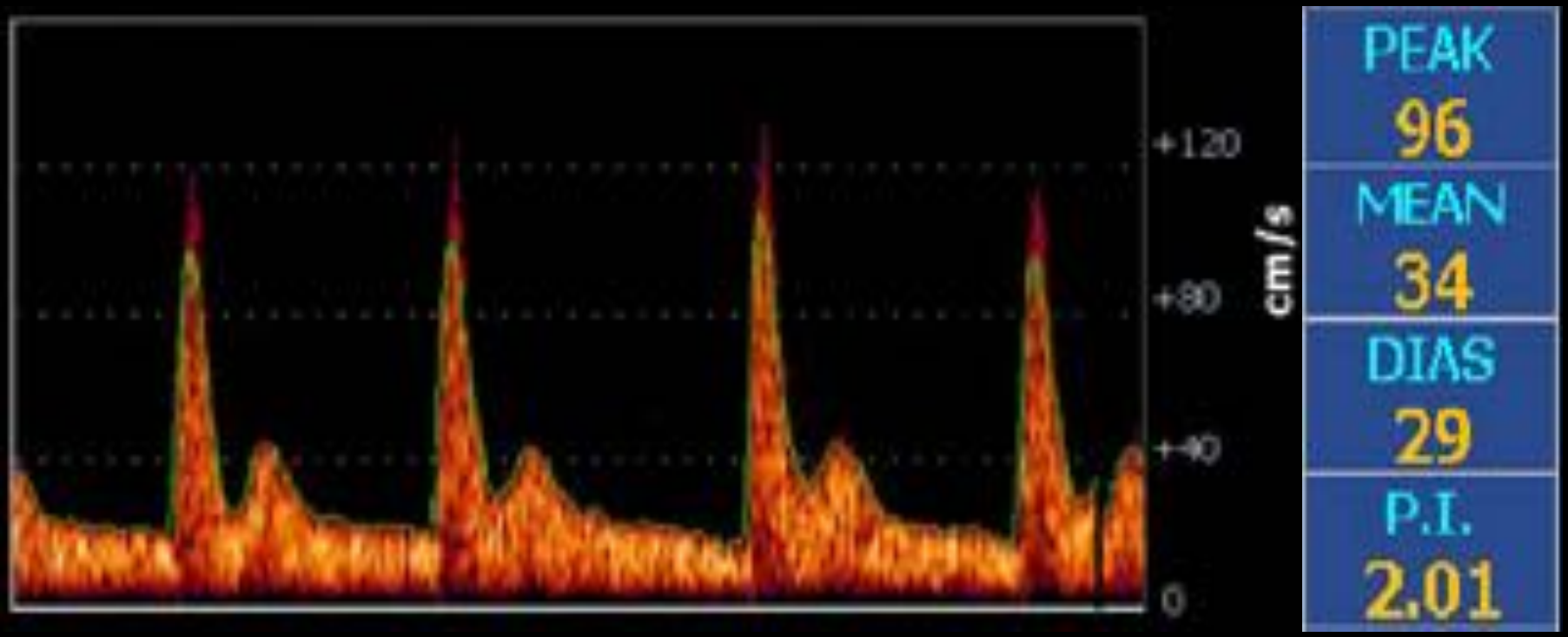
Waeyeland Anesthesiology 1994


DSC (ml/100g/min)
RELATION DEBIT SANGUIN CEREBRAL ET ISCHEMIE
Young W et al Anesthesia and Neurosurgery 1994
30
20
10
Penlucida
Penumbra
INFARCTUS CEREBRAL
1
2
3
Temps (heures)

2. Diagnostic d’HTIC

Doppler intra crânien (ACM) :

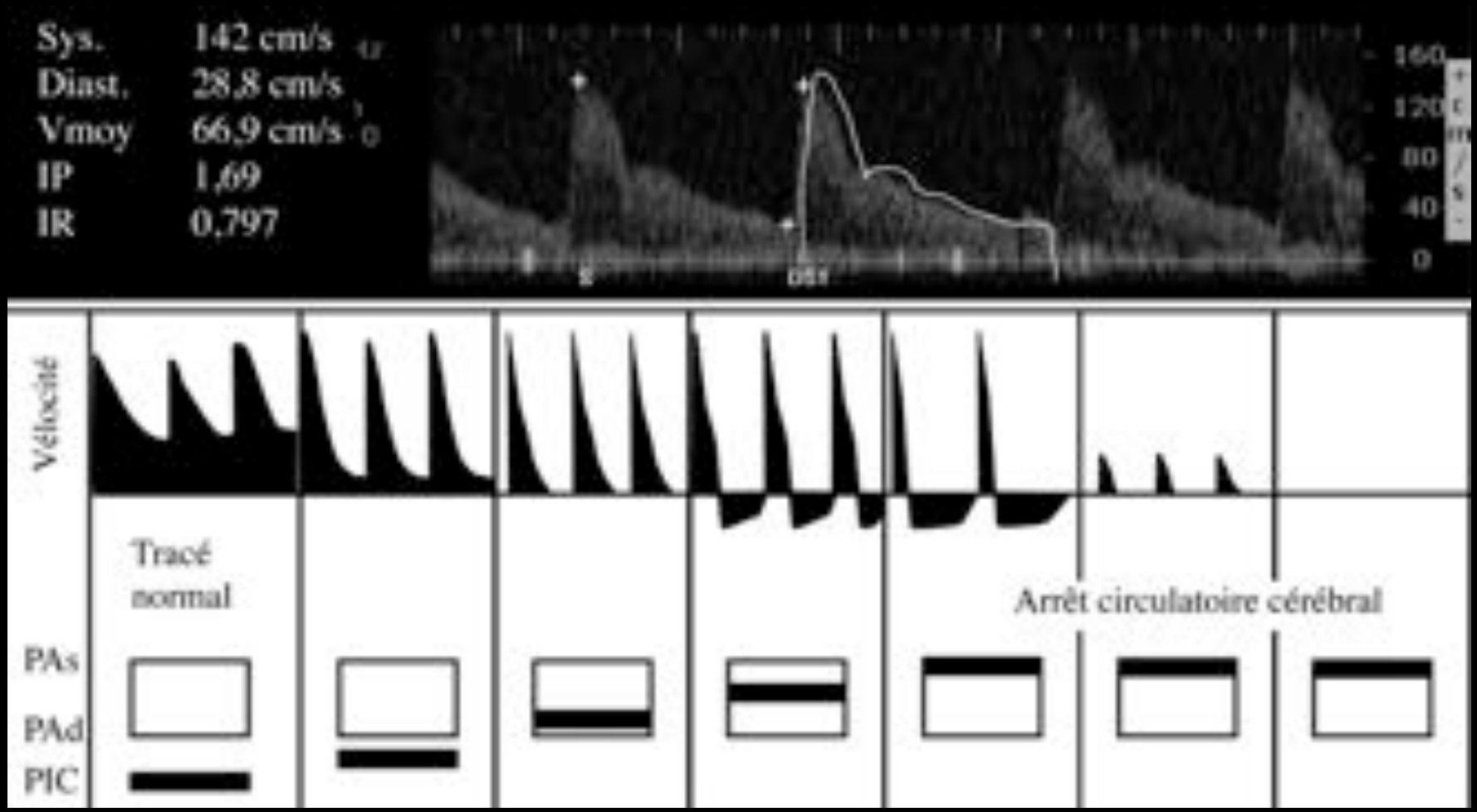
… aspect typique d'HTIC : Vs haute, Vd basse



White et al Intensive Care Med 2006

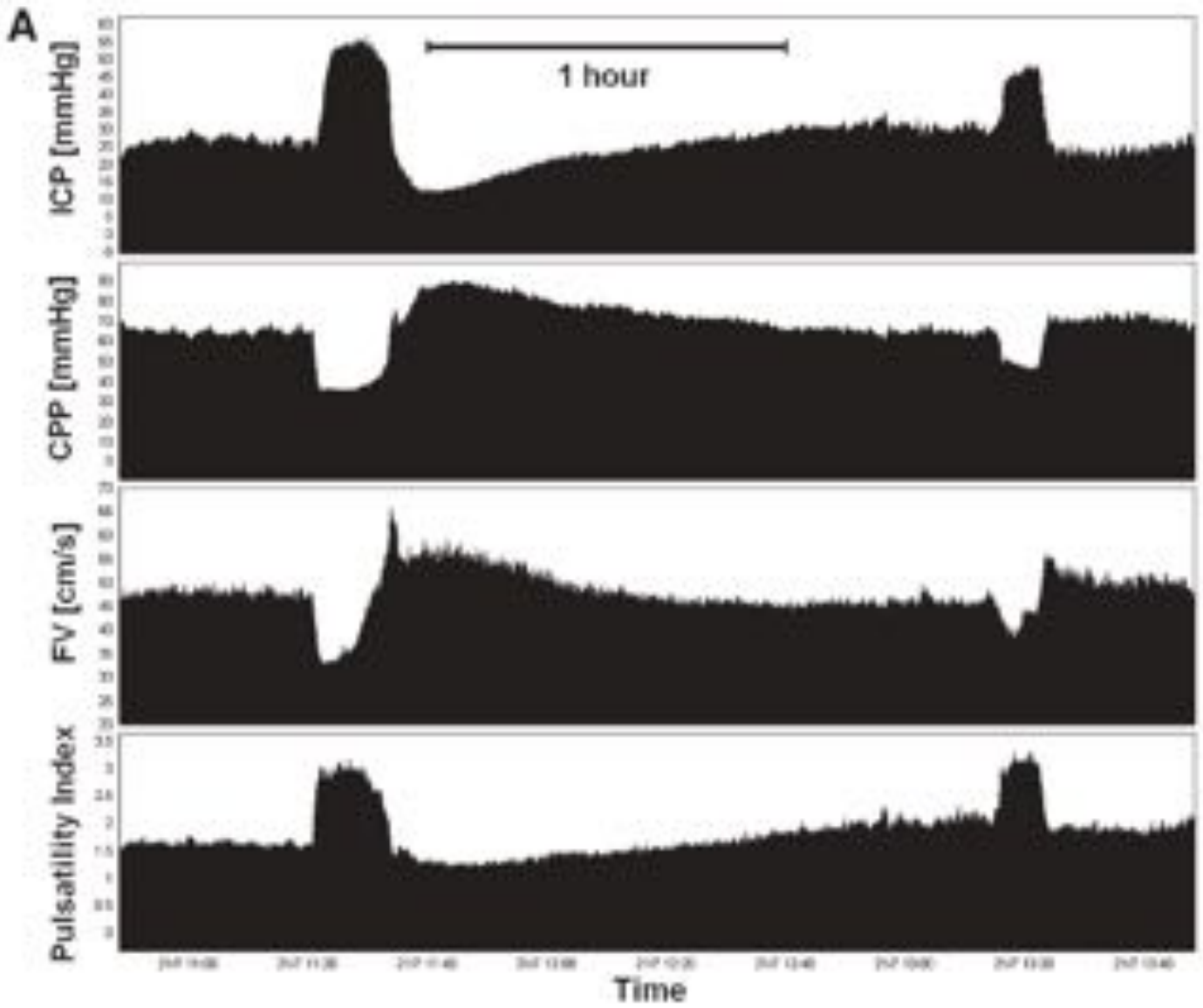
Evolution schématique du DTC lors de l'HTIC

La diastolique est plus affectée que la systolique



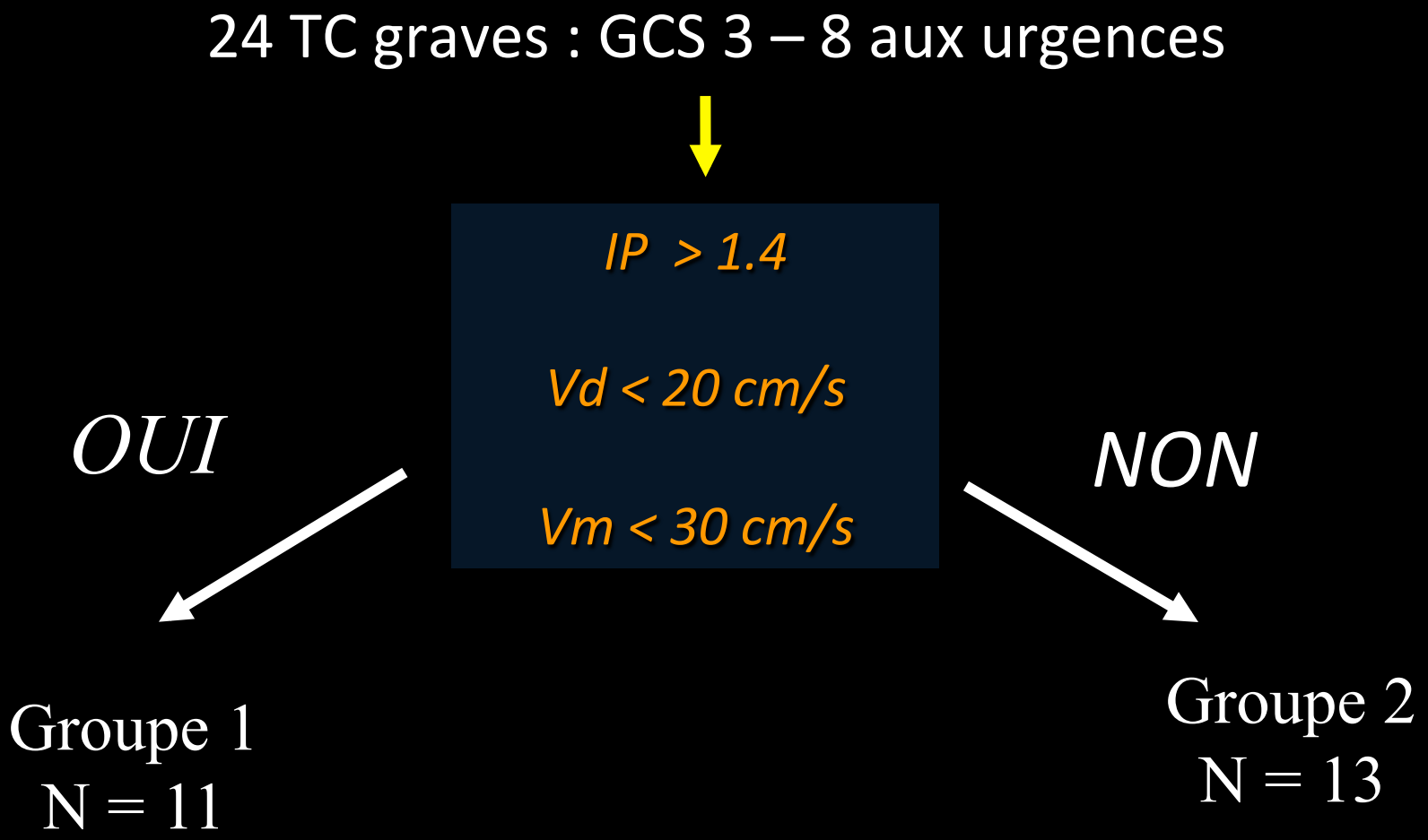
P Zetlaoui SFAR 2009

Evolution des VM, IP, de la PIC, de la PPC



Zweifel et al Neurosurgery 2012

Transcranial Doppler ultrasound goal-directed therapy for the early management of severe traumatic brain injury.



Ract et al Intensive Care Medicine 2007

Transcranial Doppler ultrasound goal-directed therapy for the early management of severe traumatic brain injury.

	Doppler altéré	Doppler Nal
PIC	32±13	22±10**
PPC	73±15	71±14
$SvjO_2$	67±2	72±9

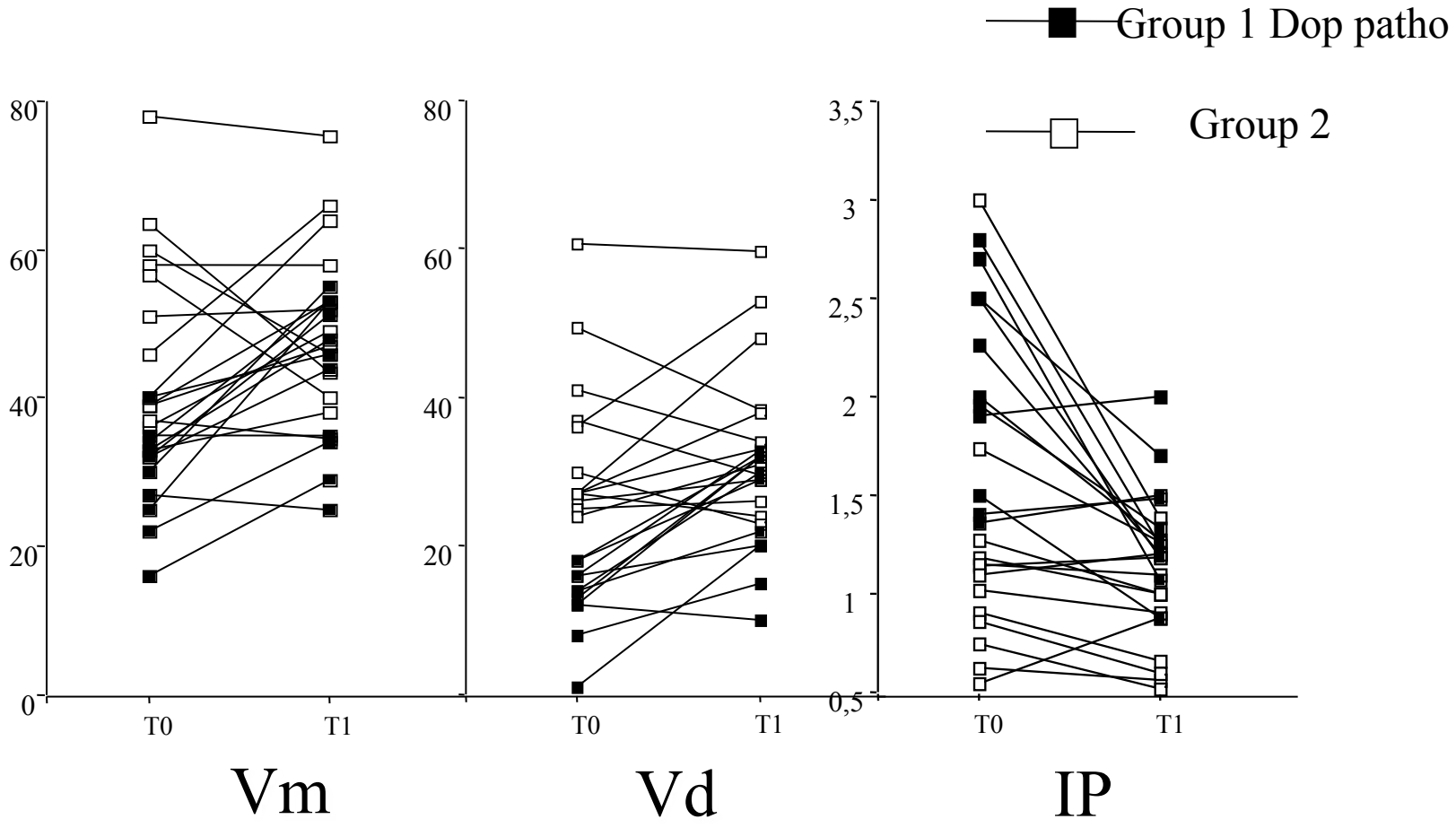
Ract et al Intensive Care Medicine 2007

Intensive Care Med (2007) 33:645–651
DOI 10.1007/s00134-007-0558-6

ORIGINAL

Catherine Ract
Sophie Le Moigno
Nicolas Bruder
Bernard Vigué

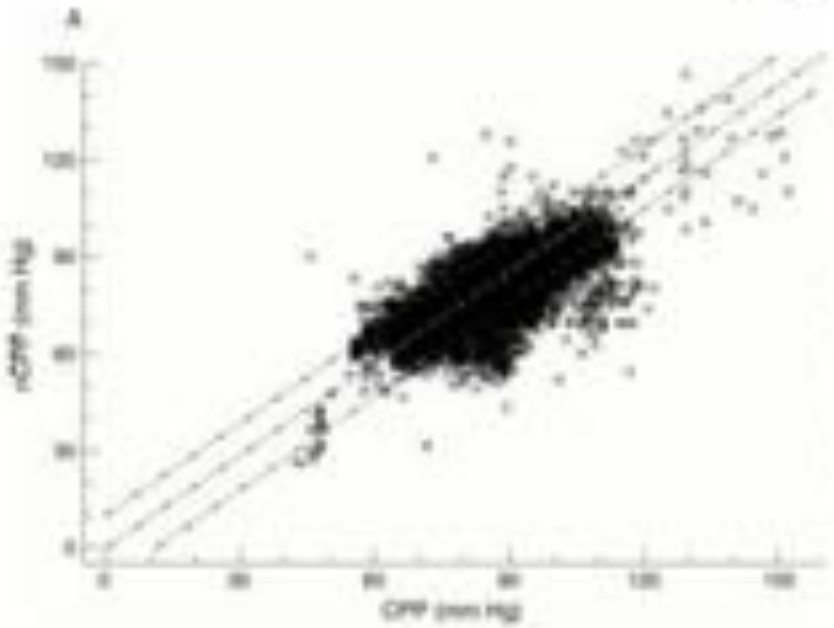
Transcranial Doppler ultrasound goal-directed therapy for the early management of severe traumatic brain injury

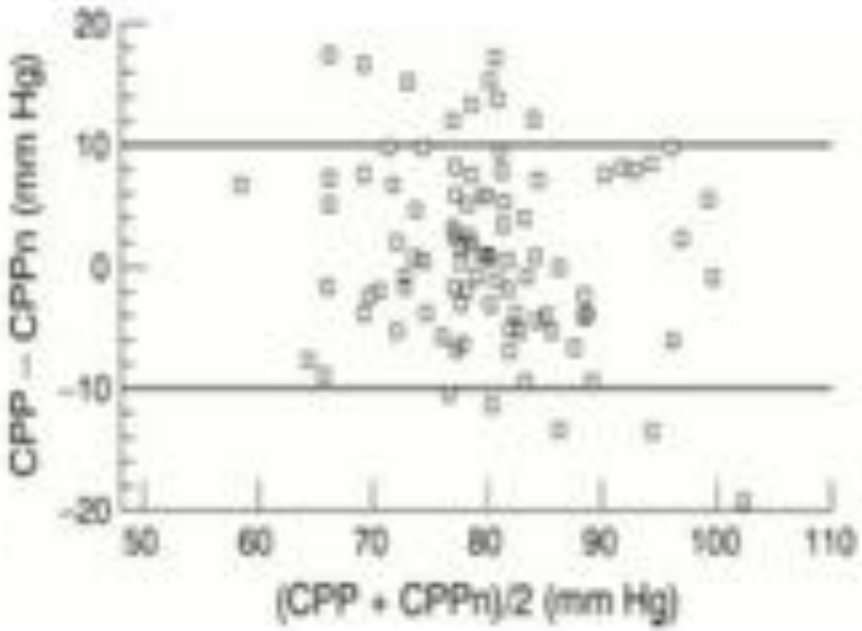


Le Doppler permet de guider le traitement initial

Doppler de l'ACM : corrélé à la PPC

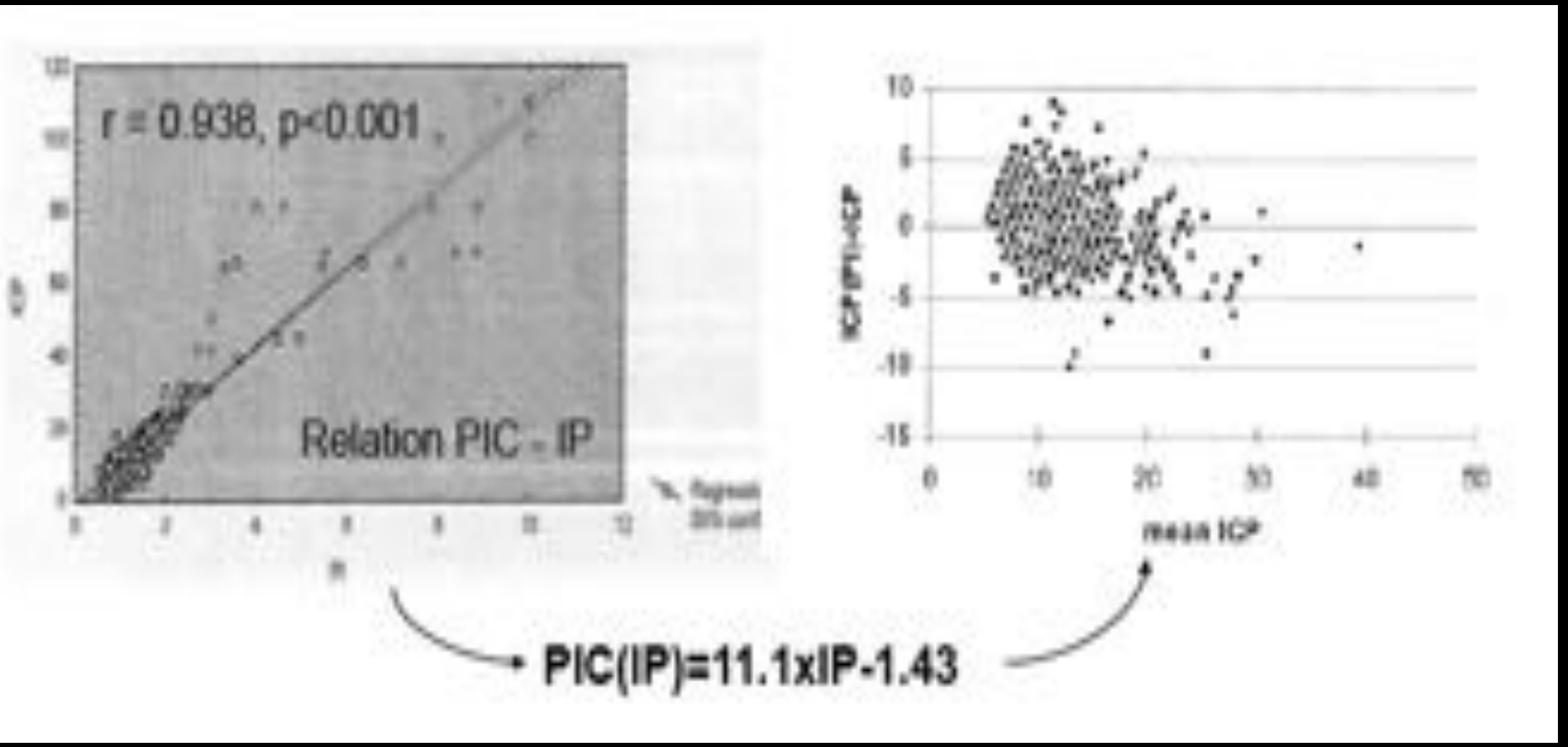
$$PPCe = \frac{PAm \times Vdiast}{Vmoy} + 14mmHg$$





Czosnyka et al J Neurosurg 1998
Schmidt et al JNNP 2001
Zweifel et al Neurosurgery 2012

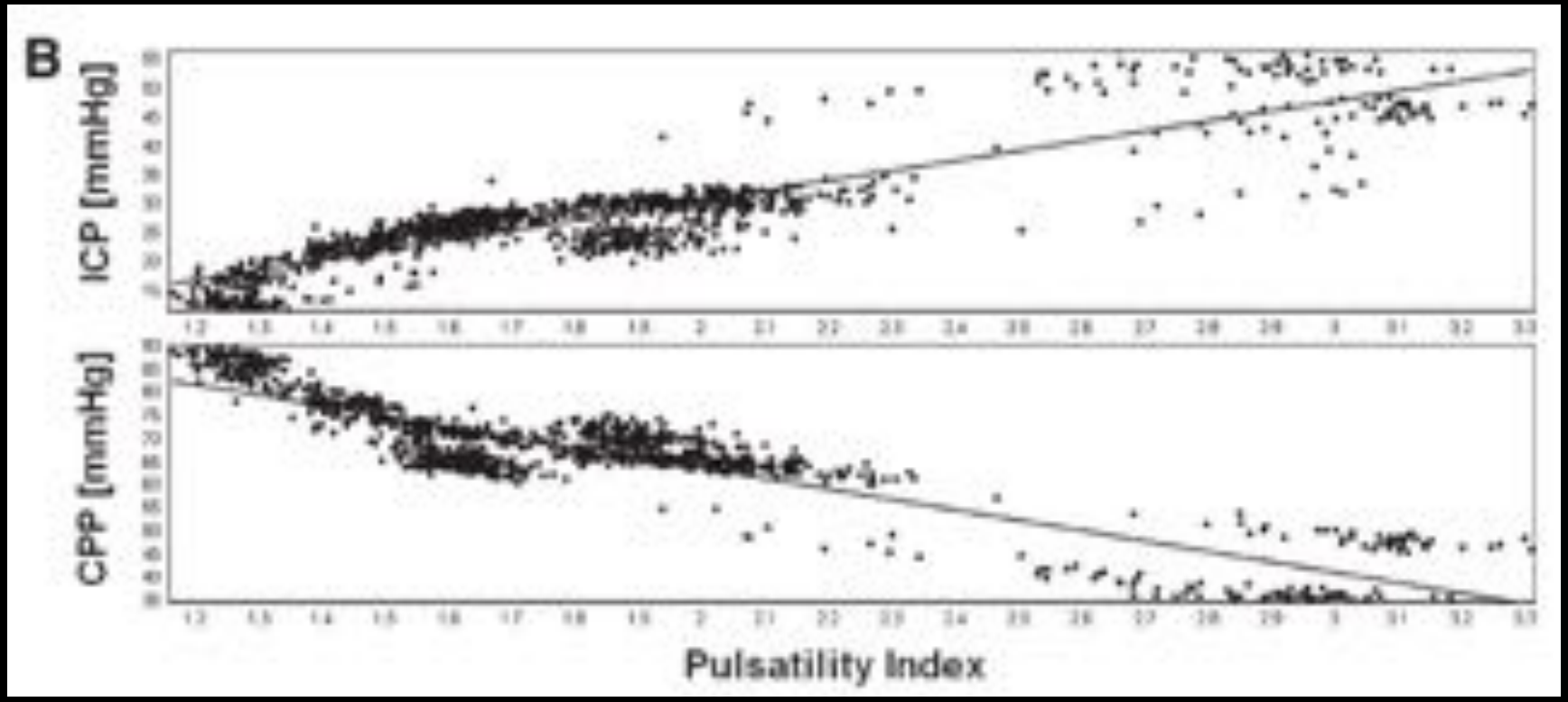
Doppler transcrânien et PIC : *une assez bonne corrélation*



Bellner et al Surg Neurol 2004
Brandi et al Acta Neurochir 2010

Doppler transcrânien et PIC : *il faut se méfier des corrélations*

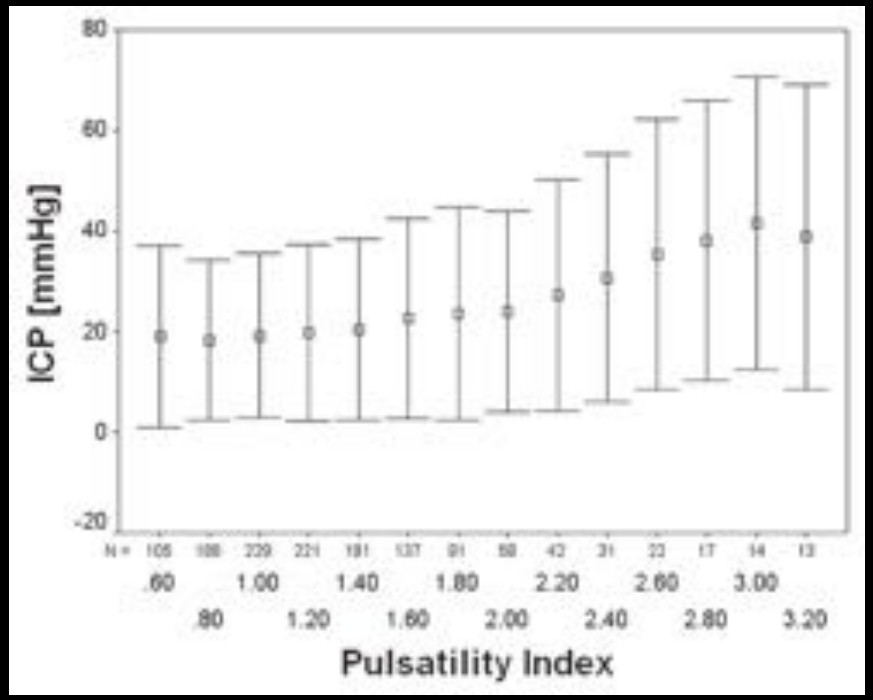
1. La corrélation est excellente

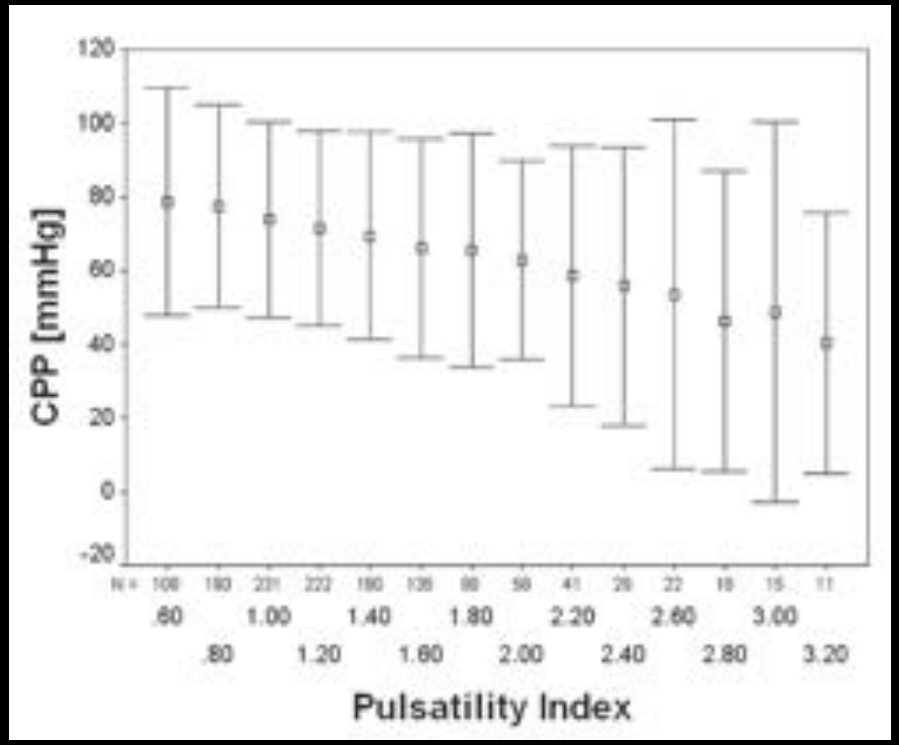


Zweifel et al Neurosurgery 2012

Doppler transcrânien et PIC : *il faut se méfier des corrélations*

2. …Pourtant les déviations standards sont larges

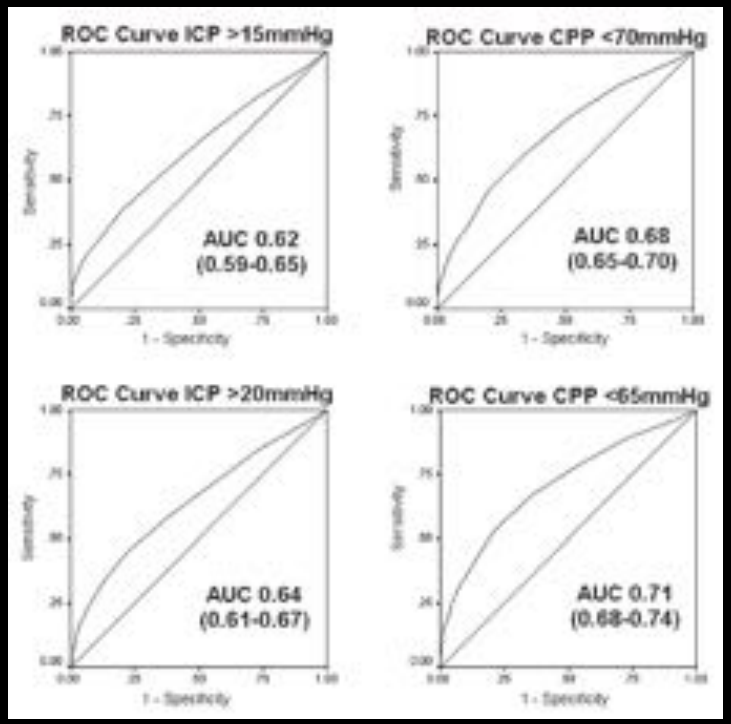


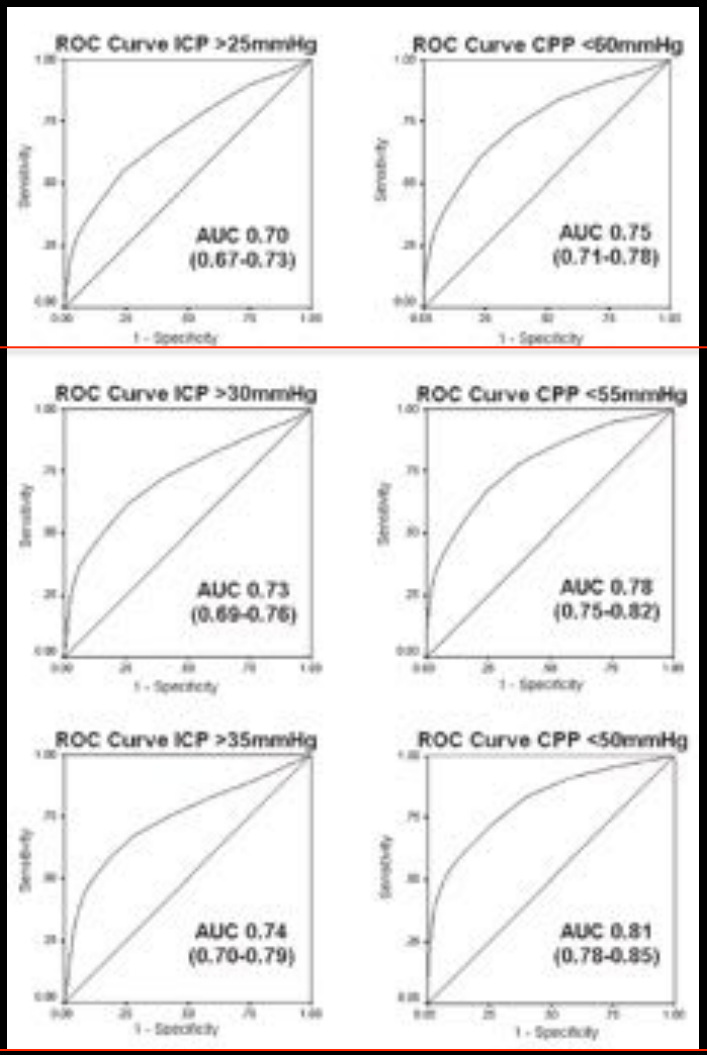


Zweifel et al Neurosurgery 2012

Doppler transcrânien et PIC : *il faut se méfier des corrélations*

3. ..et le Doppler n'est bon que pour les valeurs de PIC élevées (ou PPC basse)





Zweifel et al Neurosurgery 2012

Doppler transcrânien et PIC : *bon dans des situations caricaturales*
Ne remplace pas un monitorage continu de la PIC

RESULTS: Seven hundred sixty-two recorded daily sessions from 290 patients were analyzed with a total recording time of 499.9 hours. The correlation between PI and ICP was 0.31 ($P < .001$) and for PI and CPP -0.41 ($P < .001$). The 95% prediction interval of ICP values for a given PI was more than ±15 mm Hg and for CPP more than ±25 mm Hg. The diagnostic value of PI to assess ICP area under the curve ranged from 0.62 (ICP >15 mm Hg) to 0.74 (ICP >35 mm Hg). For CPP, the area under the curve ranged from 0.68 (CPP <70 mm Hg) to 0.81 (CPP <50 mm Hg). Probability charts for elevated ICP/lowered CPP depending on PI were created.

CONCLUSION

The diagnostic value of TCD FV pulsatility index for direct noninvasive assessment of ICP and CPP is very limited. However, because its measurement can be readily and repeatedly performed, and given careful probability-led interpretation, PI may still have value as a diagnosis-supporting tool where highly elevated ICP or dangerously decreased CPP is suspected.

Zweifel et al Neurosurgery 2012

Doppler transcrânien : *valable y compris en cas de gravité moyenne*

Transcranial Doppler to Screen on Admission Patients With Mild to Moderate Traumatic Brain Injury

TABLE 1. Univariate Analysis of Demographic and Biochemical Data Collected on Admission in 98 Patients With Mild to Moderate Traumatic Brain Injury According to Their Neurological Status on Posttrauma Day 7: Patients With and Without Secondary Neurological Deterioration[a]

	No SND (n = 77)	SND (n = 21)	P
Age, y	34 (15-84)	46 (20-80)	.04
Sex, M/F	64/13	20/1	.16
Injury type, n			.20
Motor vehicle accident	32	8	
Sports	24	3	
Others	21	10	
Initial GSC score	14 (9-15)	13 (10-15)	<.01
ISS	9 (2-43)	13 (5-41)	<.01
H-AIS	1 (1-4)	3 (3-4)	<.01
Extracranial injuries (yes/no), n	40/37	13/8	.57
Heart rate, bpm	78 (49-119)	75 (44-120)	.46
MAP, mm Hg	90 (60-114)	93 (64-158)	.69
Hemoglobin, g/dL	14.0 (8.0-18.6)	13.5 (7.0-16.8)	.03
Serum sodium, mmol/L	141 (133-149)	140 (135-146)	.33
Mechanical ventilation (yes/no), n	10/67	11/10	<.01
Vasoactive agents (yes/no), n	3/74	8/13	<.01
TCDB I/II	53/24	0/21	<.01
Injury-to-CT time, min	180 (65-540)	120 (15-210)	<.01

- SND = secondary neurological deterioration
- = perte de 2 points de Glasgow

Bouzat et al Neurosurgery 2011

Doppler transcrânien : *valable y compris en cas de gravité moyenne*

TABLE 2. Univariate Analysis of Transcranial Doppler Measurements Collected on Admission in 98 Patients With Mild to Moderate Traumatic Brain Injury According to Their Neurological Status on Posttrauma Day 7: Patients With and Without Secondary Neurological Deterioration[a]

	No SND (n = 77)	SND (n = 21)	P
FVm, cm/s	49 (31-80)	31 (18-60)	<.01
FVs, cm/s	84 (47-128)	69 (38-119)	<.01
FVd, cm/s	34 (18-64)	18 (11-36)	<.01
Pulsatility index	1.02 (0.66-1.83)	1.47 (1.07-2.33)	<.01
Injury-to-TCD time, min	215 (42-700)	300 (90-690)	.03

Bouzat et al Neurosurgery 2011

Doppler transcrânien : *valable y compris en cas de gravité moyenne*

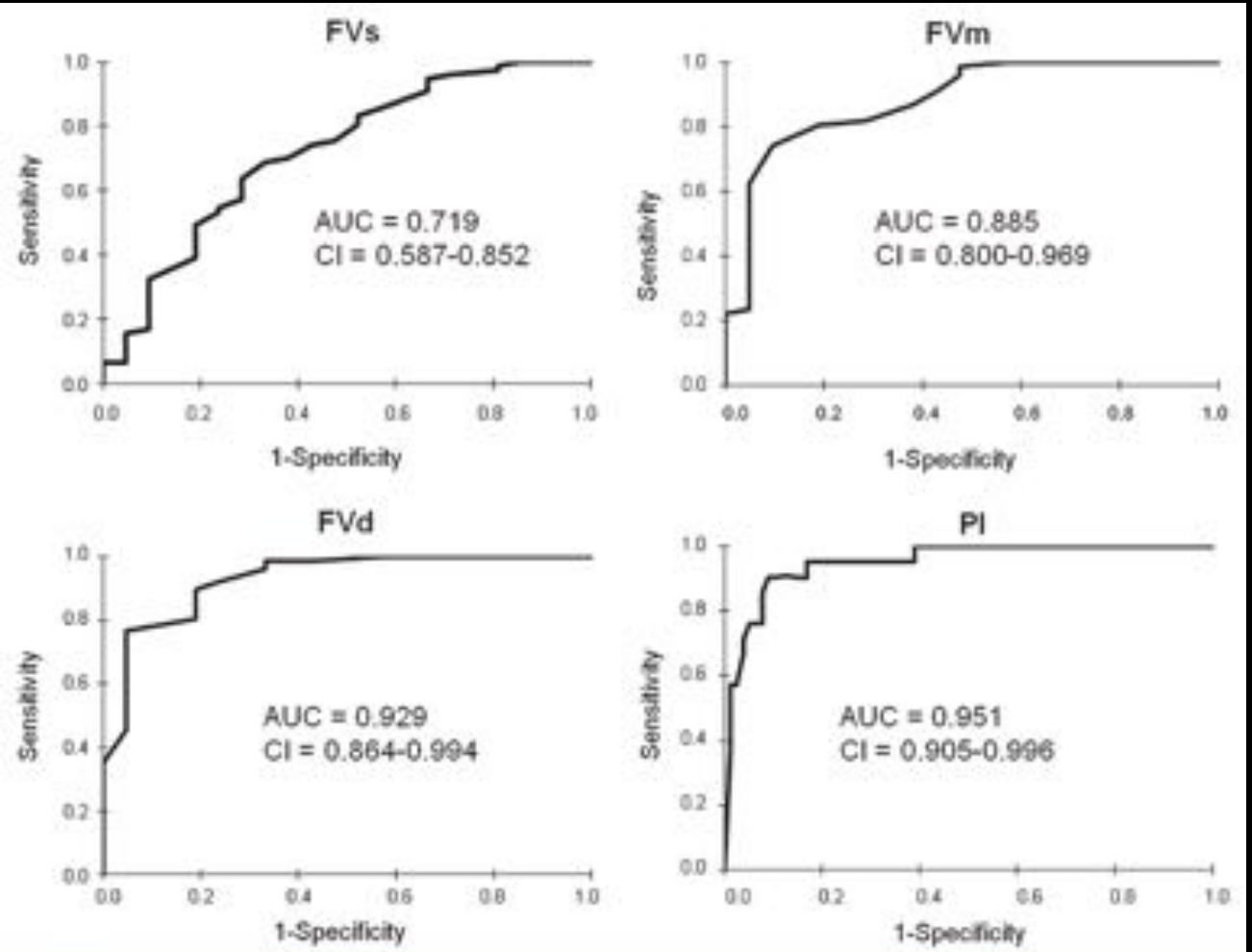


FIGURE 1. *Receiver-operating characteristic curves of the transcranial Doppler (TCD) parameters. AUC, area under the curve; CI, 95% confidence interval; FVd, FVm, and FVs, diastolic, mean, and systolic cerebral blood flow velocities, respectively; PI, pulsatility index.*

Bouzat et al Neurosurgery 2011

Doppler transcrânien :
valable y compris en cas de gravité moyenne

TABLE 3. Threshold Values and the Corresponding Sensitivity, Specificity, and Positive and Negative Likelihood Ratios of Each Transcranial Doppler Parameter[a]

TCD Parameter	Cutoff	Sensitivity, %	Specificity, %	Correctly Classified, %	PLR	NLR
FVm	33 cm/s	99	52	89	2.1	0.02
FVs	58 cm/s	95	33	82	1.4	0.16
FVd	25 cm/s	92	76	89	3.9	0.10
PI	1.25	90	91	91	9.9	0.10

Bouzat et al Neurosurgery 2011

Doppler transcrânien : *valable y compris en cas de gravité moyenne*

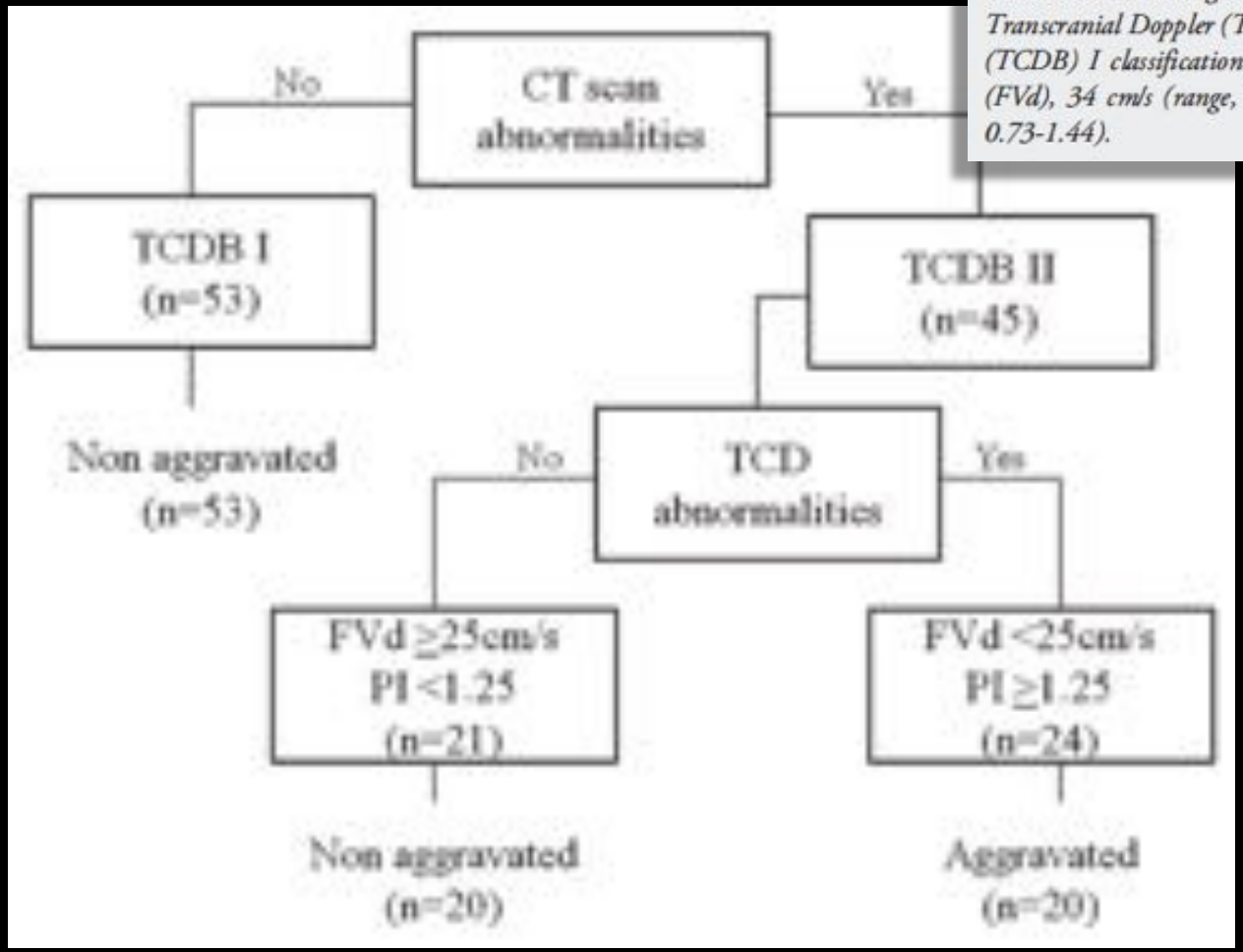


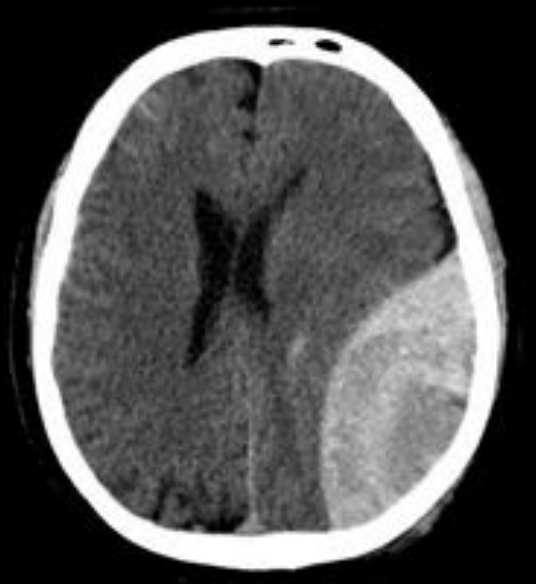
FIGURE 2. *Prediction tree constructed from recursive-partitioning analysis according to the incidence of subsequent neurological deterioration in 98 patients admitted to the emergency room after mild to moderate traumatic brain injury. Transcranial Doppler (TCD) values of patients with Trauma Coma Data Bank (TCDB) I classification were as follows: diastolic cerebral blood flow velocity (FVd), 34 cm/s (range, 18-64 cm/s); and pulsatility index (PI), 1.03 (range, 0.73-1.44).*

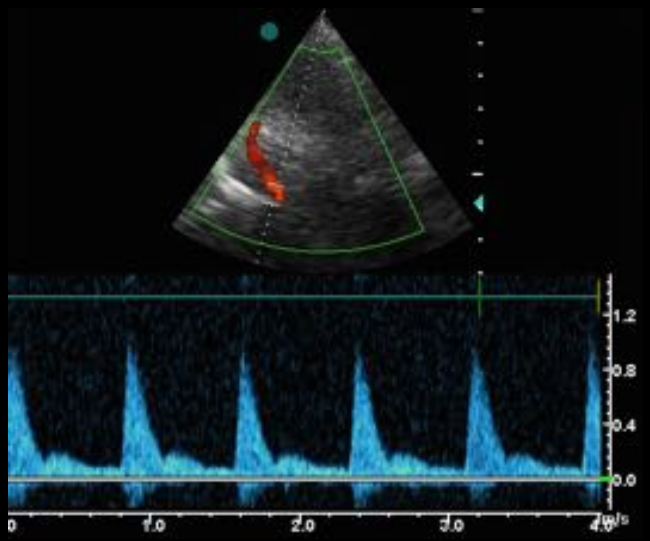
Bouzat et al Neurosurgery 2011

Circulation cérébrale et HIC :

reconnaitre une indication de traitement urgent

Ne pas baisser les bras trop vite

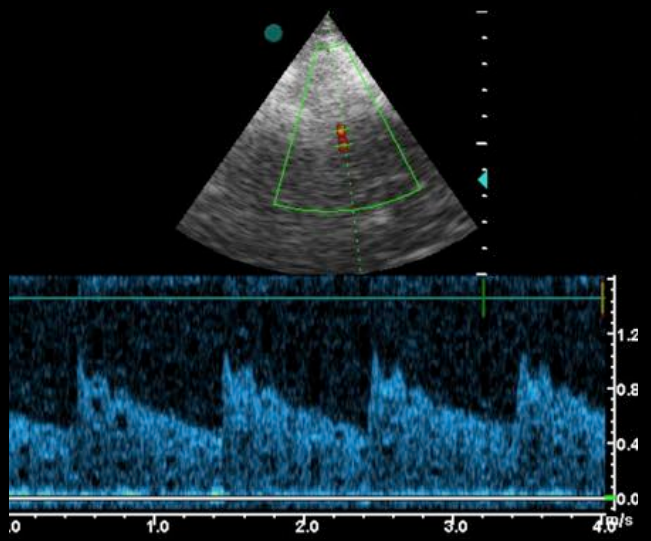




Pré op

PA = 90/50

Glasgow 8



Post op

PA = 140/90

Glasgow 13

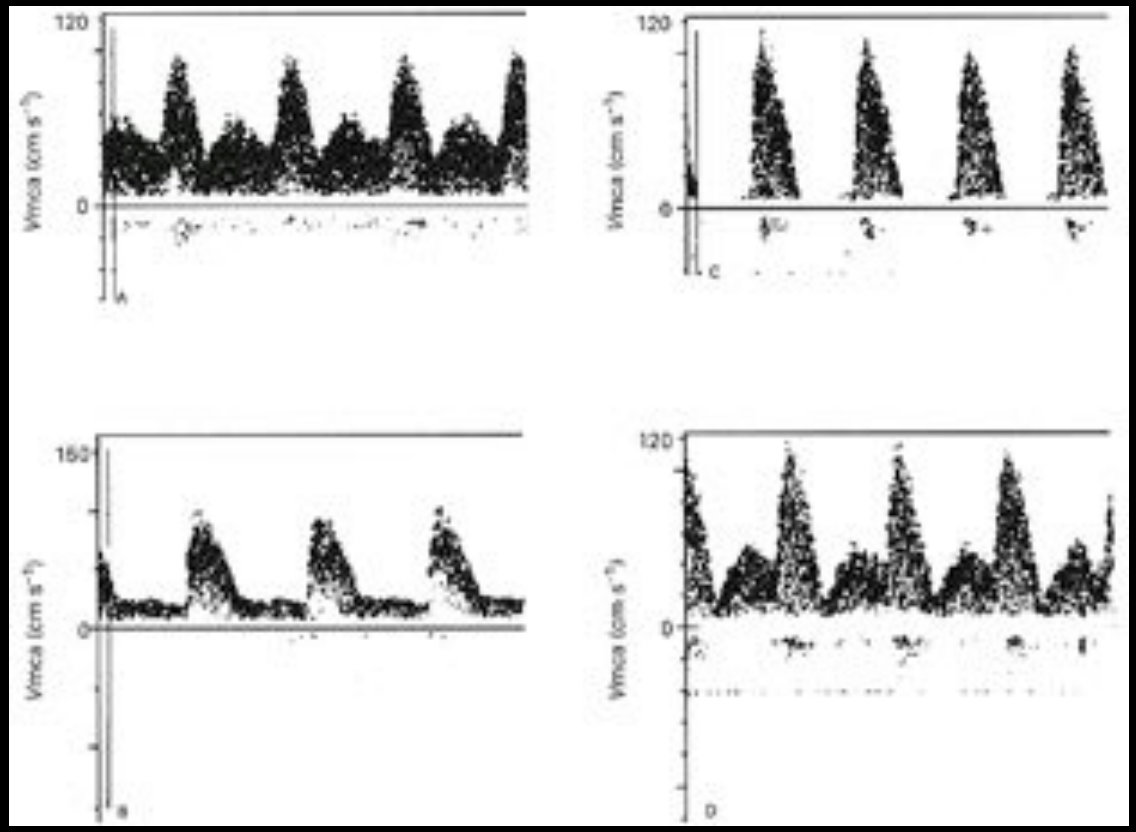
Doppler transcrânien et détection des ACSOS :
Premier ACSOS = niveau de PA

110/60 mm Hg

Vmca = 61 cm/s

85/37 mm Hg

Vmca = 46 cm/s



68/35 mm Hg

Vmca = 34 cm/s

115/58 mm Hg

Vmca = 60 cm/s

A Lam. *Br J Anaesth*; 1992, 68:424-428

Doppler transcrânien et HTIC :
Risques de faux positifs si HTA ancienne

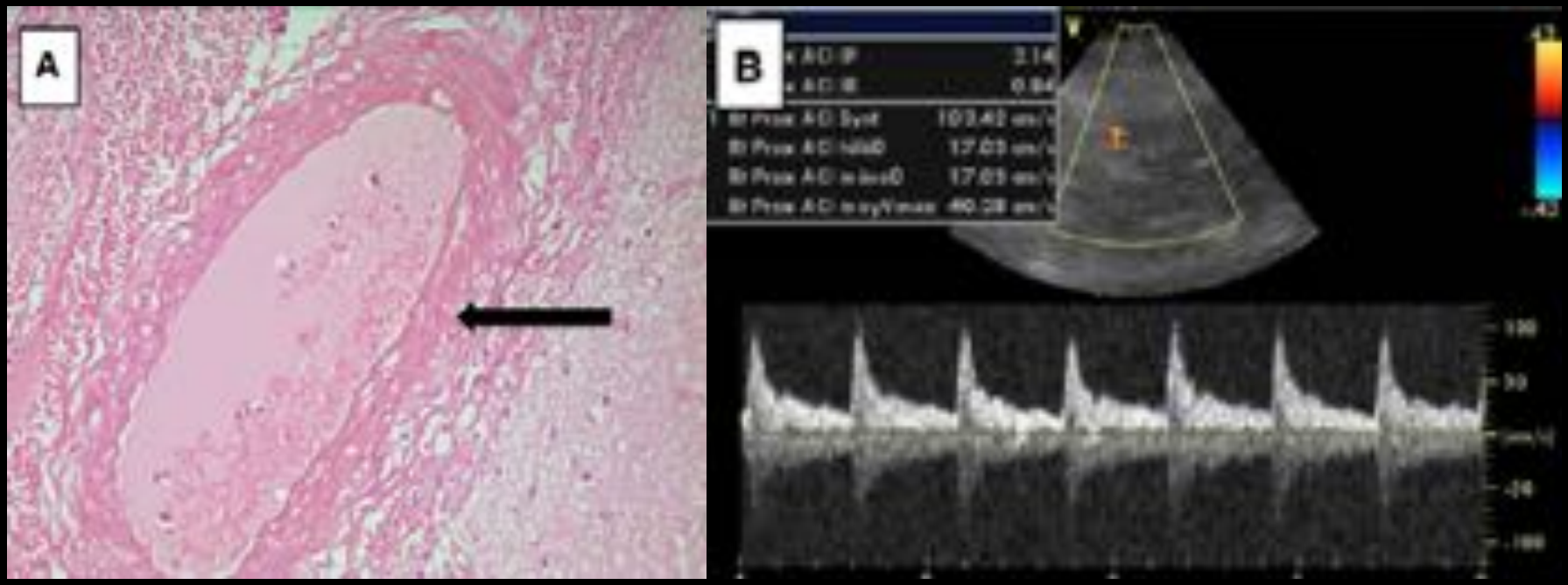


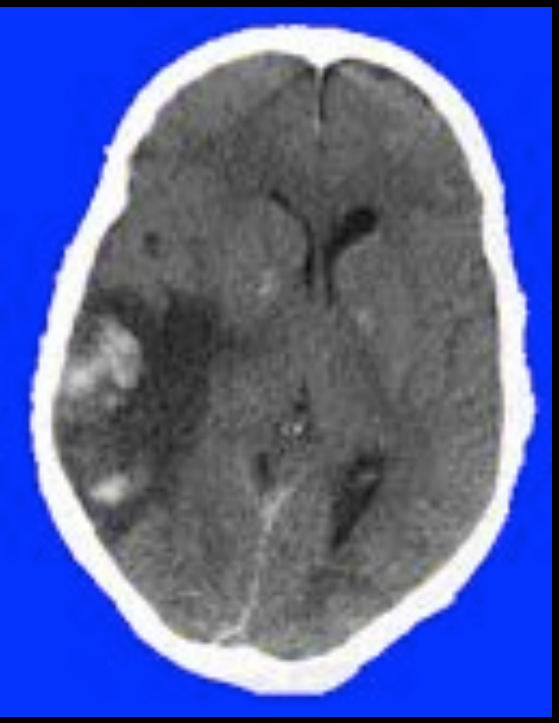
Fig. 1 Example post-mortem histopathology of brain tissue showing vasculopathy in cerebral vessels in one patient with low ICP and high PI (*Panel A*). Note the thickness of the vessel wall at the media level (*arrow*). Example of trancranial Doppler of the middle cerebral artery with low DV and high PI despite low ICP (*Panel B*)

Ahmad et al Intensive Care Med 2013

Doppler trancrânien :
…monitorage des traitements

Diapo personnelle N Bruder CHU Marseille

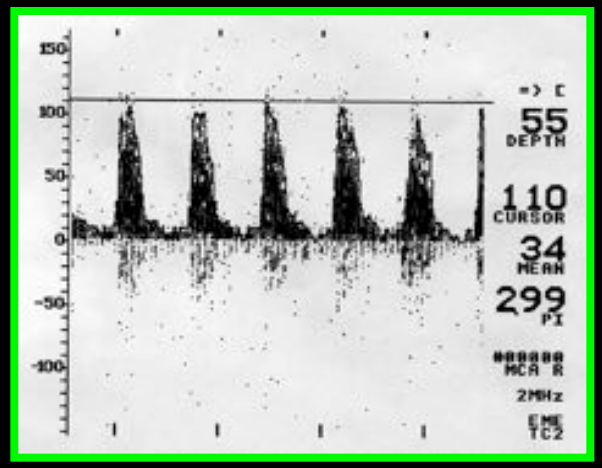
Traitement de l'HIC : Mannitol

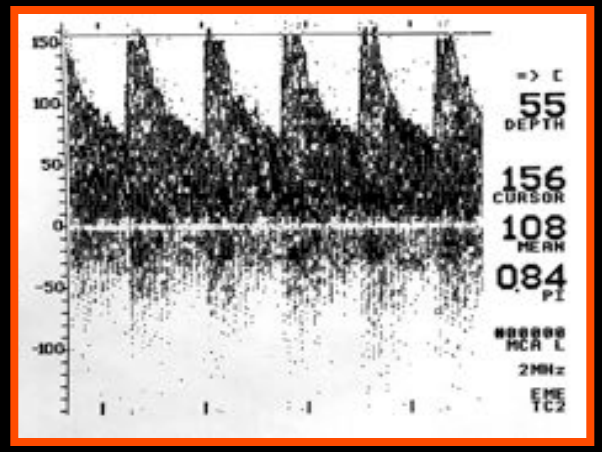


PIC	PPC	SjO_2
71	46	51
22	96	61
mm Hg	mm Hg	%

Avant

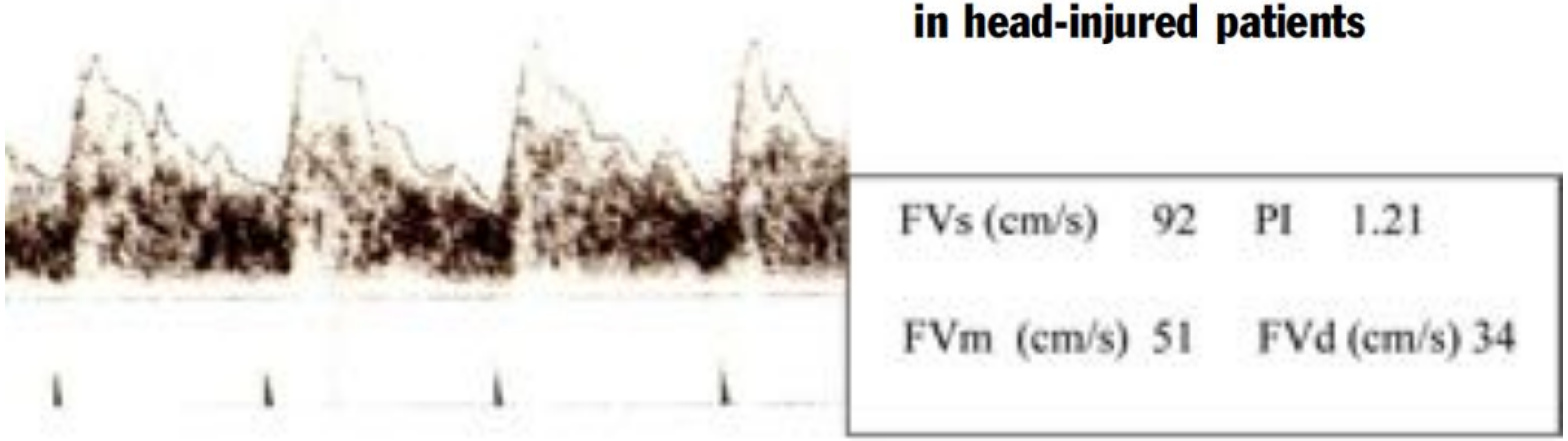
Après





Diagnostic indirect de dissection carotidienne

Detecting traumatic internal carotid artery dissection using transcranial Doppler in head-injured patients

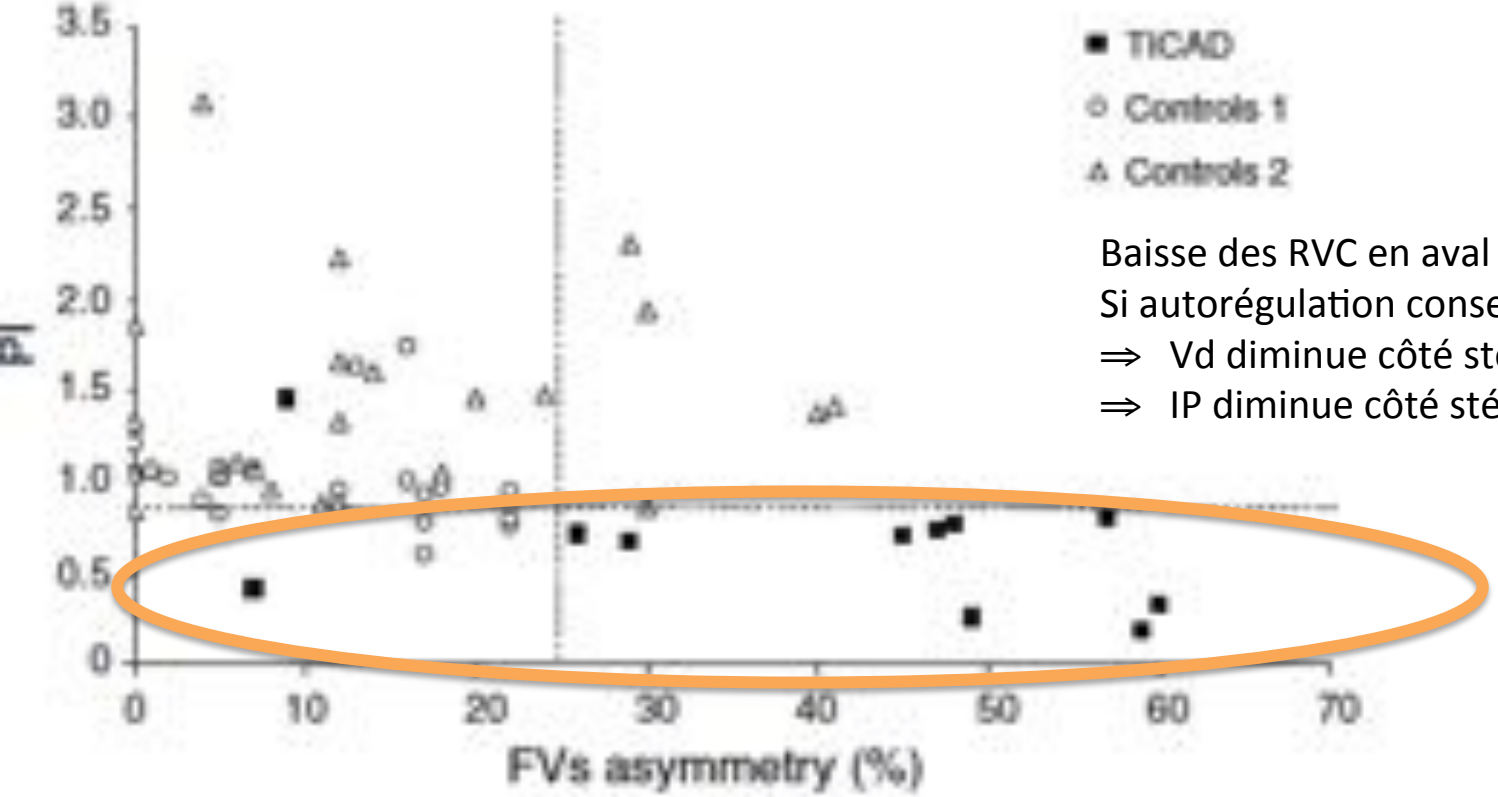


Asymétrie Vs > 25 % et IP < 0.8

Bouzat et al Intensive Care Med 2010

Diagnostic indirect de dissection carotidienne

Detecting traumatic internal carotid artery dissection using transcranial Doppler in head-injured patients



Baisse des RVC en aval de la sténose
Si autorégulation conservée
⇒ Vd diminue côté sténose
⇒ IP diminue côté sténose

Bouzat et al Intensive Care Med 2010

3. Variations avec le CO2

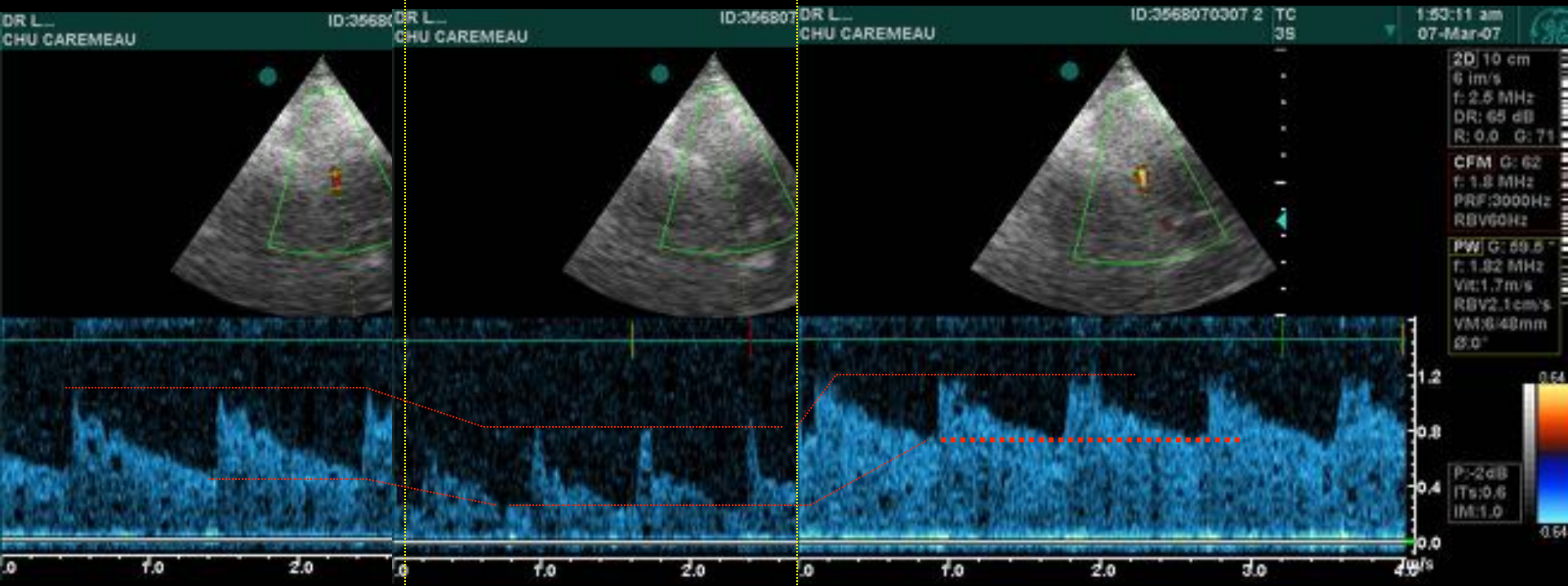
... surveiller la tolérance d'une hypocapnie

Variations du débit sanguin cérébral avec la capnie :
… Exemple sur volontaire sain

Normocapnie

Hypocapnie

Hypercapnie



Vasoconstriction
Bas débit
Risque ischémique

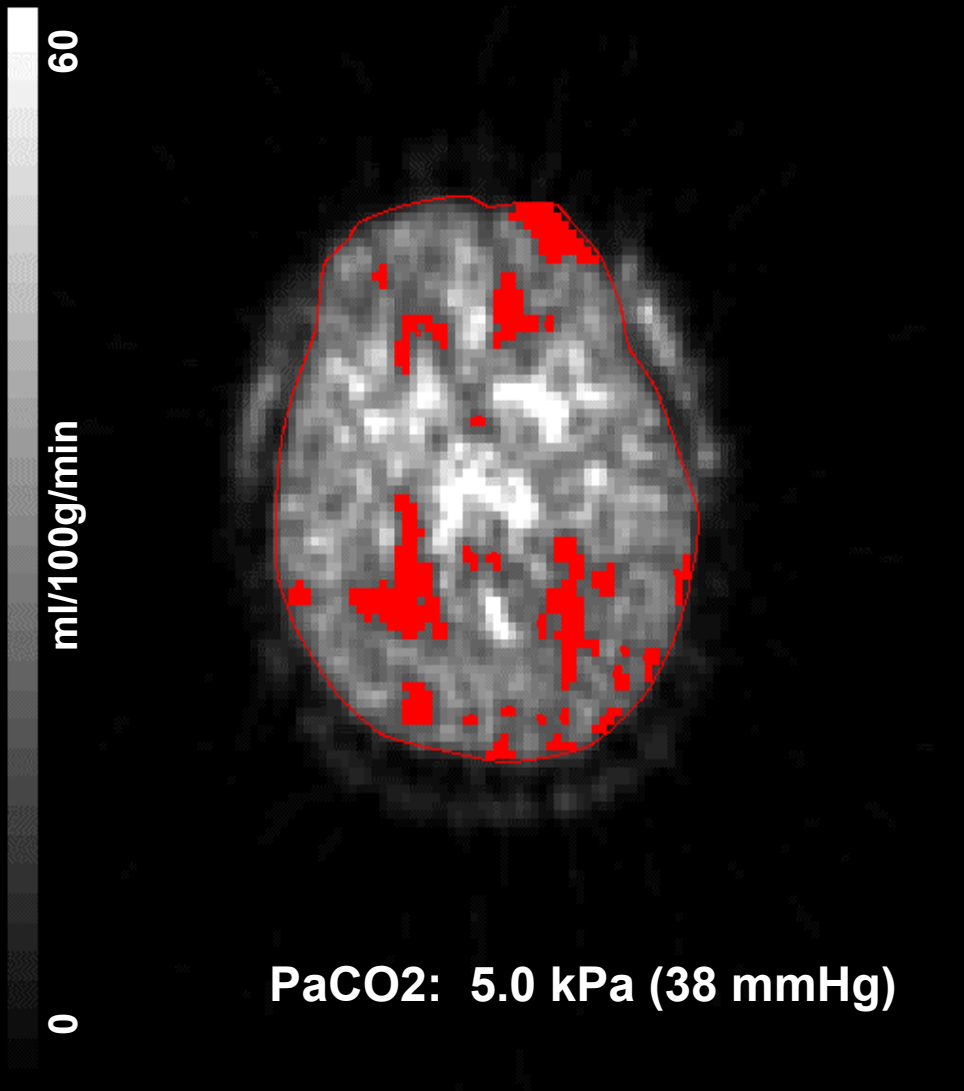
Vasodilatation
Hyperhémie
Risque de majoration HTIC

Wolfson Brain Imaging Centre
University of Cambridge

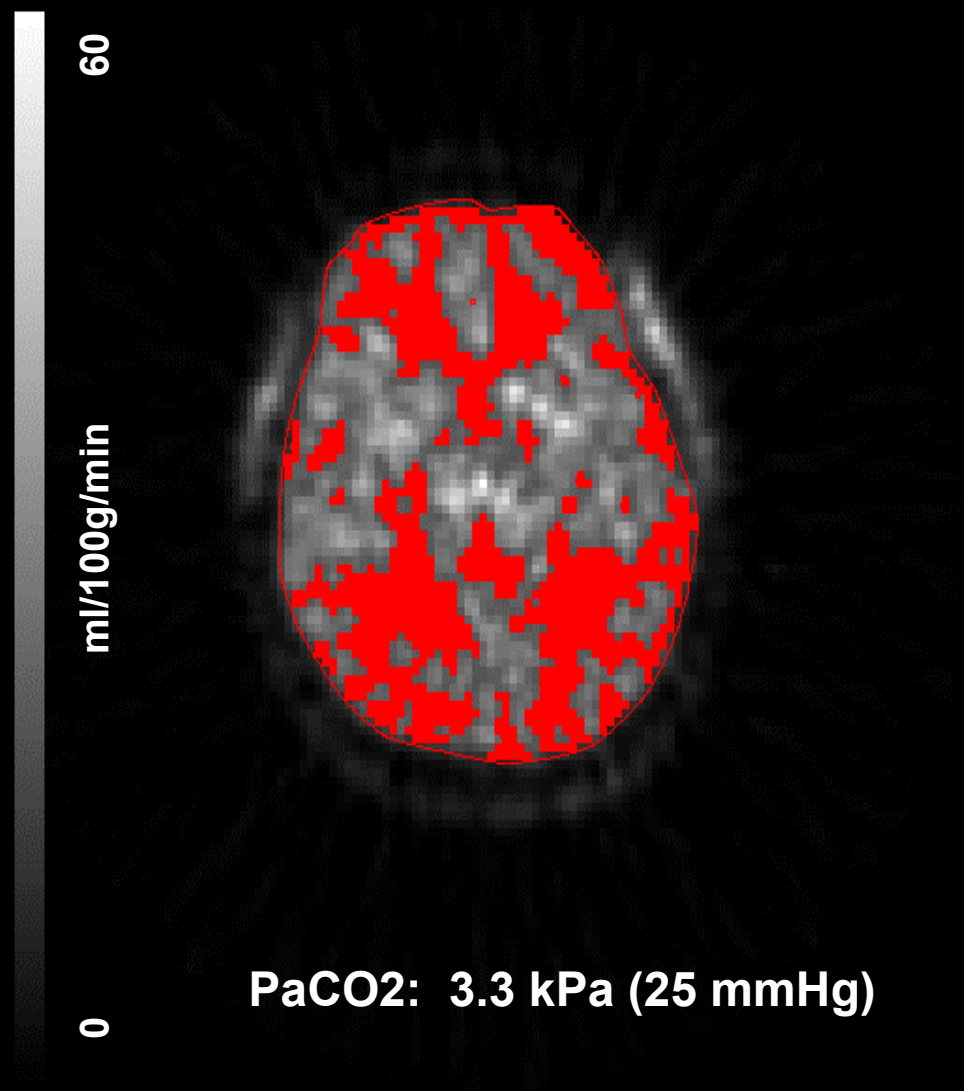
Acute head injury (6 hrs post impact)

Areas in red show regions with rCBF ≤ 20 ml/100g/min)

(Coles et al. Crit Care Med. 2002)



PaCO2: 5.0 kPa (38 mmHg)

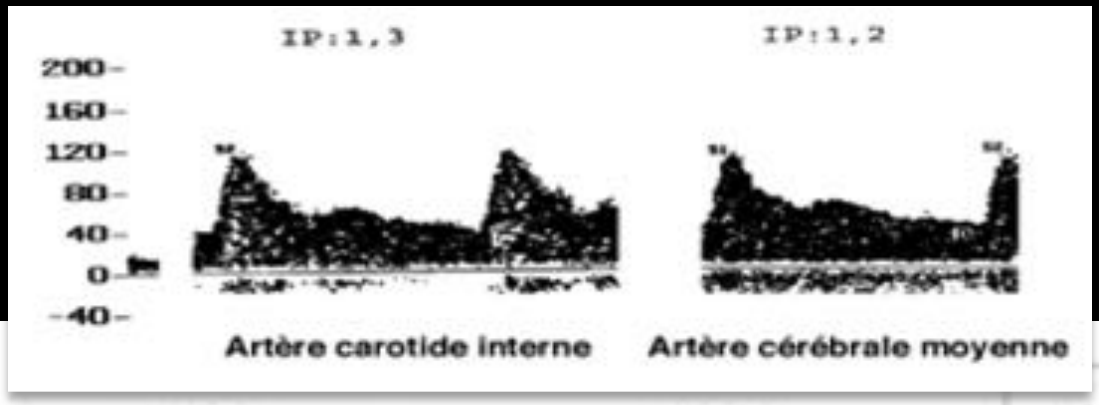


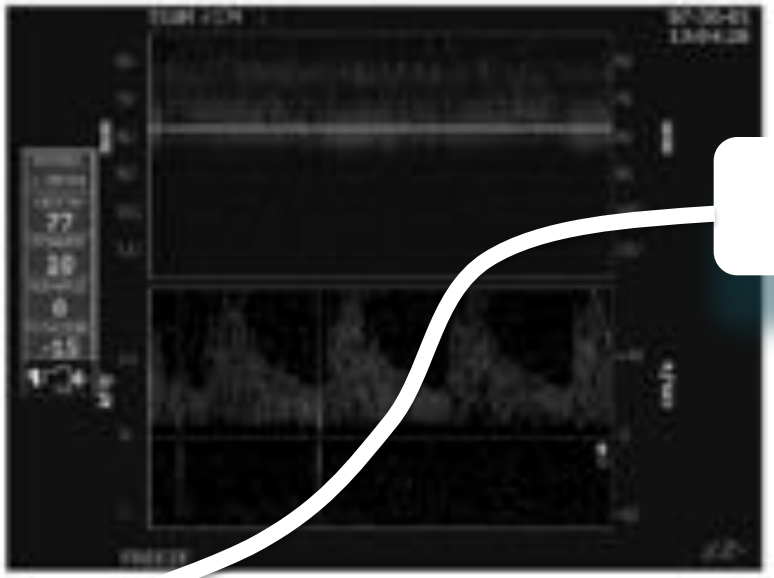
PaCO2: 3.3 kPa (25 mmHg)

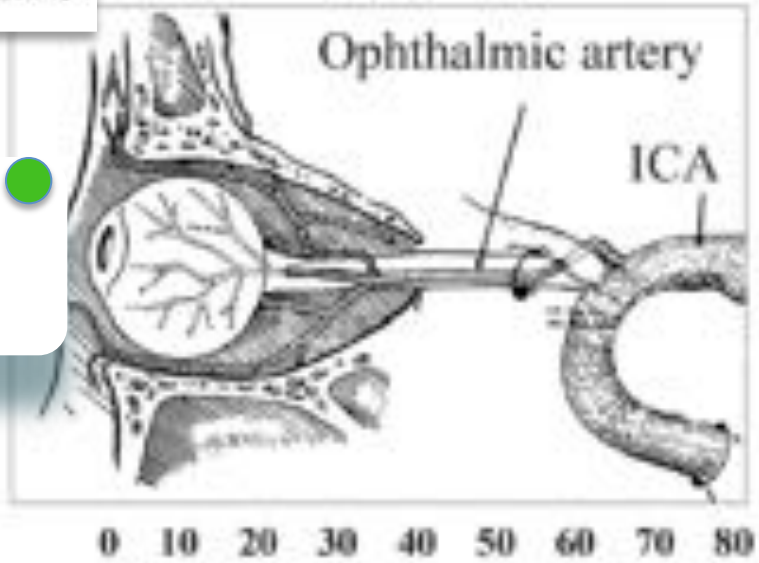
4. Artère carotide interne

..portion intra crânienne par voie ophtalmique

Doppler intra crânien : approche trans orbitaire







ICA siphon signature at 60 to 80 mm depth

Saqqur et al Crit Care Med 2007

Doppler intra crânien : approche trans orbitaire

Diagnosis of Brain Death by Transcranial Doppler Sonography: Solutions for Cases of Difficult Sonic Windows

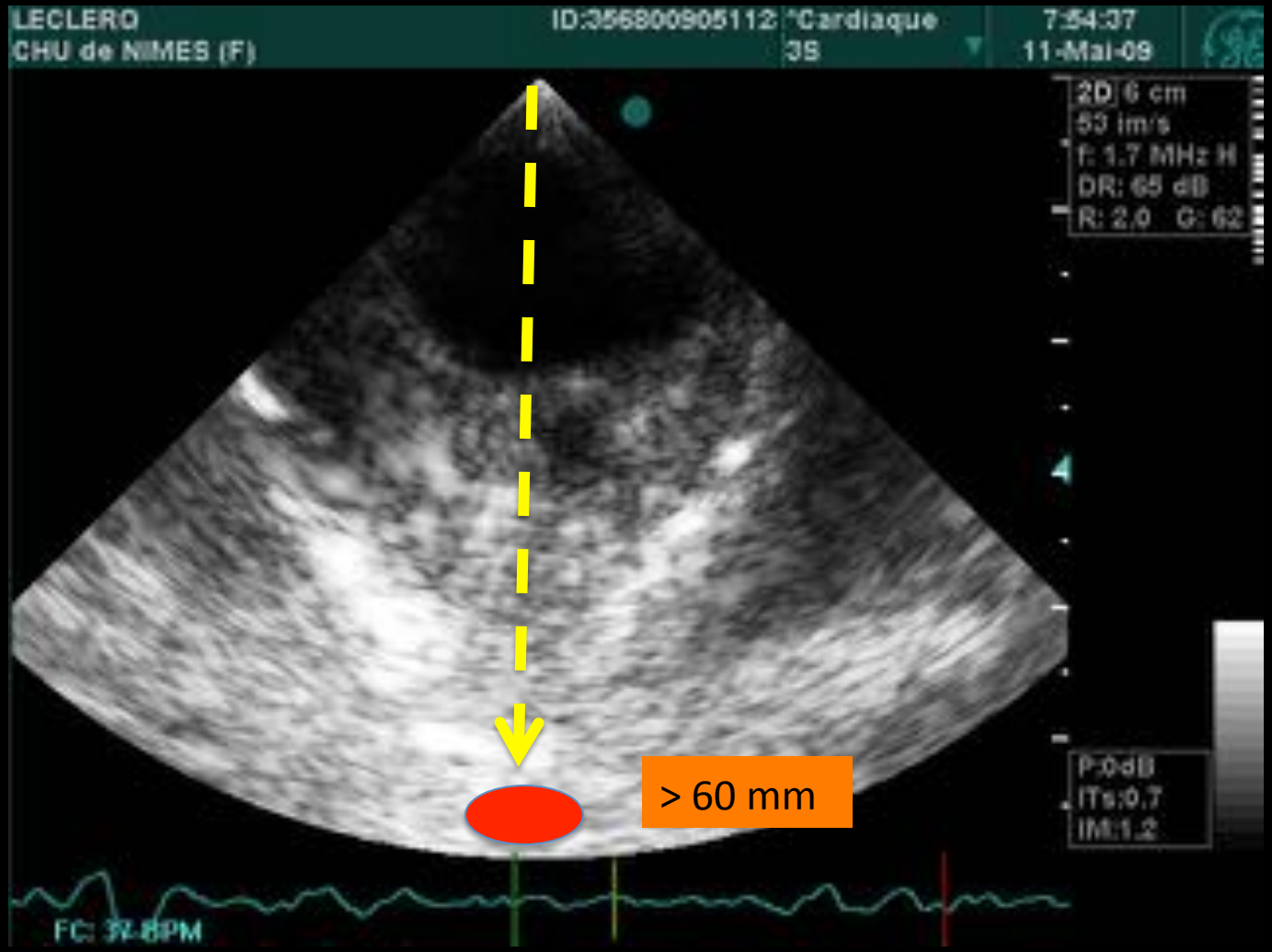
Table 1. Patients With Effective Insonation of the Arteries Through the Temporal Window (n = 43) and Orbital Window (n = 14)

	Right MCA	Left MCA	Right Carotid Siphon	Left Carotid Siphon	Carotid or MCA Insonation
Temporal window (n = 43)	40 (93%)	39 (91%)			43 (100%)
Orbital window (n = 14)			14 (100%)	14 (100%)	

MCA, middle cerebral artery.

Dominguez-Roldan et al Transplantation proceedings 2004

Doppler intra crânien : approche trans orbitaire

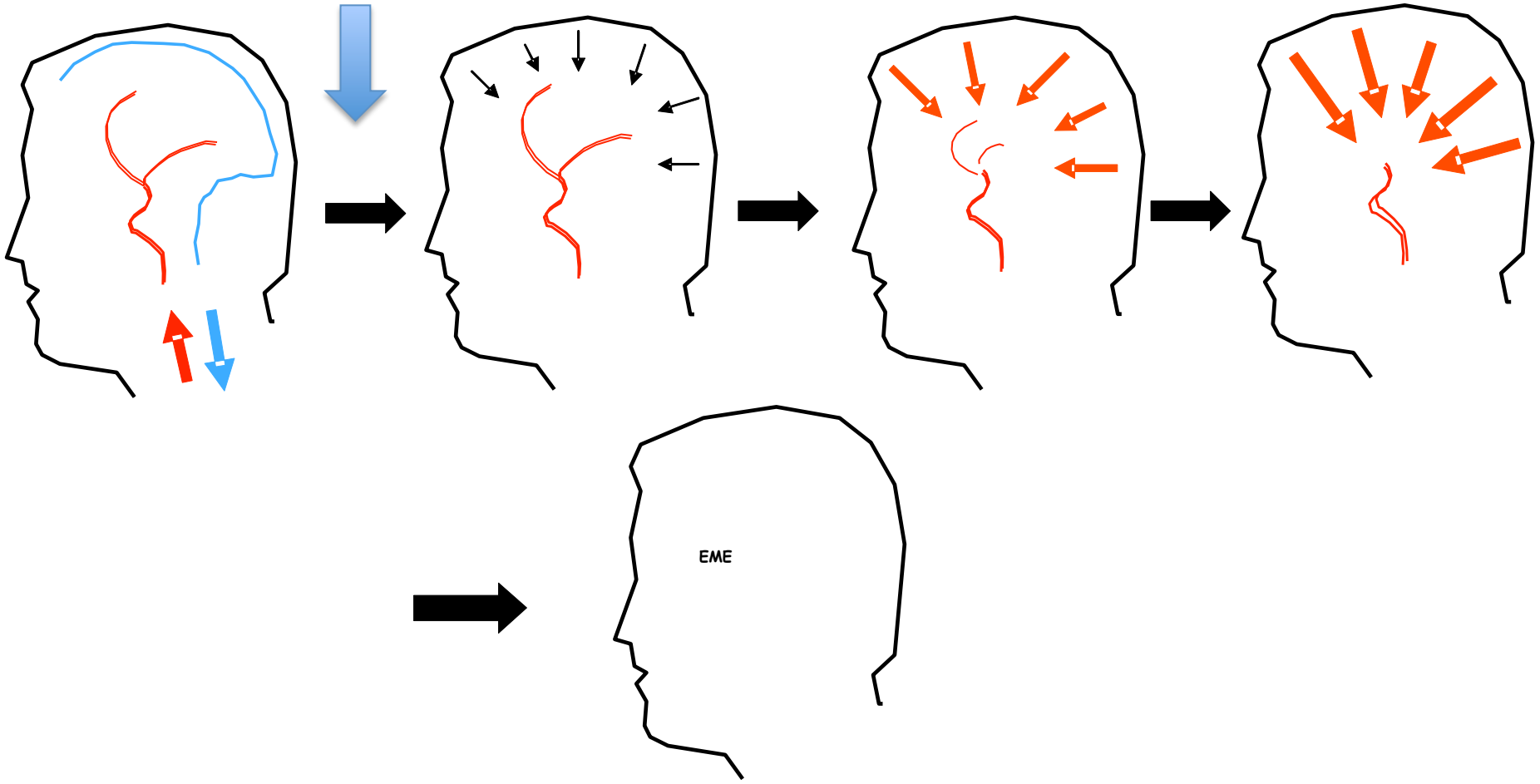


Saqqur et al Crit Care Med 2007

5. Mort cérébrale

... détecter le bon moment pour l'angioscanner ou l'EEG

Progression de l'HTIC = arrêt circulatoire cérébral



Angioscanner pour la **confirmation paraclinique** de ME :

Recommandations 2011 : abandon de 7 critères pour 4 (3 en pratique)

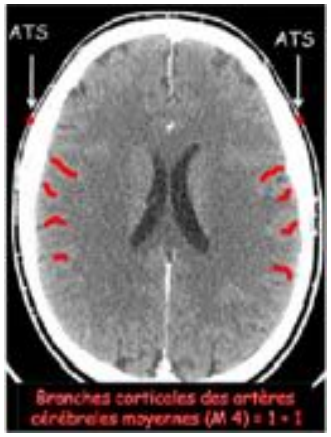
- **L'opacification de M2 ou M3 est fréquente au cours de la ME**

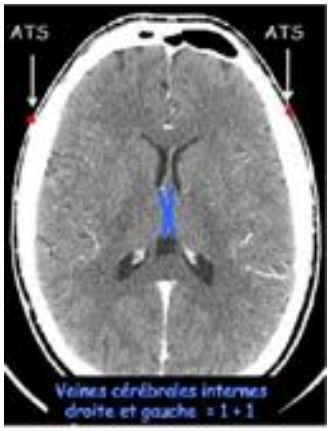
- En cas d'opacification unilatérale de M4, le diagnostic de ME peut être confirmé en l l'absence d'opacification des veines cérébrales internes

- La conclusion doit être « arrêt circulatoire cérébral » ou « absence d'arrêt circulatoire cérébral »

- Le constat de mort encéphalique est clinique, porté par deux cliniciens. C'est un certificat différent du CR d'angioscanner

- Attendre 6 heures entre clinique et TDM





Journal of Neuroradiology (2011) 38, 36—39

Doppler transcrânien et mort encéphalique : *choisir le bon moment pour l'angiographie ou l'EEG*

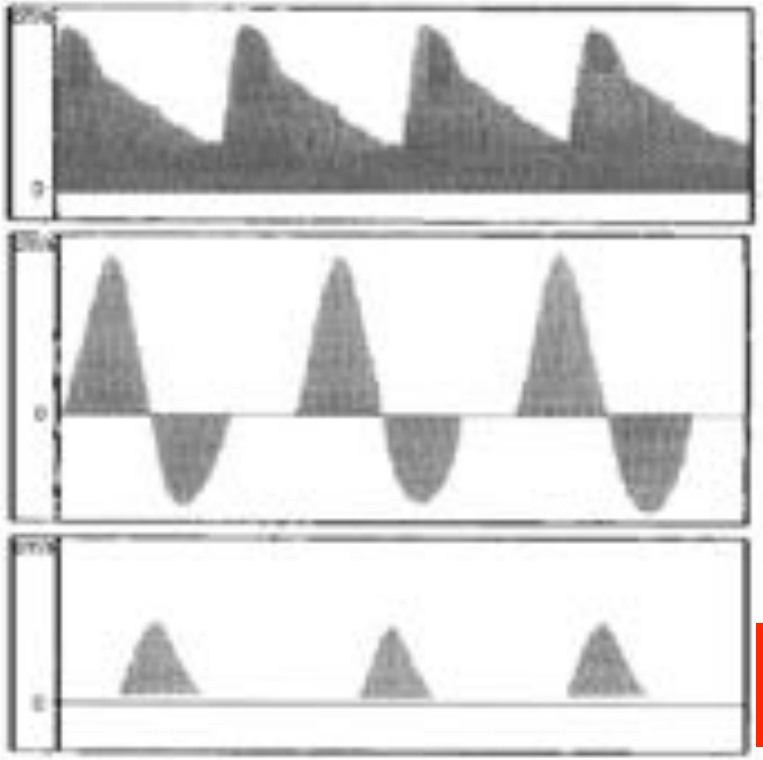


Fig. 1 Transcranial Doppler flow patterns. Transcranial Doppler flow patterns demonstrate normal flow with systolic and diastolic forward flow (*top*), oscillating flow with systolic forward flow and reversed diastolic flow (*middle*), and brief systolic forward flow (*bottom*)

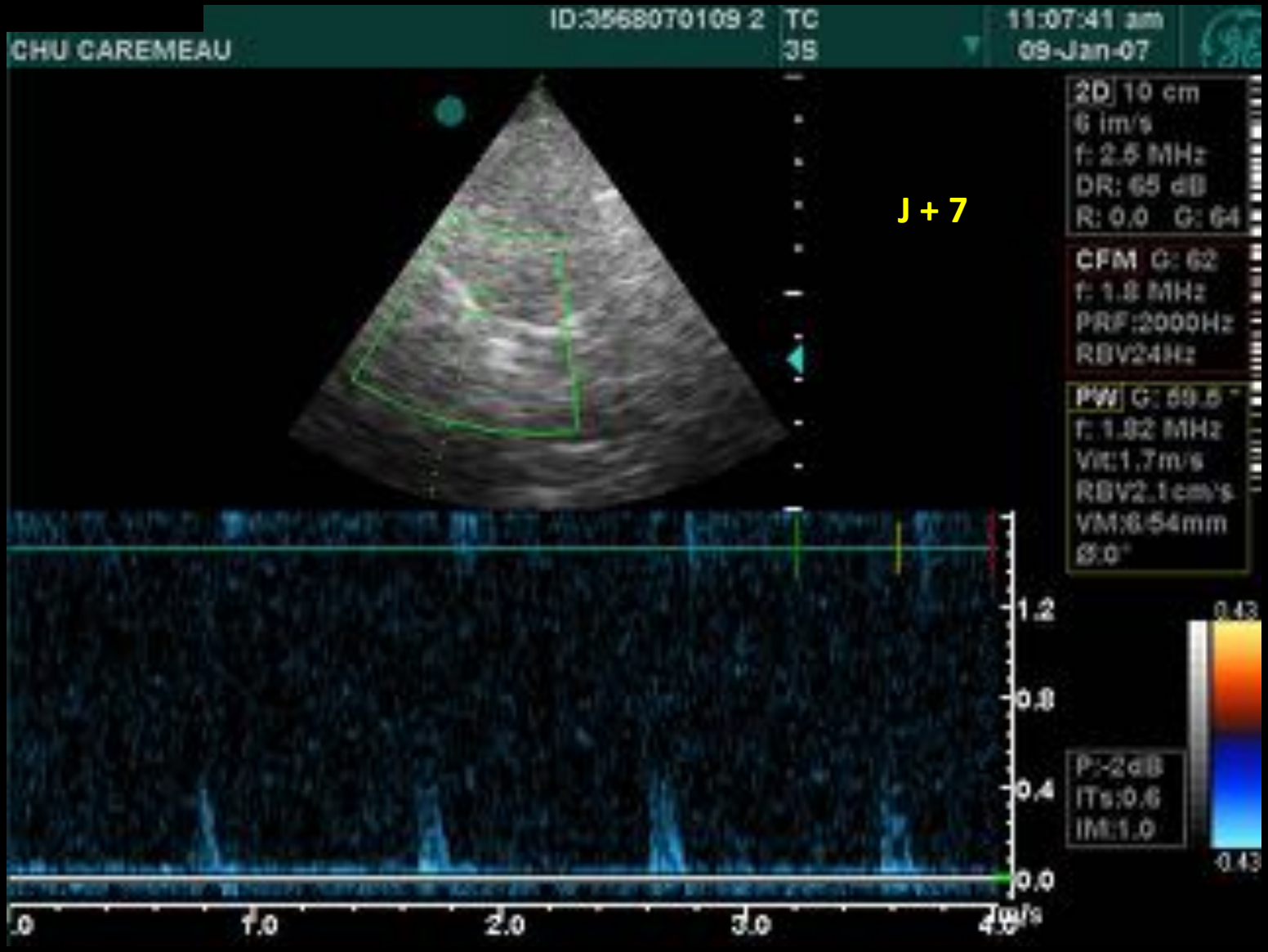
Table 2 Meta-analysis of high quality studies and sensitivity analysis of all included studies. *CI* confidence interval

Primary analysis: only high-quality studies		95% CI	
Sensitivity (%)	95	92	97
Specificity (%)	99	97	100
Sensitivity analysis: all studies, Veltkuyen et al. [24]: cerebral angiography and clinical criteria as reference test		95% CI	
Sensitivity (%)	89	86	91
Specificity (%)	99	99	100
Sensitivity analysis: all studies, Veltkuyen et al. [24]: EEG and clinical criteria as reference test		95% CI	
Sensitivity (%)	89	86	91
Specificity (%)	99	98	100

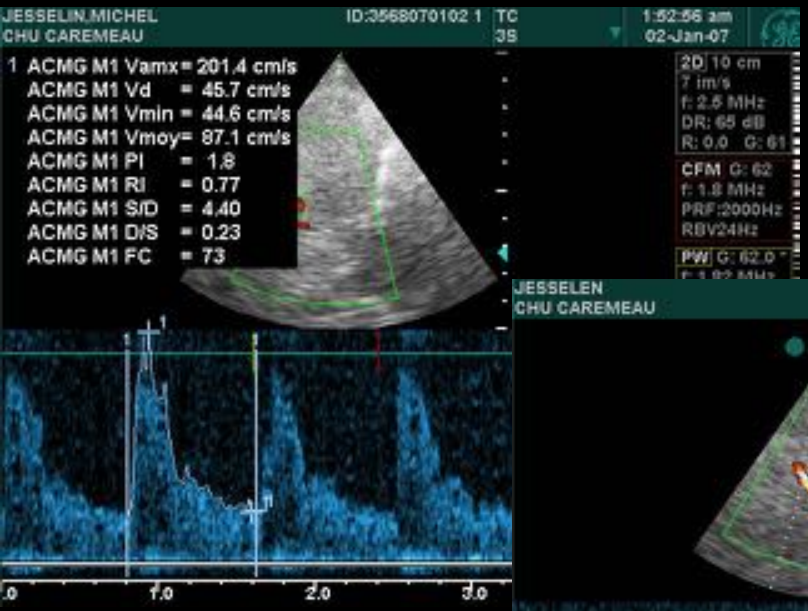
In conclusion, CCA by TCD in the basilar and both middle cerebral arteries correctly predicted fatal brain damage in all patients; therefore, TCD could be used to determine the appropriate moment for angiography. To accept a test for defining brain death, specificity should be 100%. We do believe that further research is needed to demonstrate that repeated TCD examination is able to produce this level of specificity.

Monteiro et al Intensive Care Med 2006

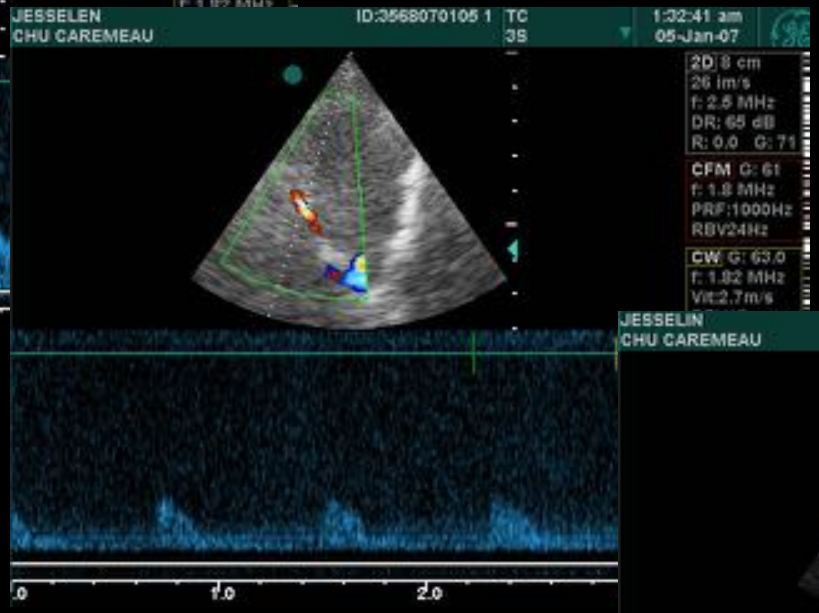
Patient de 67 ans, TC grave Contusion hémorragique, hémorragie méningée
Coma CGS 3 – pupilles aréactives



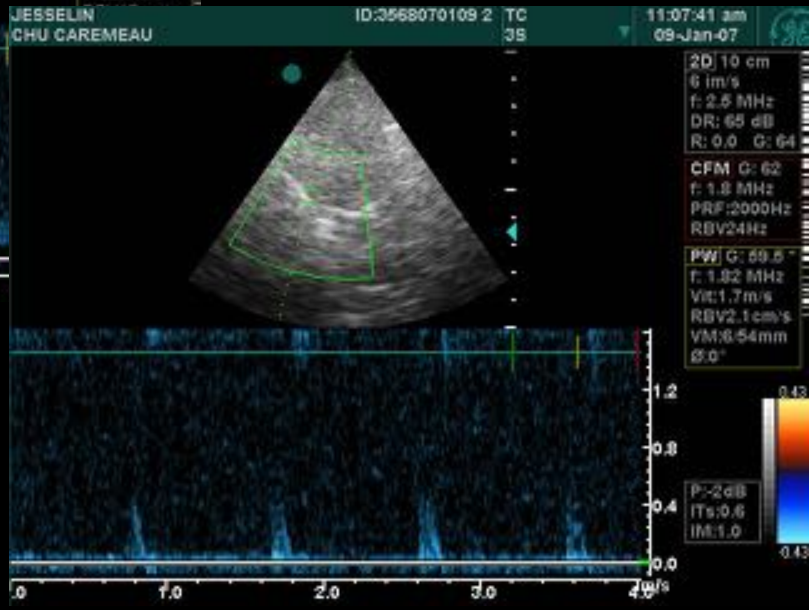
Patient de 67 ans, TC grave Contusion hémorragique, hémorragie méningée
Coma CGS 3 – pupilles réactives à l'entrée



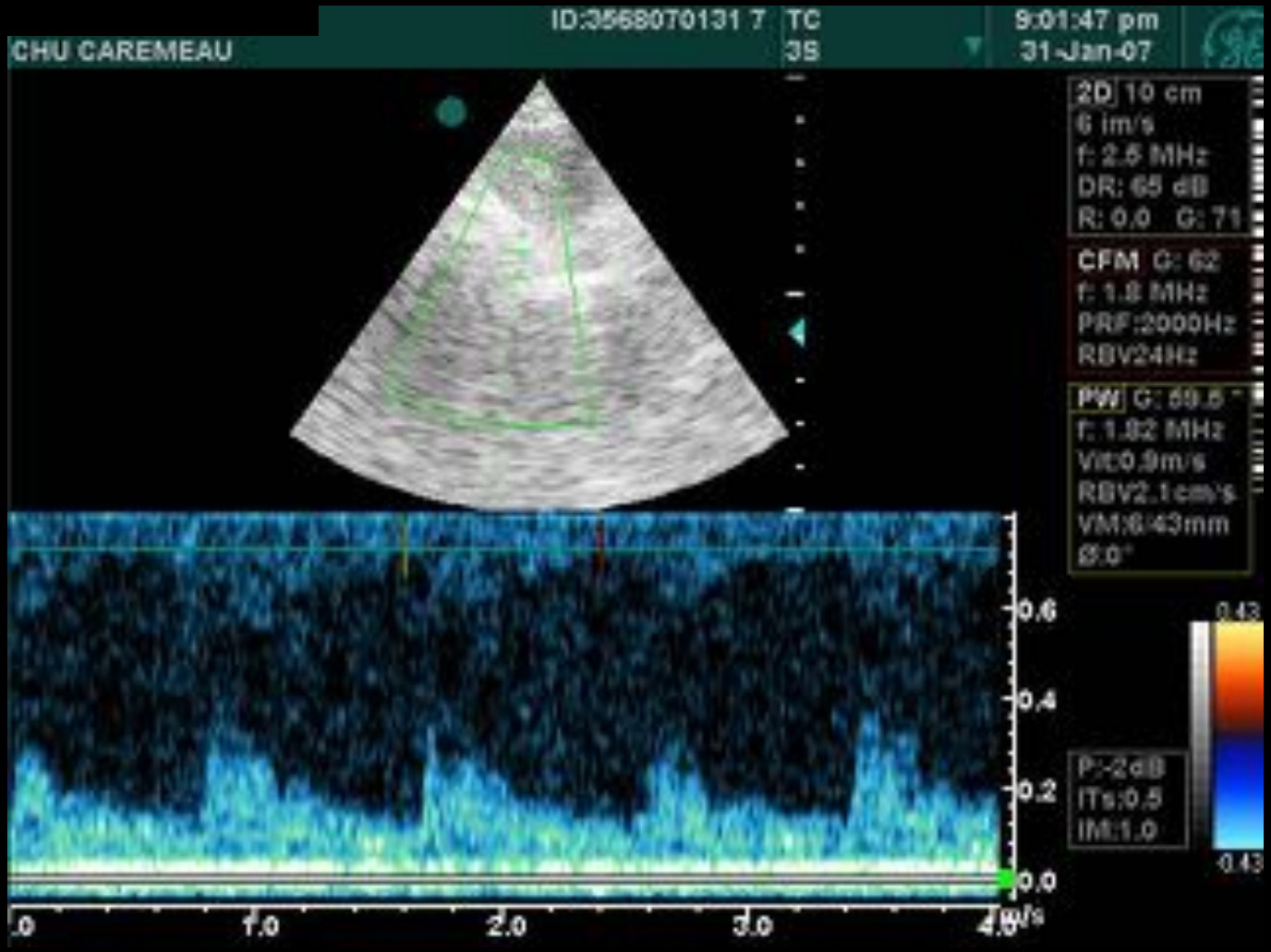
J + 3



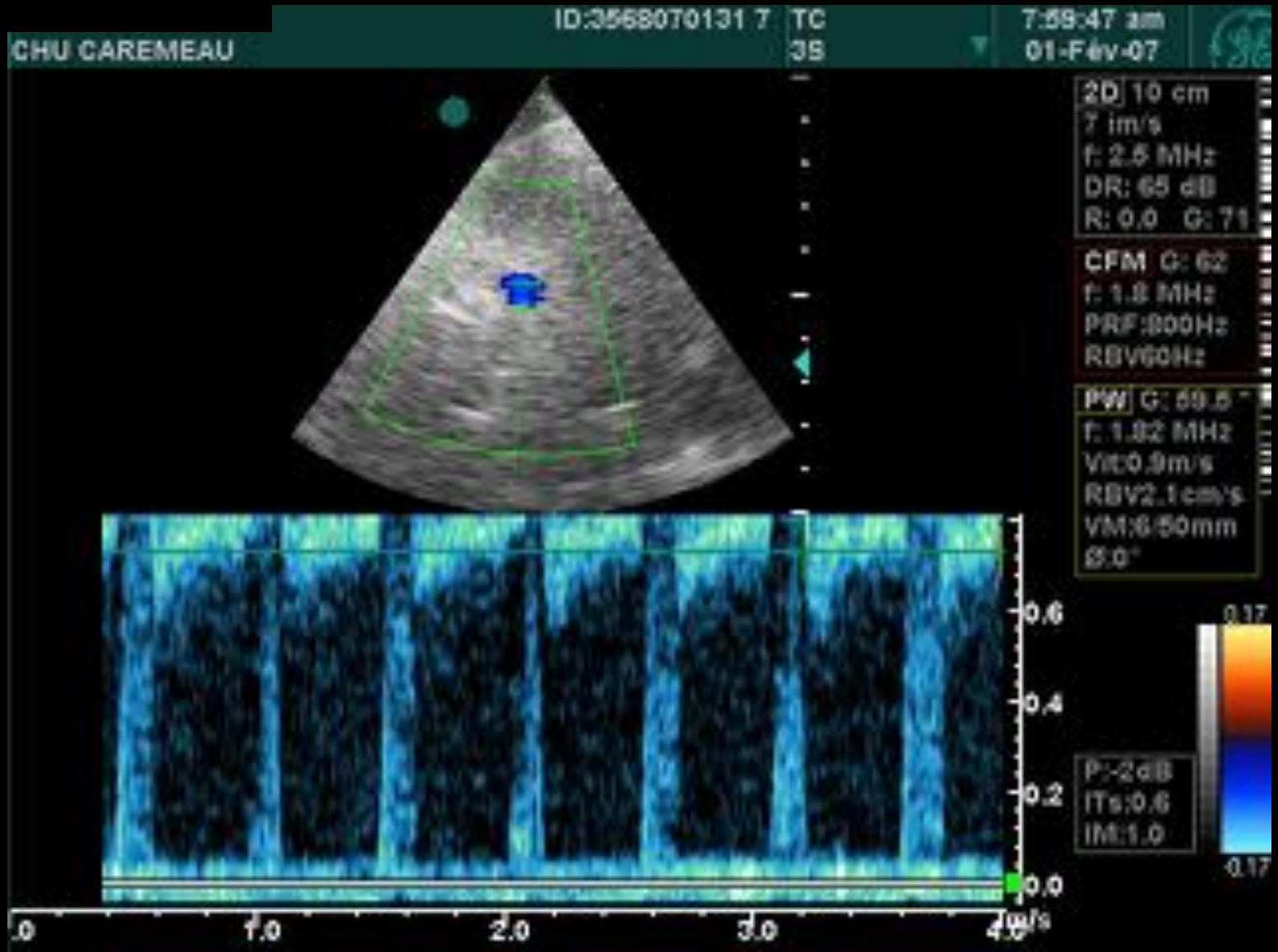
J + 7



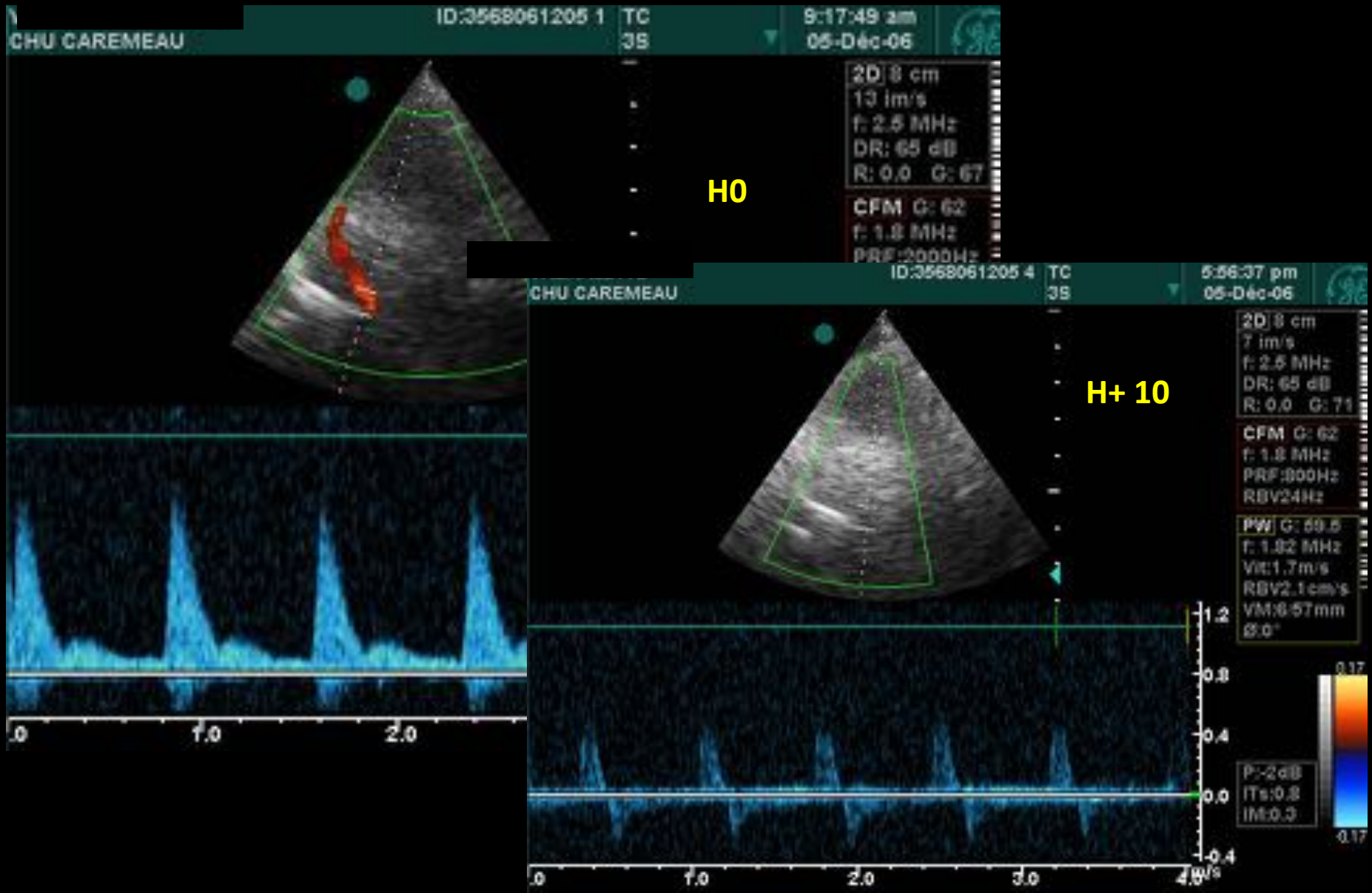
Patiente de 60 ans, inondation tétra ventriculaire – mort cérébrale clinique
Test d'apnée : absence de ventilation
Doppler réalisé à l'entrée



Patiente de 60 ans, inondation tétra ventriculaire – mort cérébrale clinique
Test d'apnée : absence de ventilation
Doppler réalisé 12 heures après l'entrée

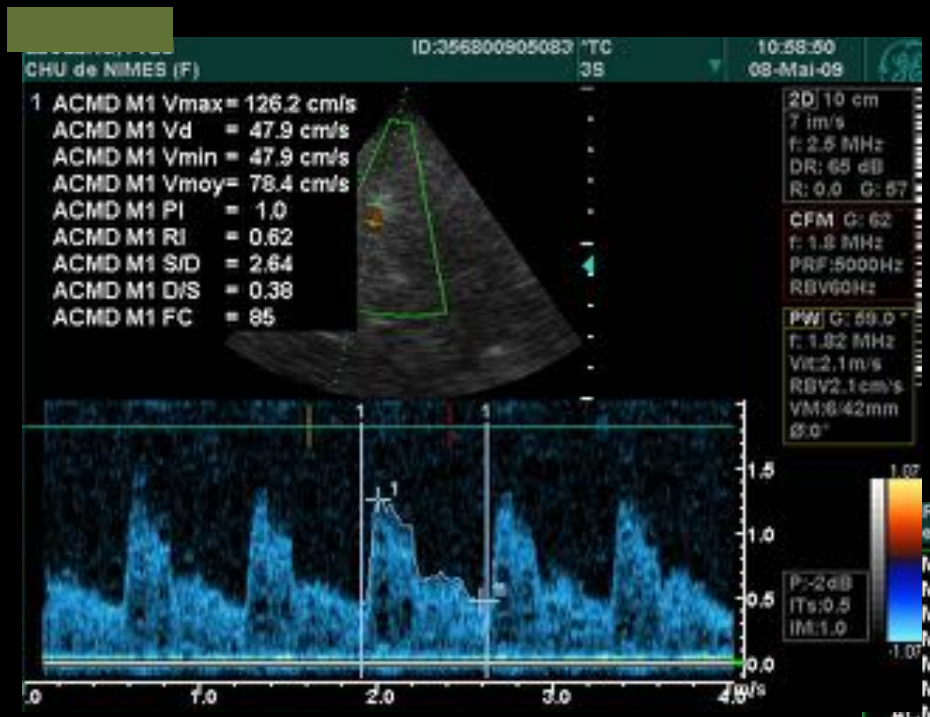


Patiente de 69 ans, AVC hémorragique

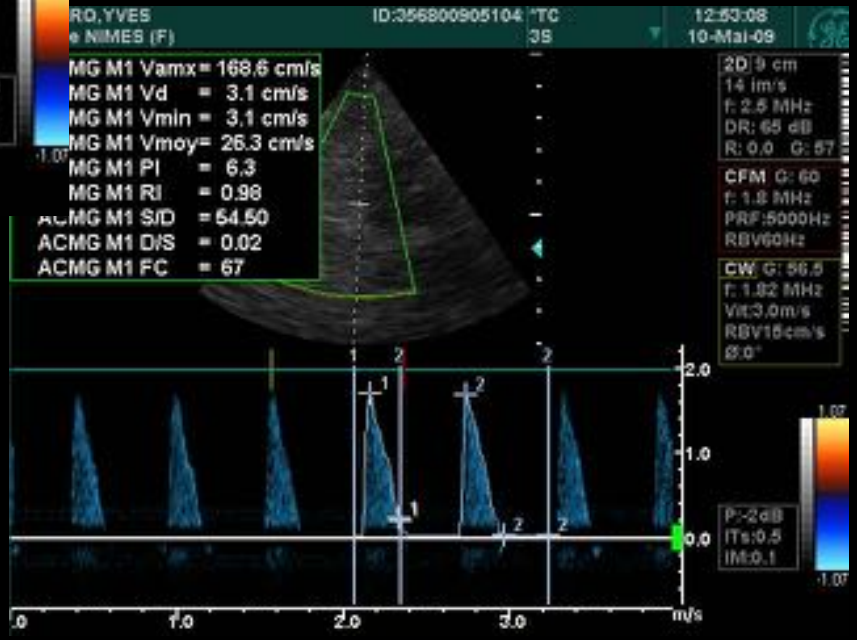


Doppler TC et mort encéphalique : flux pendulaires

Doppler TC et mort encéphalique : abolition du flux diastolique



J0



J2

6. Vasospasme

Doppler intra crânien : *vasospasme*

Vitesses moyennes élevées :

- ACM >120cm/s (>90 cm/s dans les 48°h)
- ACA >100cm/s
- TB > 85 cm/s
- 50cm/s des vitesses en 24h ou /côté controlatéral

120-150 Spasme modéré

150-200 Spasme menaçant

>200 Spasme symptomatique

Doppler intra crânien : *vasospasme*

Index de Lindegaard

$$\frac{\text{Vm MCA}}{\text{Vm ICA}}$$

< 3 : Hyperhémie
> 3 : Vasospasme modéré
> 6 : Vasospasme sévère

7. Echographie cérébrale

Doppler intra crânien : *déviation de la ligne médiane*

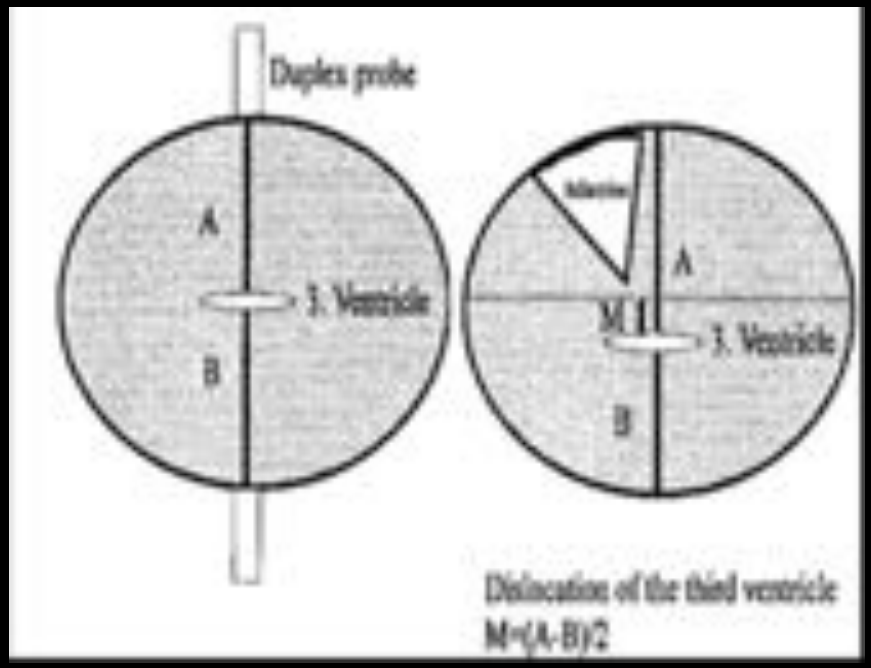
L'effet de masse

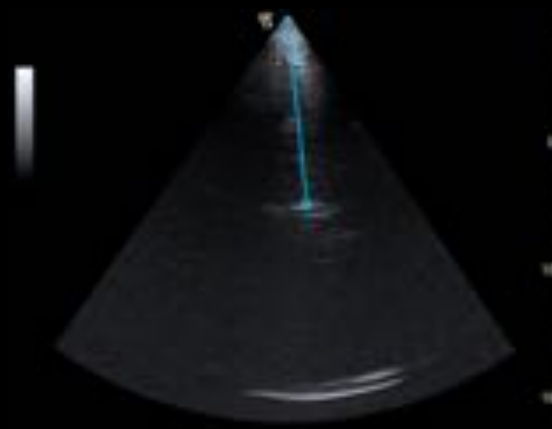
La déviation de la ligne médiane de plus de 0.5 cm

=> facteurs pronostiques majeurs

Perel et al BMJ 2008

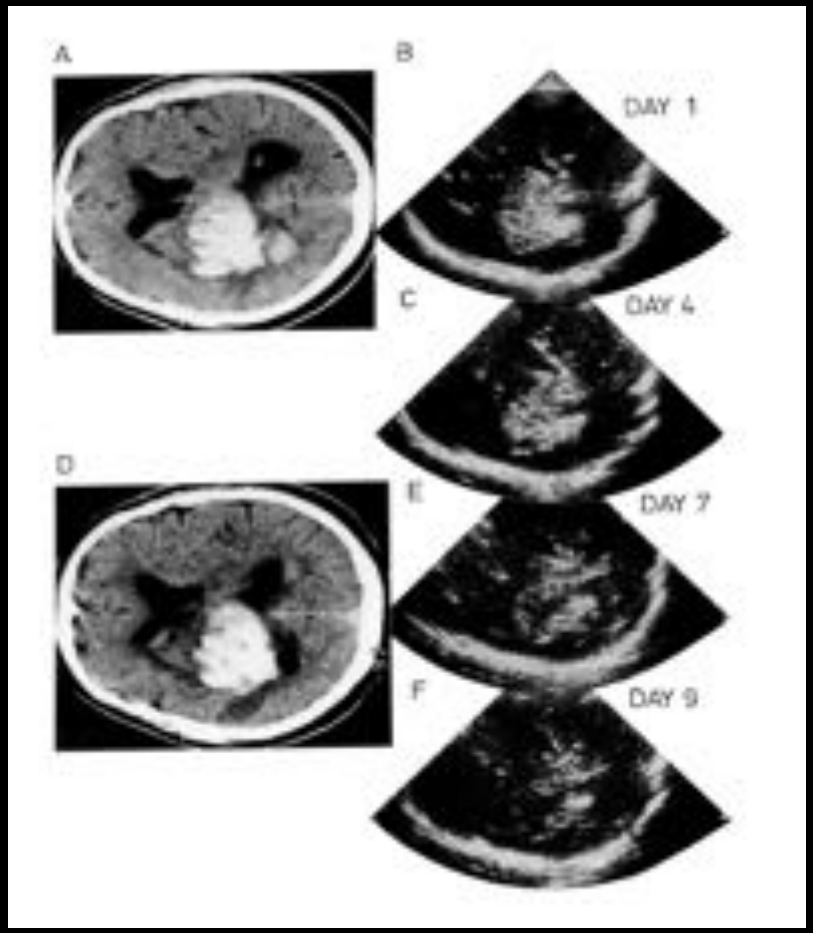
Doppler intra crânien : *déviation de la ligne médiane*





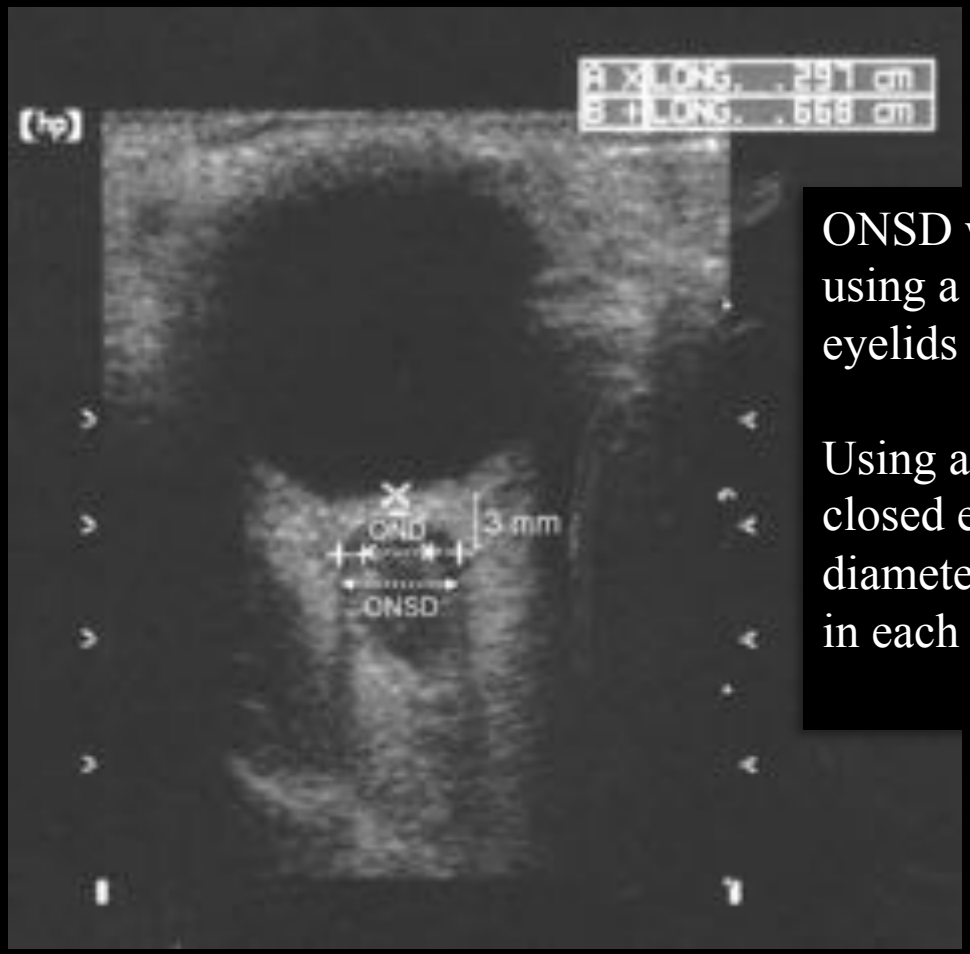
Sensibilité 84 %
Spécificité 94 %
Pour DLM > 0.5 cm

Doppler intra crânien : *visualisation des hématomes*



Seidel et al J neuroimaging 1996

Evaluation de la PIC par le diamètre de la gaine du nerf optique



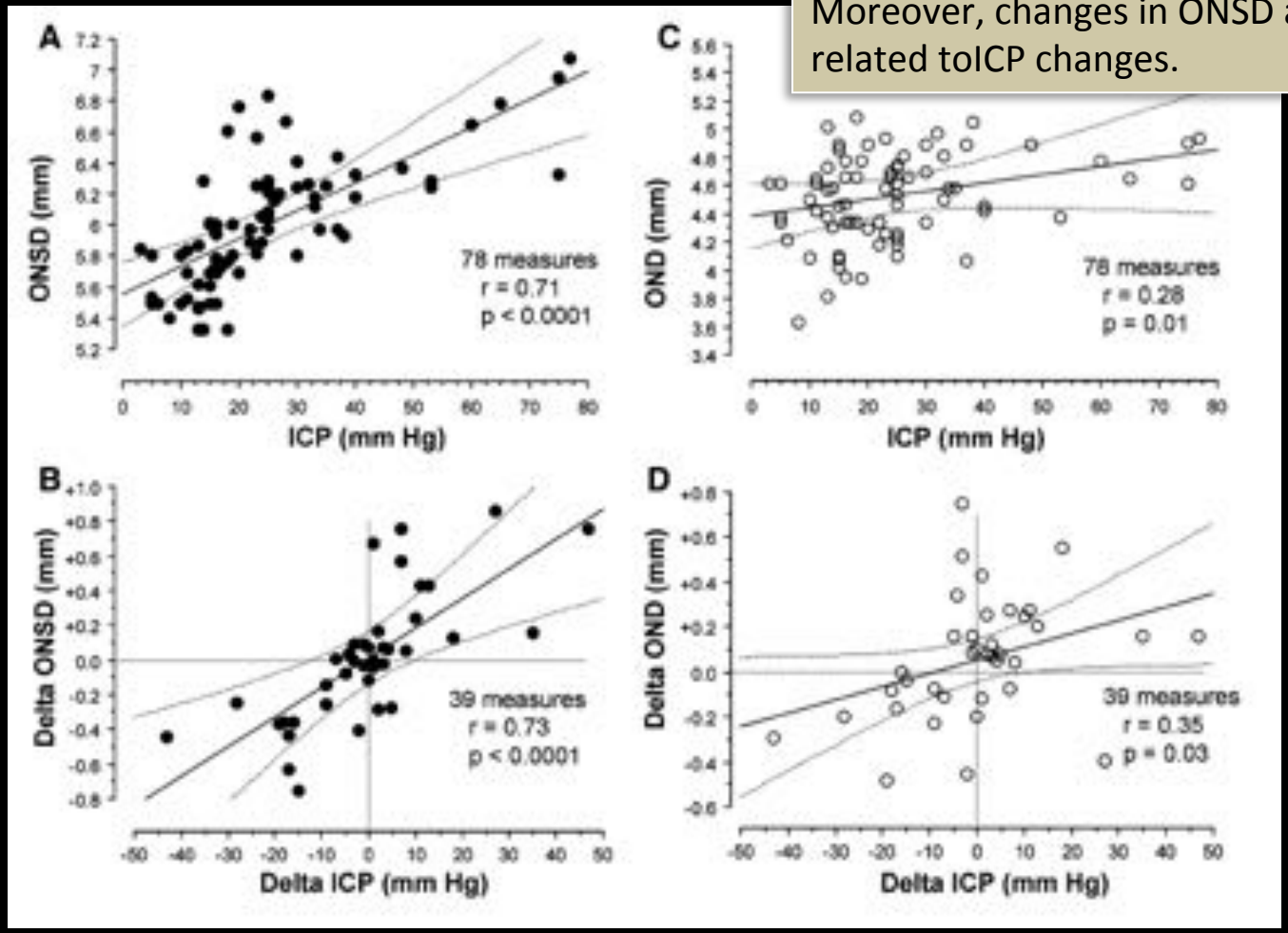
ONSD was measured 3 mm behind the globe using a 10-MHz linear probe on the closed eyelids of supine patients, bilaterally

Using a 7.5-MHz ultrasonographic probe on the closed eyelids, a single optic nerve sheath diameter was measured 3 mm behind the globe in each eye.

Geeraerts et al Intensive Care Medicine 2008
Blaivas et al Acad Emerg Med 2003

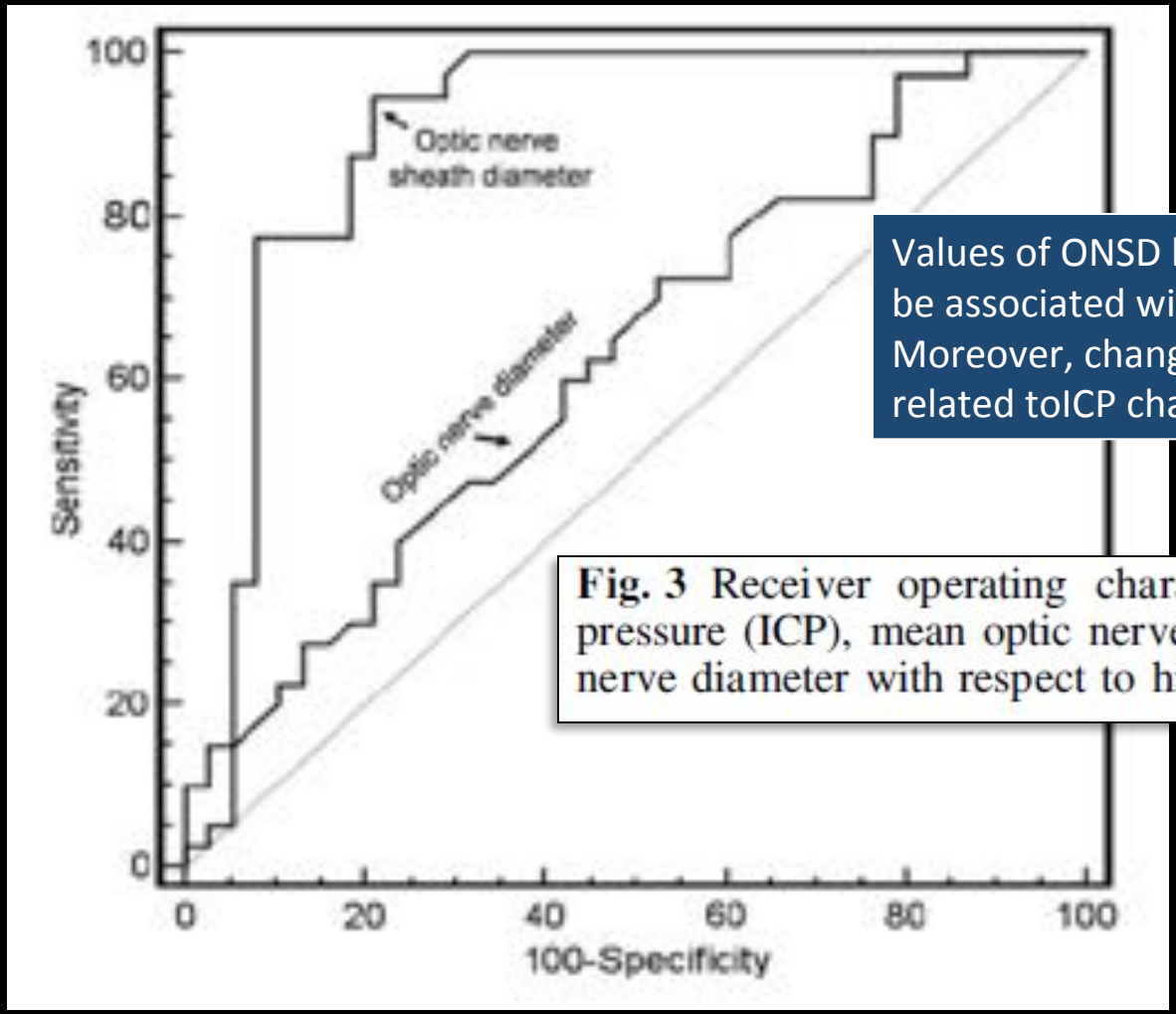
Evaluation de la PIC par le diamètre de la gaine du nerf optique

Values of ONSD less than 5.8 mm are not likely to be associated with ICP above 20 mmHg. Moreover, changes in ONSD are also strongly related toICP changes.



Geeraerts et al Intensive Care Medicine 2008

Non-invasive assessment of intracranial pressure using ocular sonography in neurocritical care patients

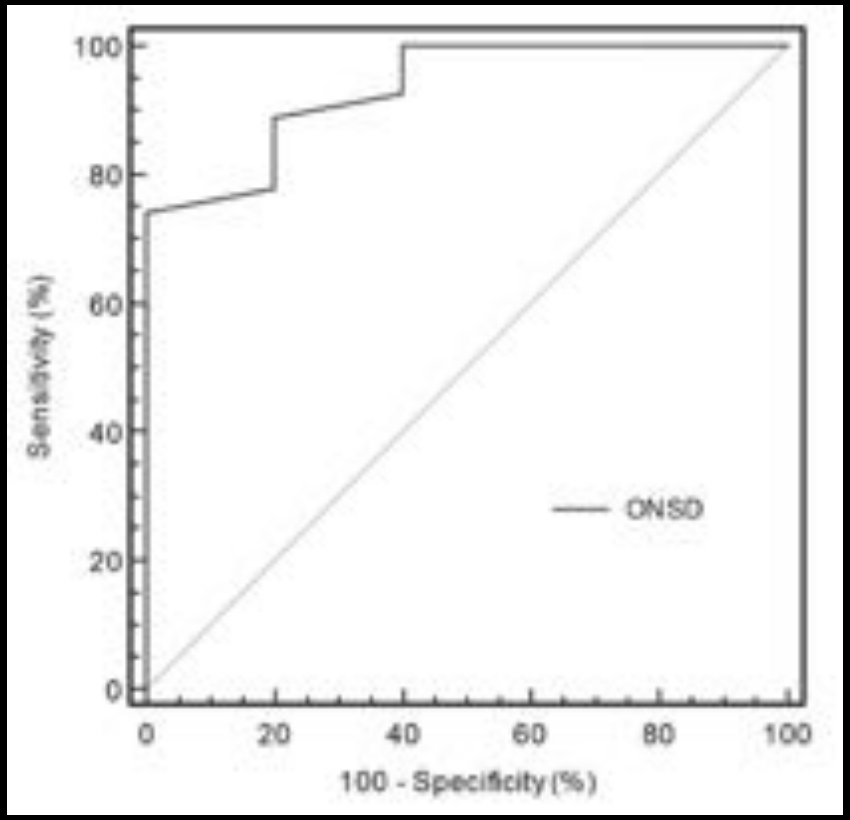


Values of ONSD less than 5.8 mm are not likely to be associated with ICP above 20 mmHg. Moreover, changes in ONSD are also strongly related toICP changes.

Fig. 3 Receiver operating characteristic curves for intracranial pressure (ICP), mean optic nerve sheath diameter and mean optic nerve diameter with respect to high ICP (ICP > 20 mmHg)

Geeraerts et al Intensive Care Medicine 2008

Optic nerve sonography in the diagnostic evaluation of adult brain injury



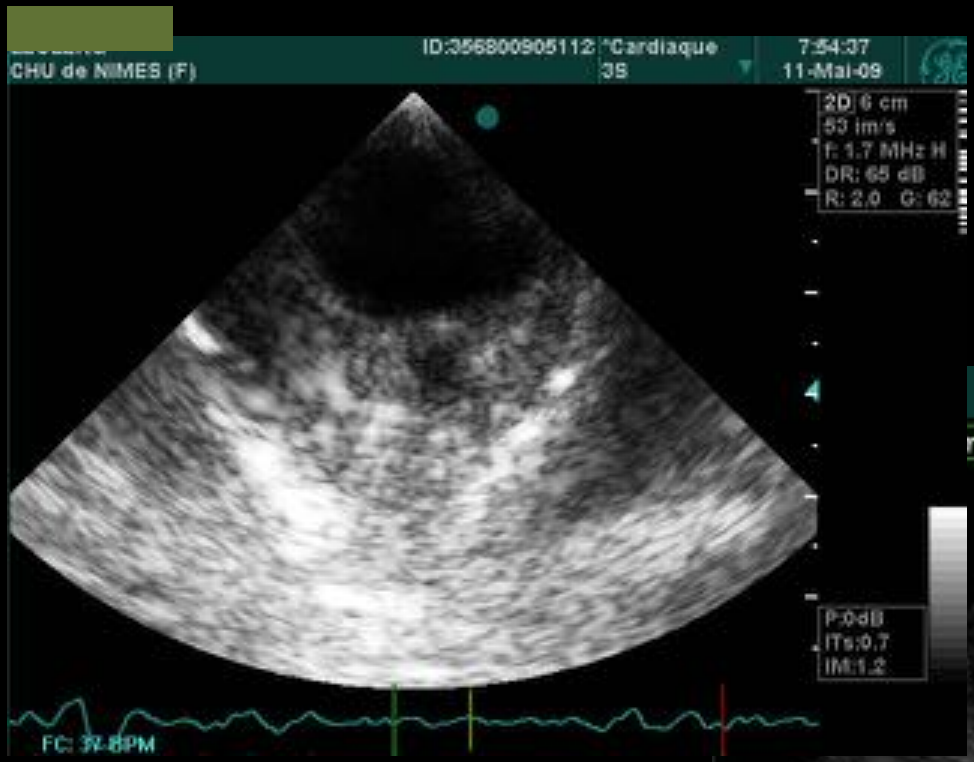
The best cut-off value of ONSD for predicting elevated ICP was 5.7 mm (sensitivity = 74.1% and specificity = 100%).

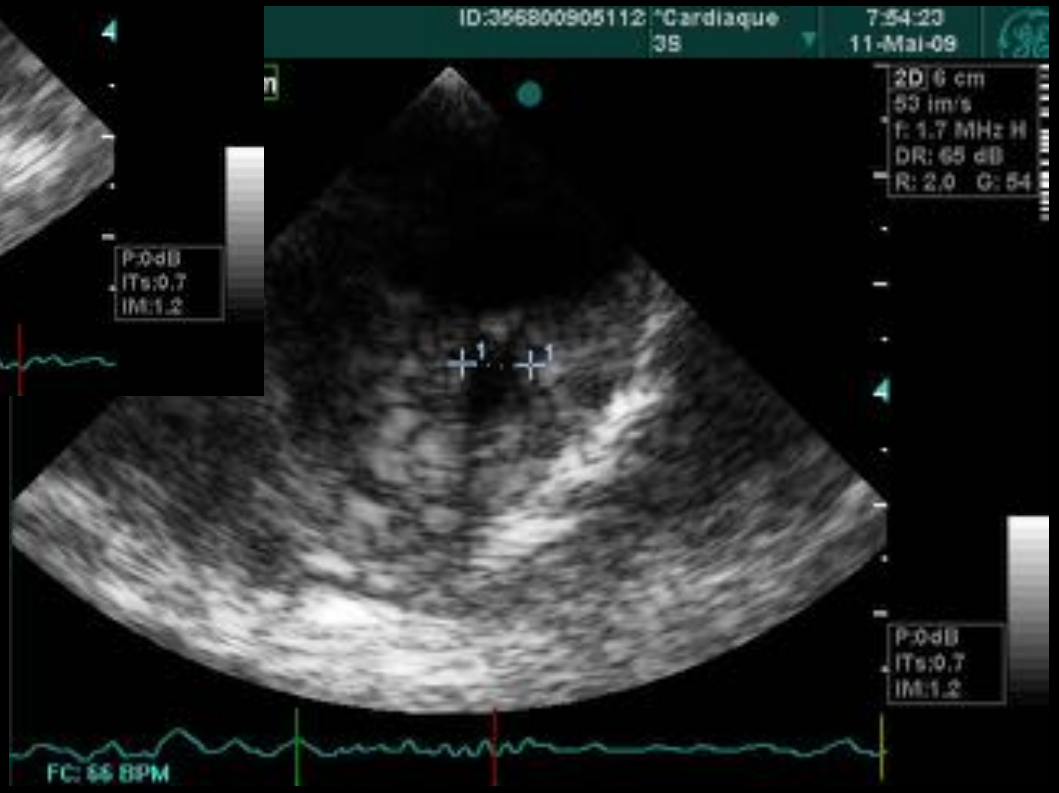
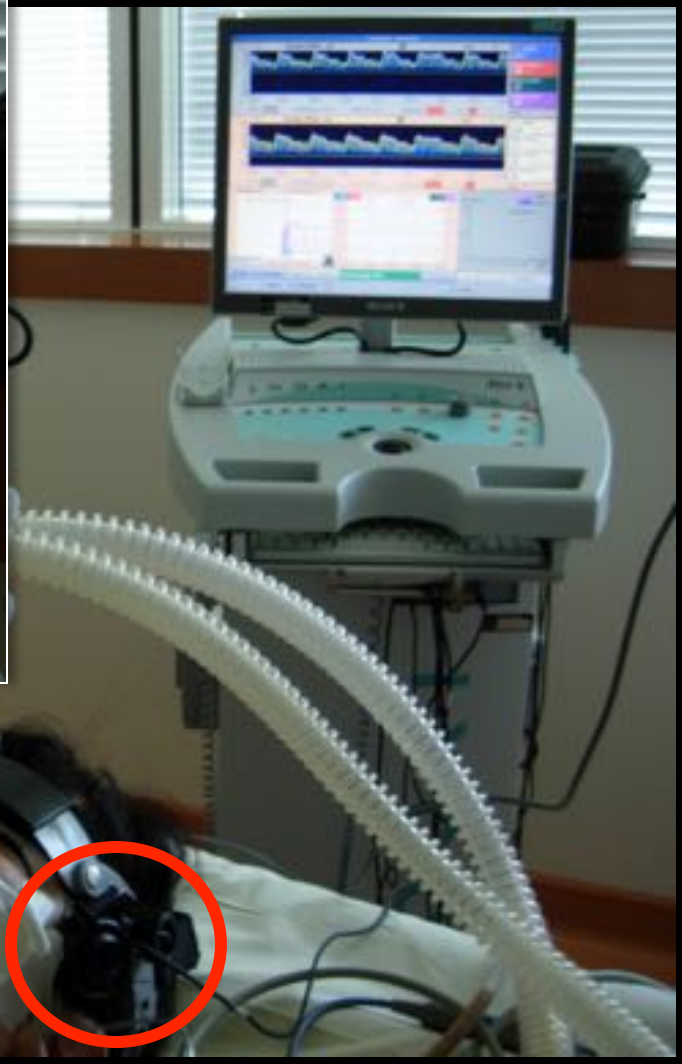
Soldatos et al Critical Care 2008

Evaluation de la PIC par le diamètre de la gaine du nerf optique

Pas si facile…

Evaluation de la PIC par le diamètre de la gaine du nerf optique : sonde cardiaque





Doppler transcrânien : monitorage continu ?