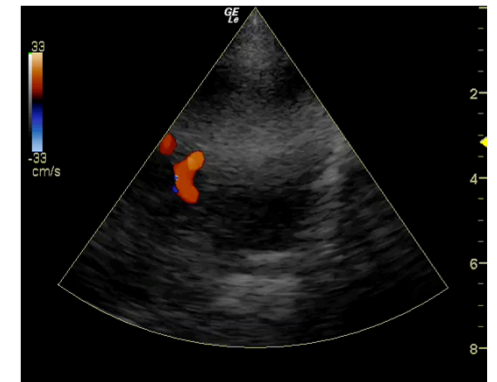


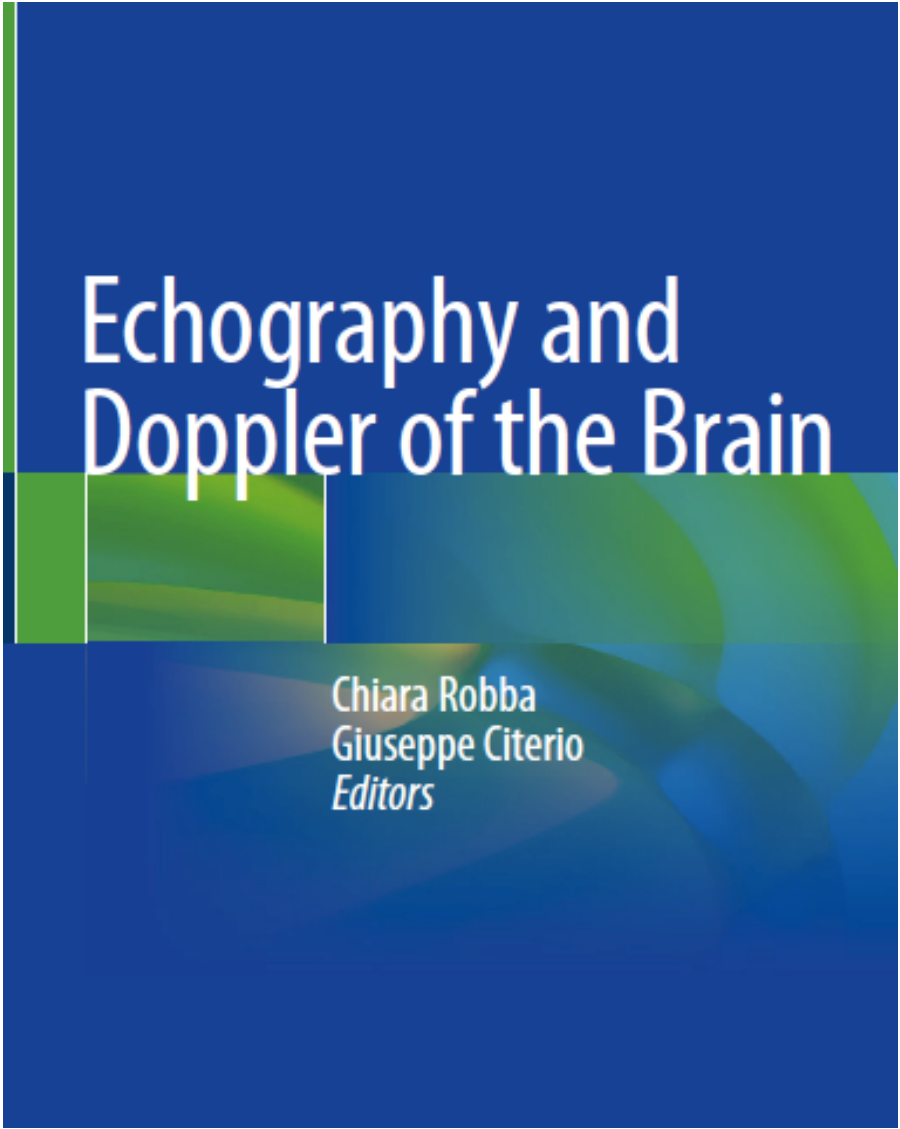
Echo-Doppler transcrânien Aspects techniques

Pr Thomas GEERAERTS
*Pôle Anesthésie Réanimation
CHU de Toulouse*



Conflits d'intérêt

- Aucun

The book cover features a dark blue background. On the left side, there is a vertical green bar. Overlapping the blue background are several abstract, flowing shapes in shades of green and light blue. The title is printed in white, sans-serif font, and the editors' names are in a smaller white font below it.

Echography and Doppler of the Brain

Chiara Robba
Giuseppe Citerio
Editors

Brain ultrasonography: methodology, basic and advanced principles and clinical applications. A narrative review

Chiara Robba^{1*} , Alberto Goffi² , Thomas Geeraerts³, Danilo Cardim⁴, Gabriele Via⁵, Marek Czosnyka⁶, Soojin Park⁷, Aarti Sarwal⁸, Llewellyn Padayachy⁹, Frank Rasulo¹⁰  and Giuseppe Citerio¹¹ 

Take-home message

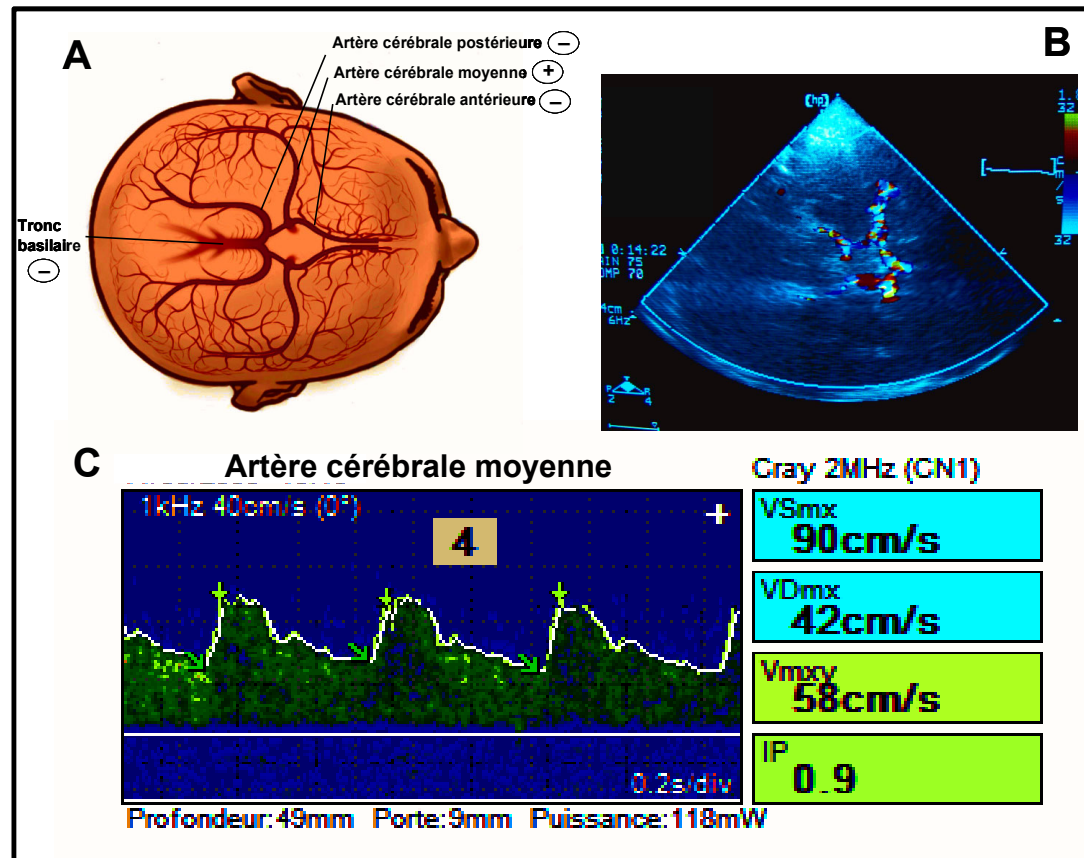
Brain ultrasonography enables assessment of the main structures of the brain, including the parenchyma and major cerebral vessels.

Brain ultrasonography can be performed using commonly used ultrasound systems, through four main acoustic windows (transtemporal, occipital, submandibular and transorbital).

Brain ultrasonography can be used for rapid bedside assessment of pathological changes in neurocritically ill patients, allowing, for example, evaluation of intracerebral haematomas, estimation of raised intracranial pressure, and detection of midline shift and intracranial masses.

Brain ultrasonography is not used exclusively in neurocritical care; clinical applications have been described in different settings, including general intensive care and the emergency department.

Doppler transcrânien



Short communication

Christian Johann Doppler: the man behind the effect

A ROGUIN, MD

Cardiology Department, Rambam Medical Center, Haifa 31096, Israel

La lumière colorée des étoiles et autres corps célestes
vire au bleu lorsque l'étoile se rapproche de la terre
et vire au rouge lorsqu'elle s'en éloigne

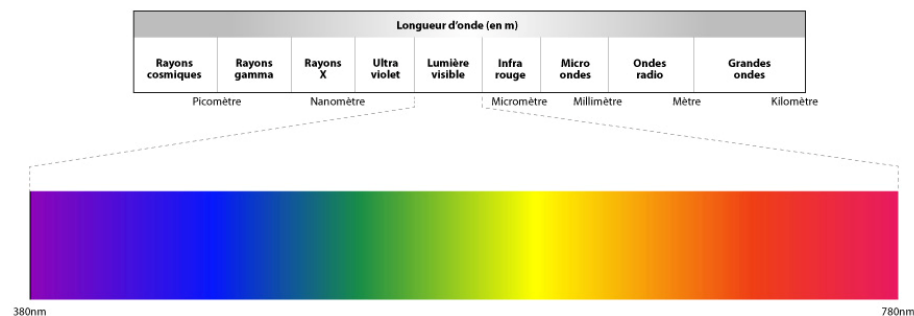
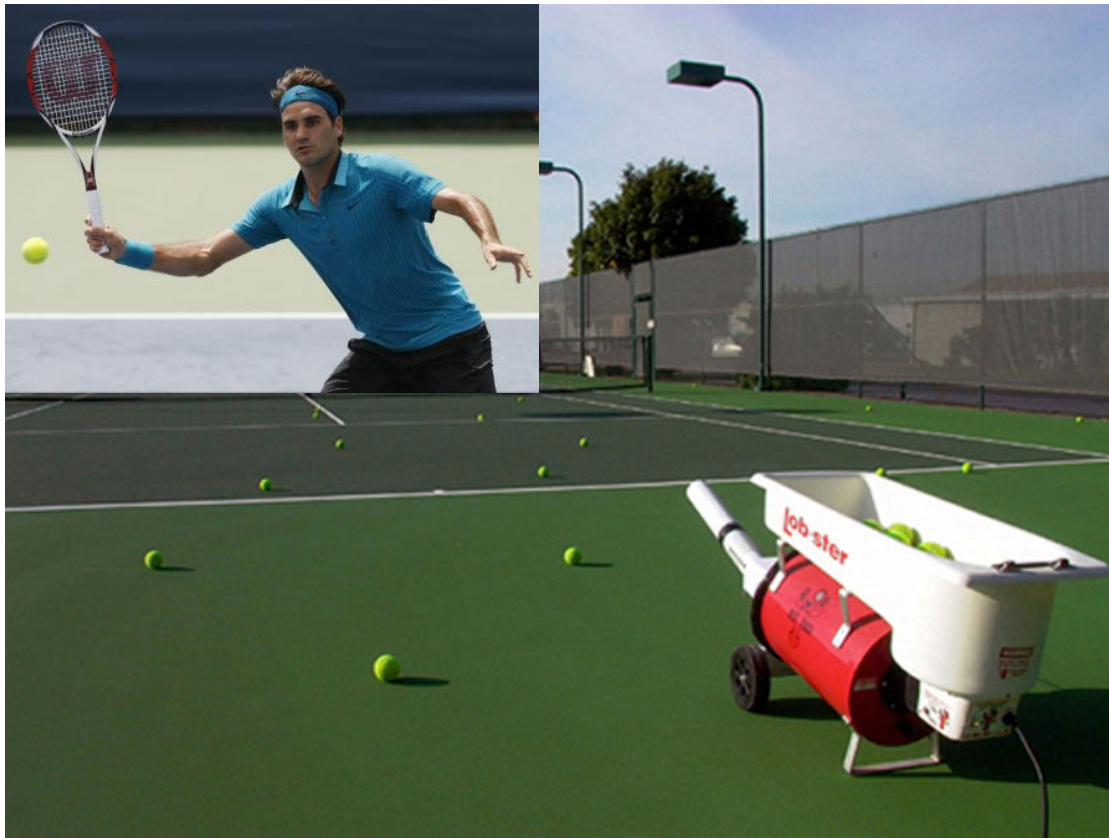


Figure 1. Christian Johann Doppler (1803–1853).

Doppler pulsé



Effet Doppler

Modifications de la fréquence et de la longueur d'onde des ondes réfléchies

$$\Delta f = 2 \cdot f_o \cdot V/C \cdot \cos\theta$$

Δf : variation de fréquence de l'onde

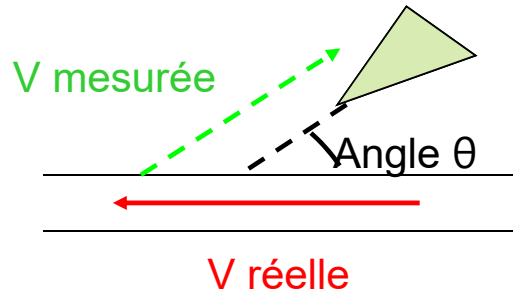
f_o : fréquence de l'onde émise

V : vitesse du flux sanguin

C : vitesse du son dans le tissu

$\cos\theta$: angle sonde et vaisseau

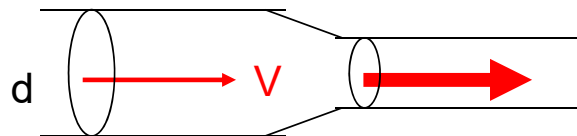
Angle d'insonation



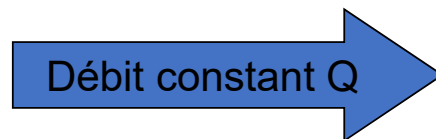
- La vitesse mesurée dépend du cosinus de l'angle d'insonation

$$V_{\text{mesurée}} = \cos \theta \times V_{\text{réelle}}$$

- On sous-estime donc forcément les vitesses...



- A débit constant, la vitesse circulatoire augmente proportionnellement avec la diminution du diamètre du vaisseau



$$V = \text{const.} \times Q / d^2$$

Vitesse n'est pas débit

La Garonne

Toulouse



Débit moyen
200 m³/sec

Bordeaux



Débit moyen
700 m³/sec

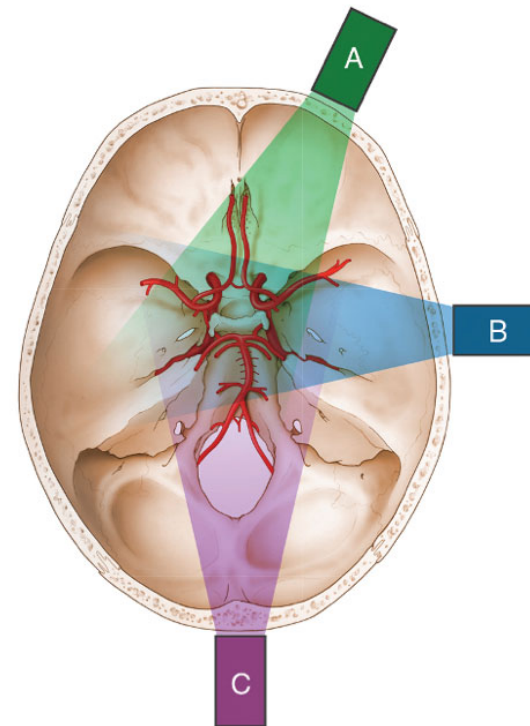
$$Q = V \times \text{section}$$

Chez l'adulte, il y a un os...

- Les fontanelles sont fermées
- Le faisceau d'ultrasons est absorbé en grande partie par l'os
- Pour obtenir un signal acceptable
 - Sonde 2 MHz
 - Sonde 1.8 – 3.6 MHz pour Doppler Couleur
 - Puissance entre 10 and 150 mW/cm²

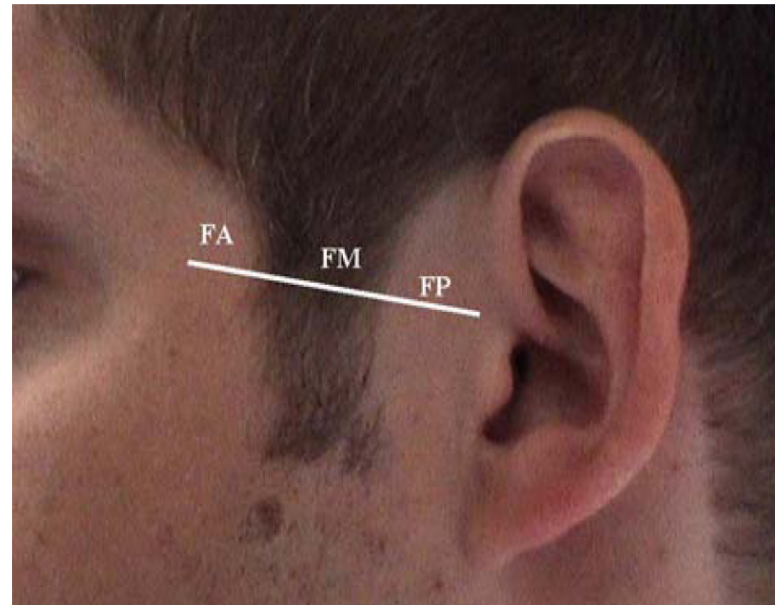
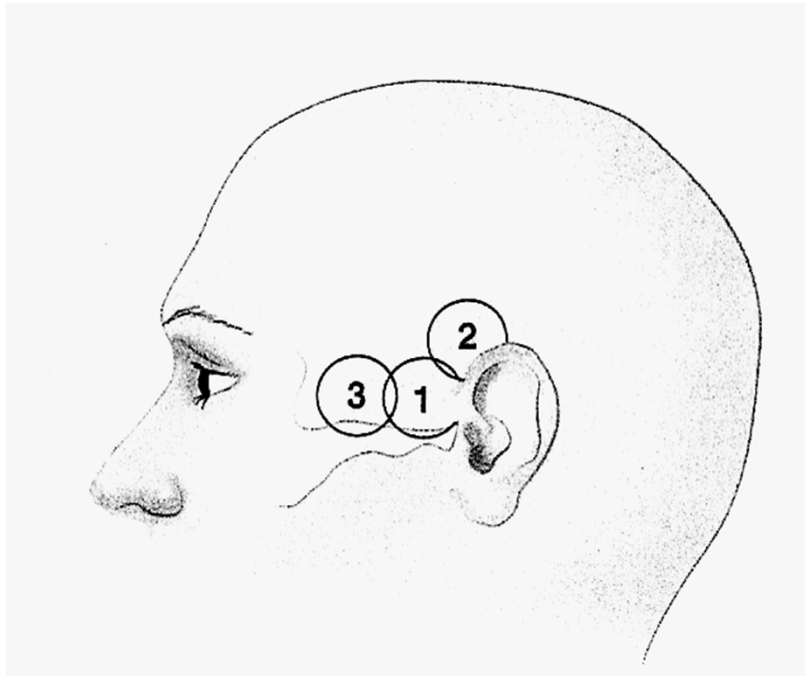
Les fenêtres osseuses

- Transtemporal
- Transorbital
- Sousoccipital
 - Transforamenal
- Sousmandibulaire



Les fenêtres

Temporale



Noninvasive transcranial Doppler ultrasound recording of flow velocity in basal cerebral arteries

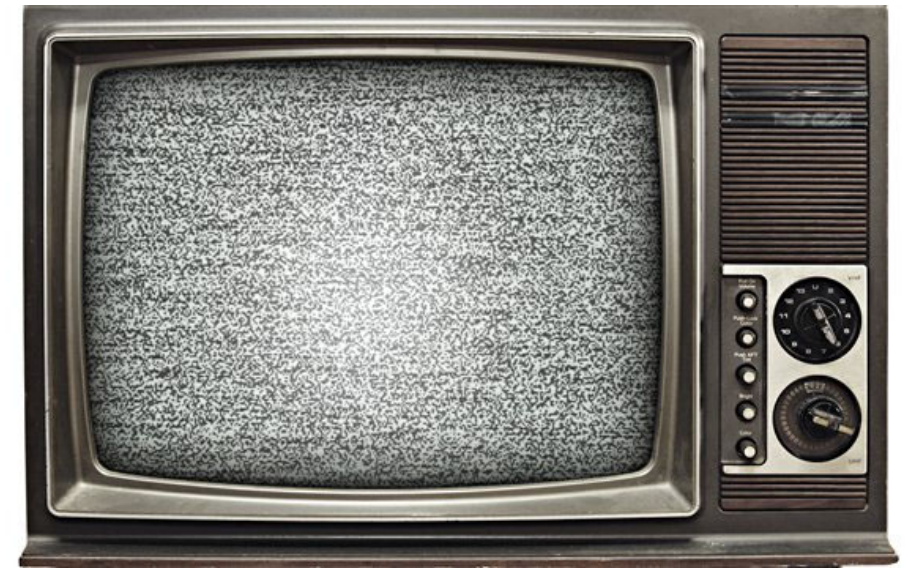
RUNE AASLID, PH.D., THOMAS-MARC MARKWALDER, M.D., AND HELGE NORNES, M.D.

technique during surgery,^{2,8,9} and in children with open fontanels.⁷ In adults, however, the skull is a severe obstacle to the penetration of ultrasound. Bone strongly attenuates the ultrasonic wave, making it impossible to record noninvasively the blood flow velocity from intracranial arteries by conventional Doppler instruments operating in the range from 5 to 10 MHz. At lower frequencies, 1 to 2 MHz, the attenuation in bone and soft tissues is considerably less. The skull bones are of varying thickness, and because the bone of the temporal

Doppler recordings of bilateral MCA blood flow velocities were obtained in all 50 subjects. However,

Parfois la fenêtre reste fermée

- Jusqu'à 18% dans les études d'AVC
- Femme
- Age
- Ethnie « non-blanche »



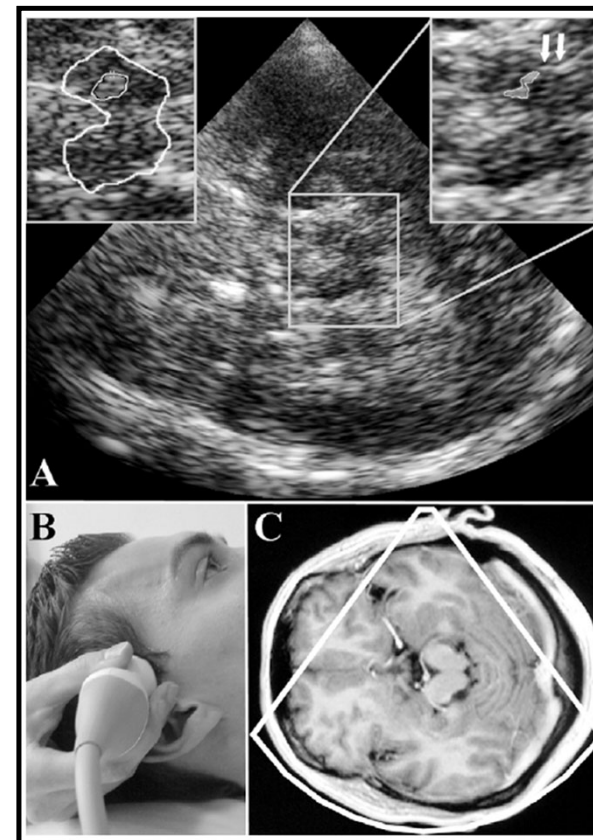
Grolimund P. Transmission of ultrasound through the temporal bone.
In: Aaslid R, ed. Transcranial Doppler sonography. Wien/New
York: Springer Verlag, 1985:10–18.

Transcranial sonography of the cerebral parenchyma: Update on clinically relevant applications

Uwe Walter*

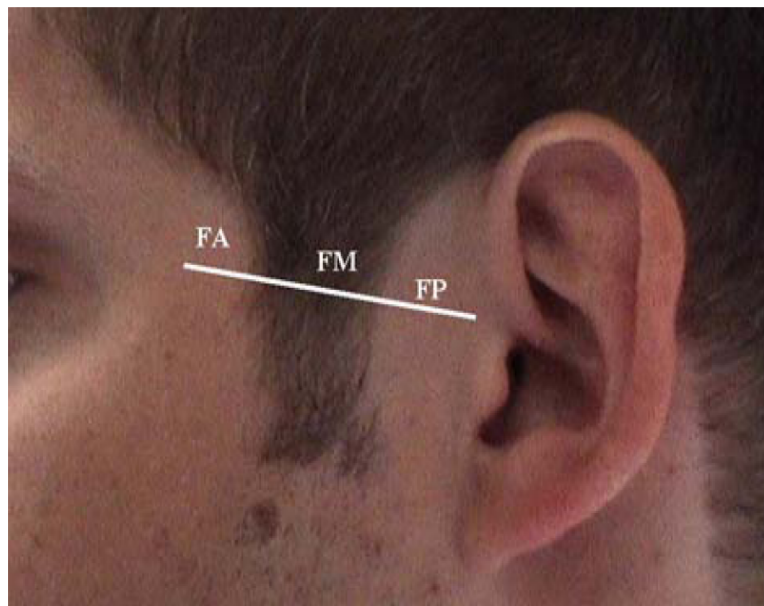
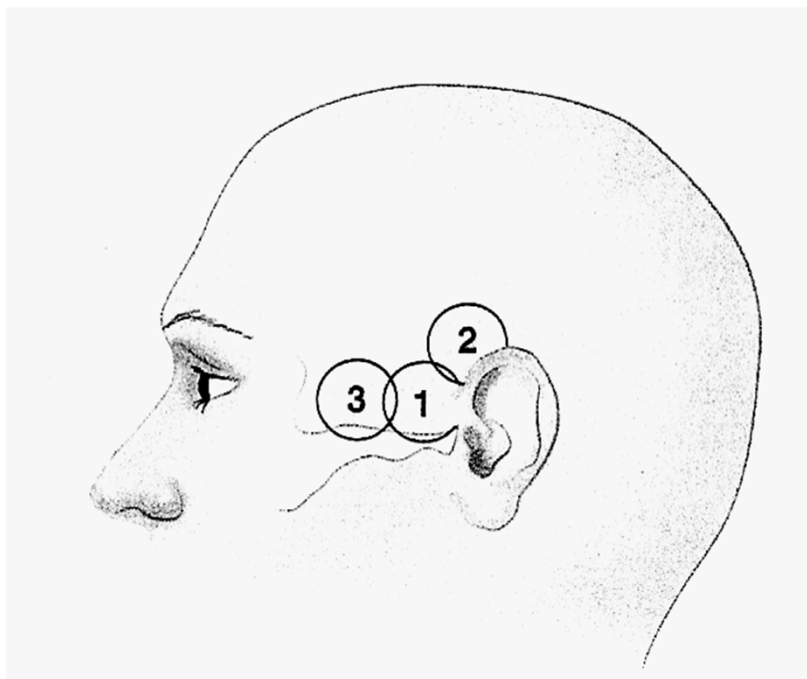
Table 1 Ultrasound system settings for transcranial sonography.

Parameter	Settings
Ultrasound system	
Penetration depth	Start with 14–16 cm, reduce if needed
Dynamic range	45–55 dB
Postprocessing function	Moderate suppression of low echo signals
Time gain compensation	Adjust manually as needed, or use the 'tissue optimization' function if available
Image brightness	Adjust manually, not too high, or use the 'tissue optimization' function if available
Ultrasound transducer	
Crystal/channel	As high as possible, ideally: 'matrix' probe
Insonation frequency (center frequency)	2.0–3.5 MHz, preferably 2.5 MHz

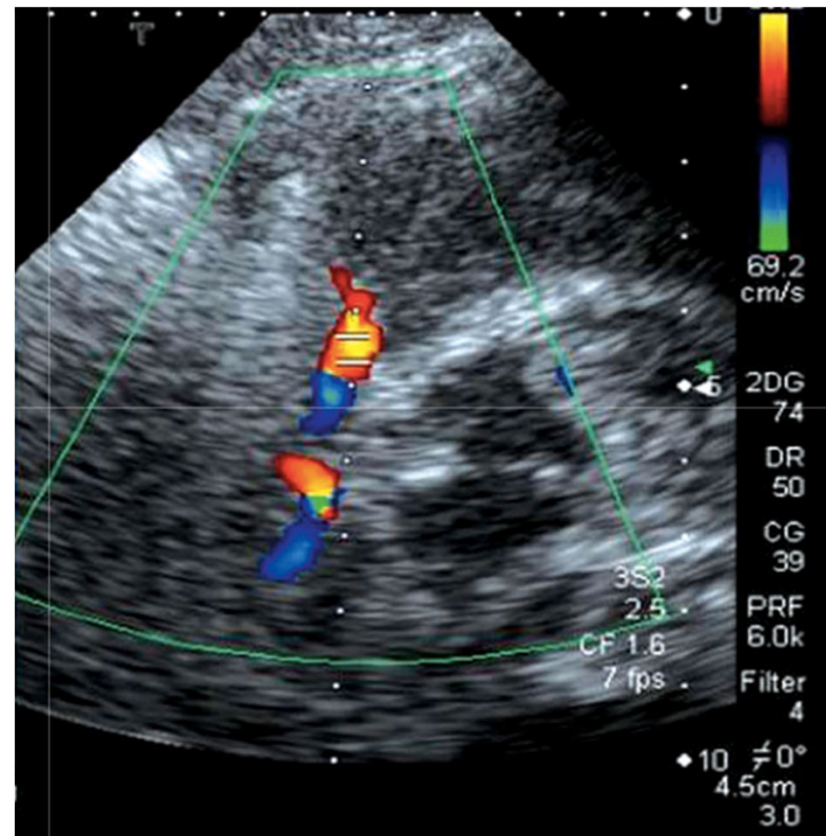


Perspectives in Medicine (2012) 1, 334–343

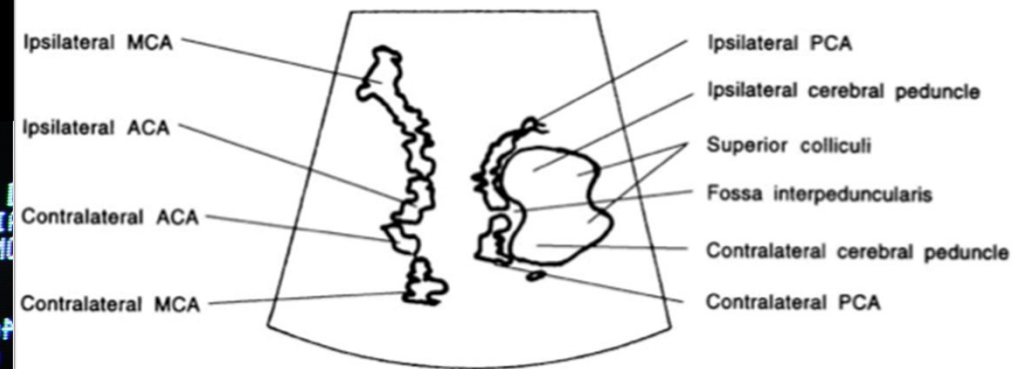
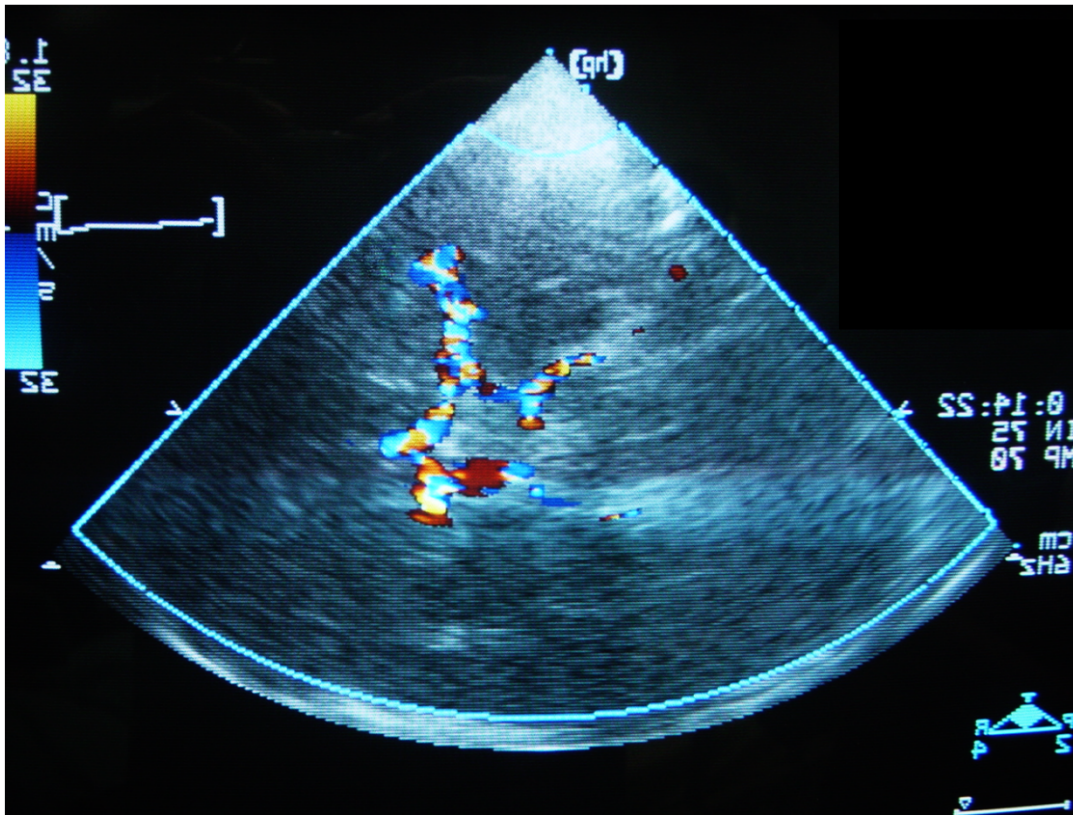
La fenêtre temporale



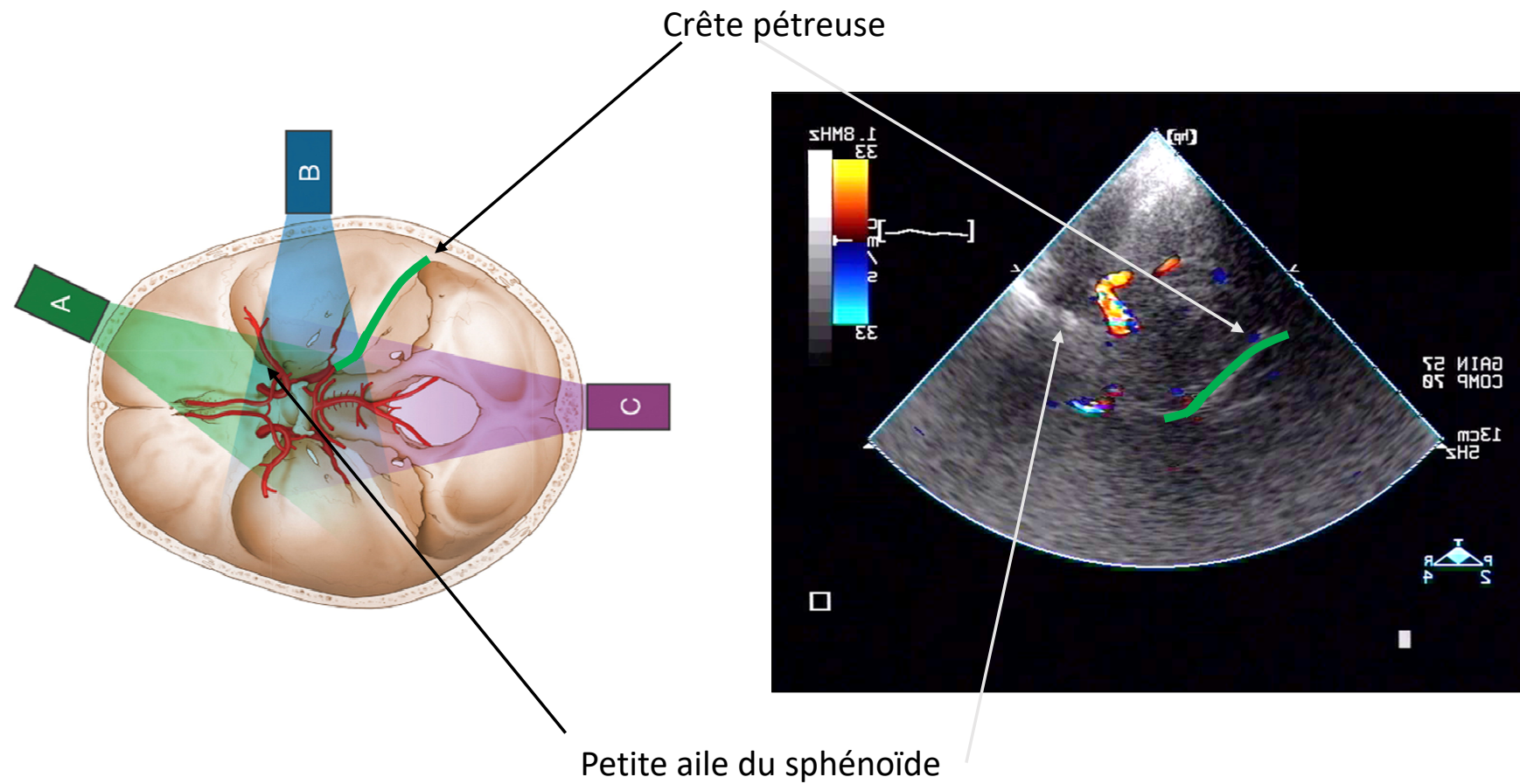
Visualiser le mesencéphale

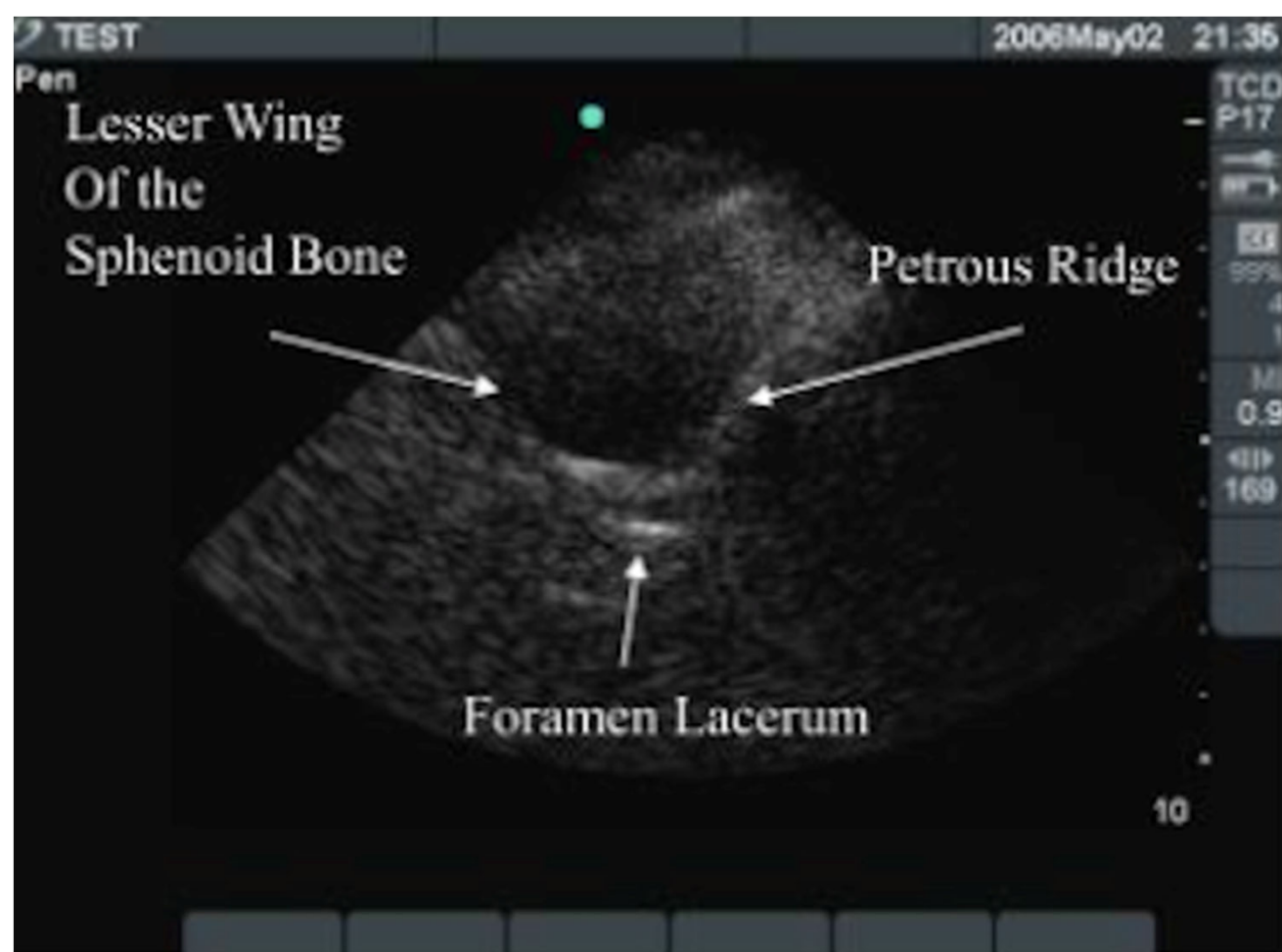


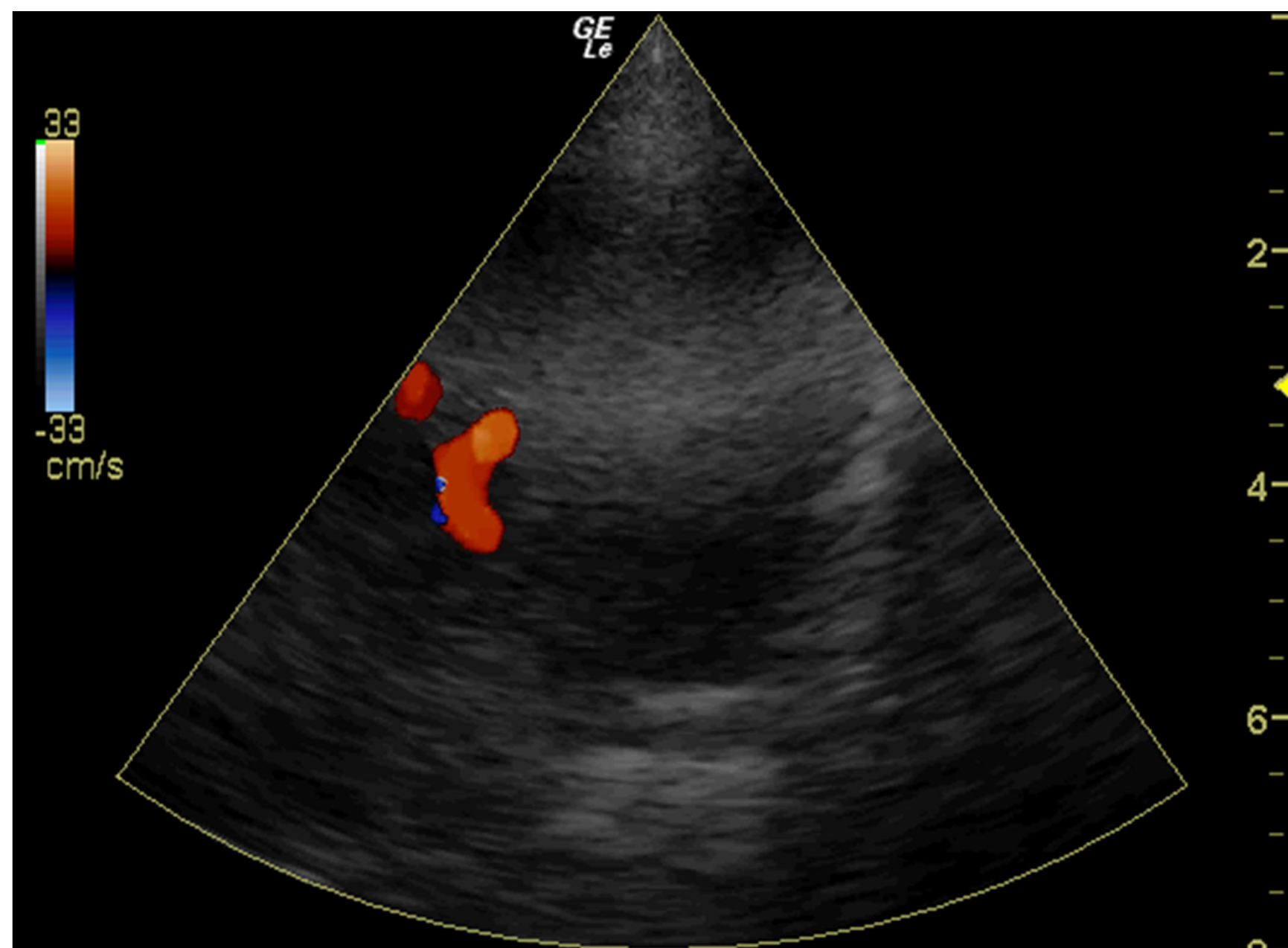
Polygone de Willis



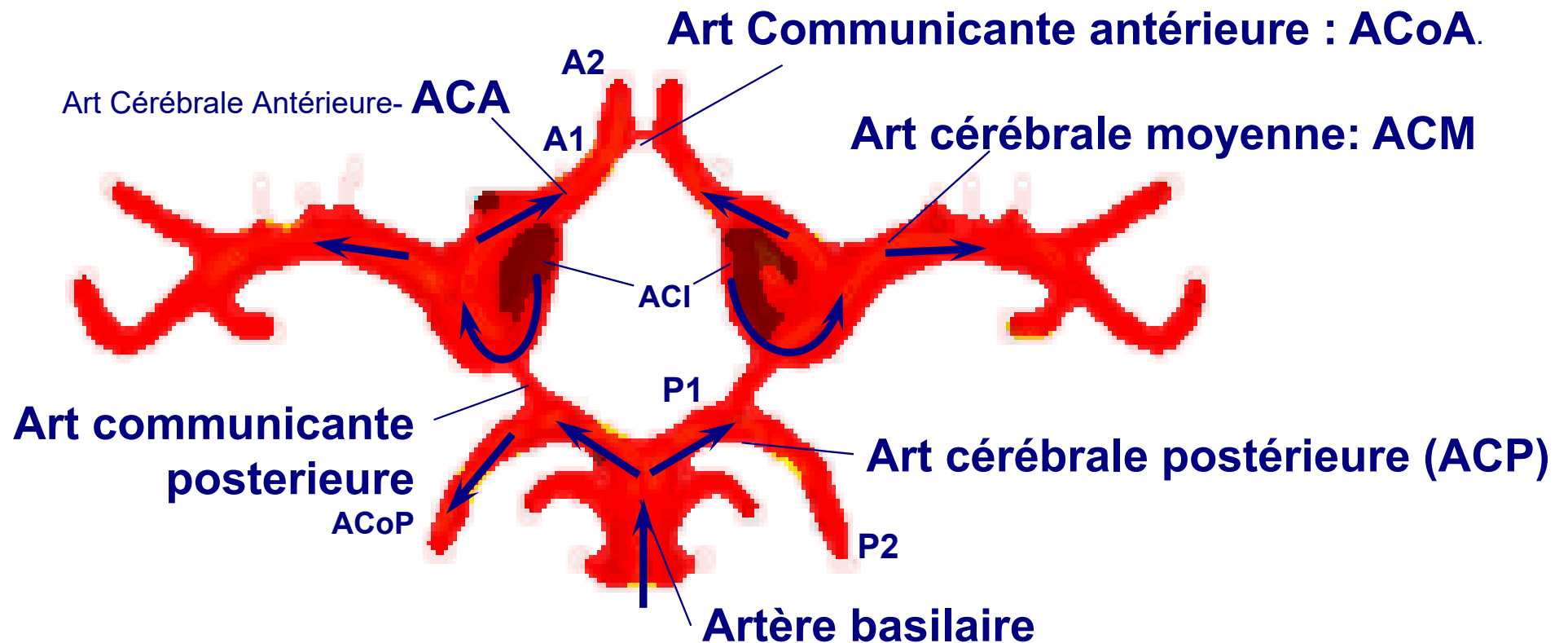
Repères osseux





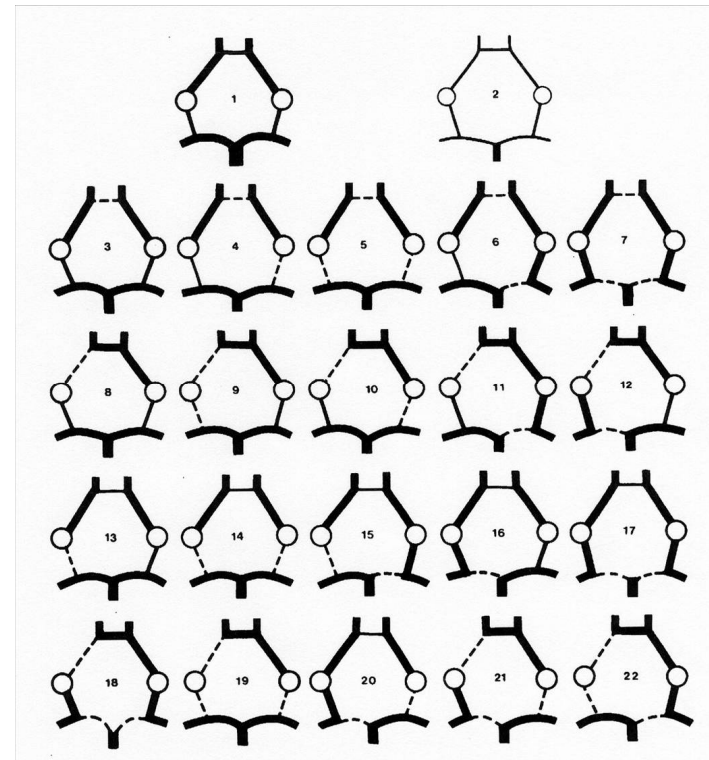


Polygone de Willis

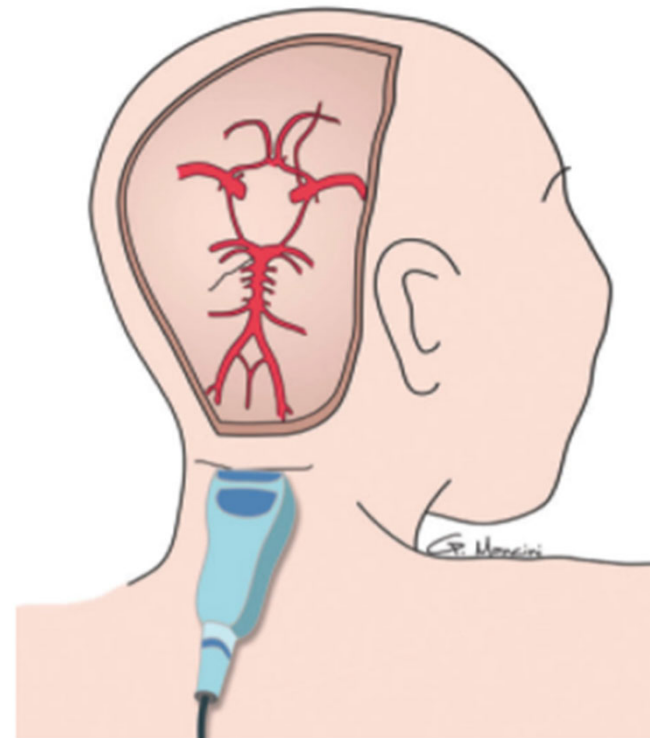
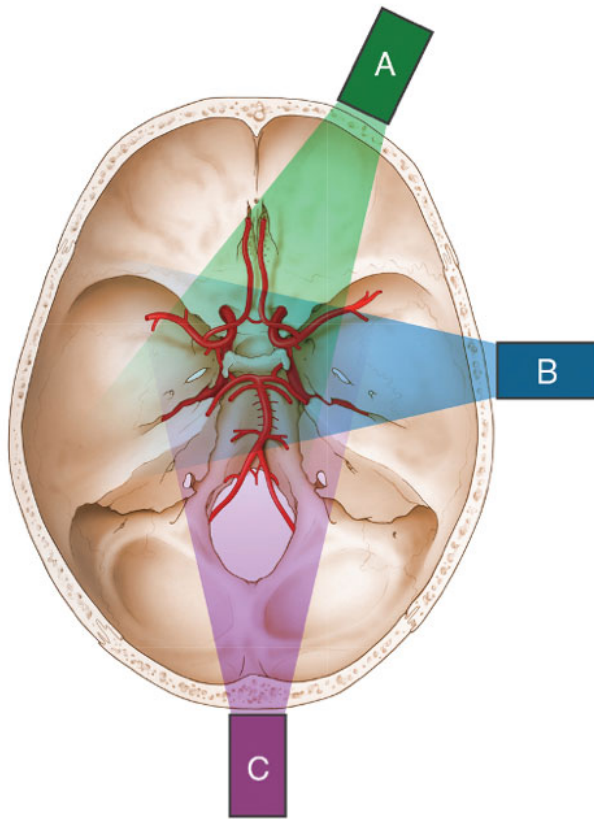


Variantes anatomiques du polygone

- Environ 20% de la population possède un polygone parfait
- 22 variantes

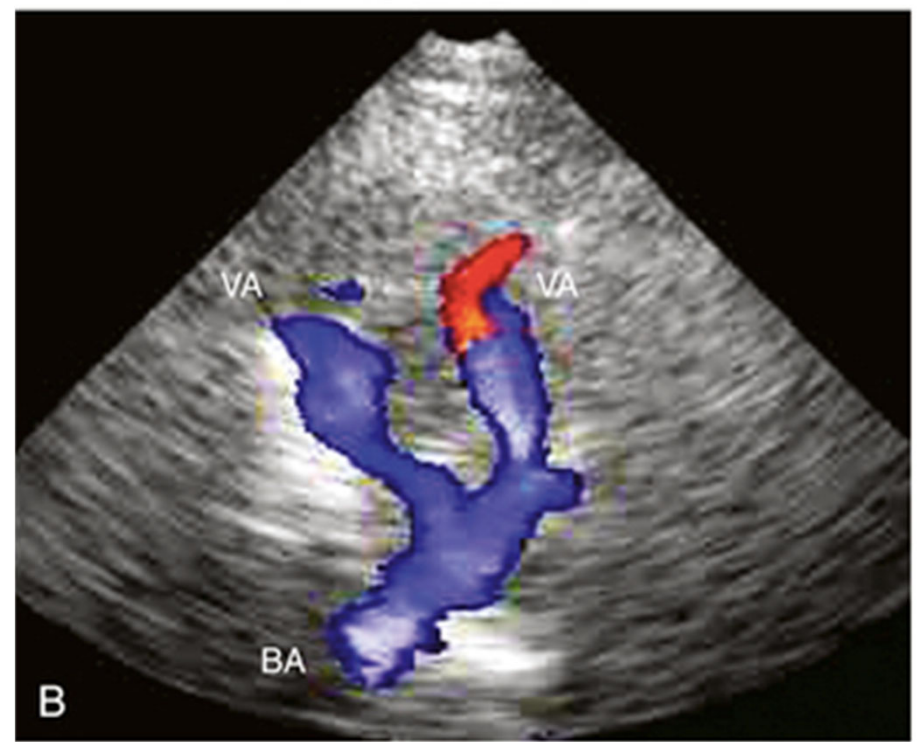
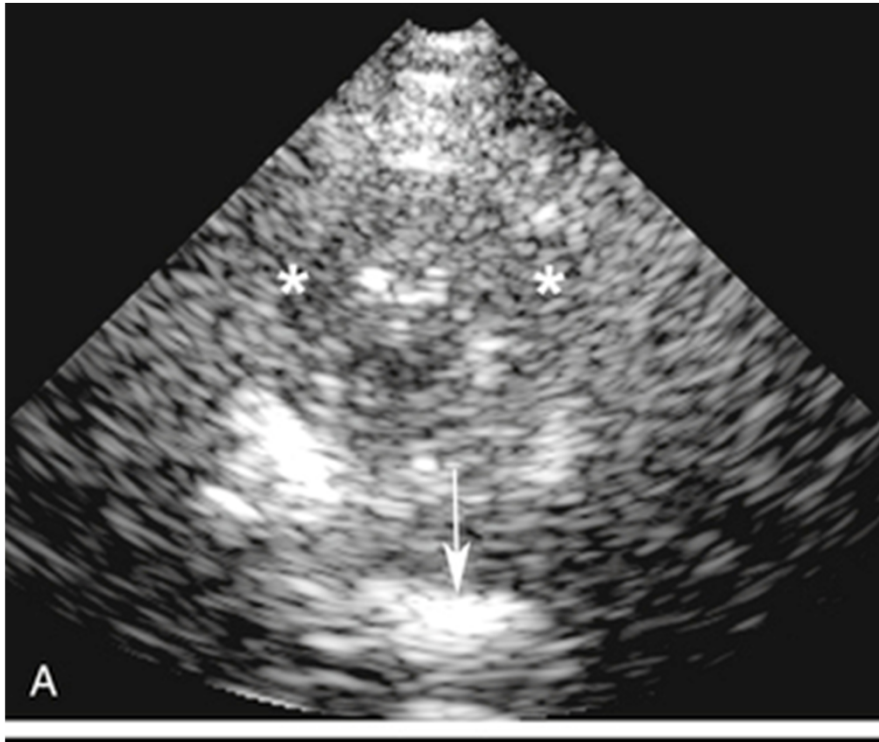


La fenêtre sous-occipitale



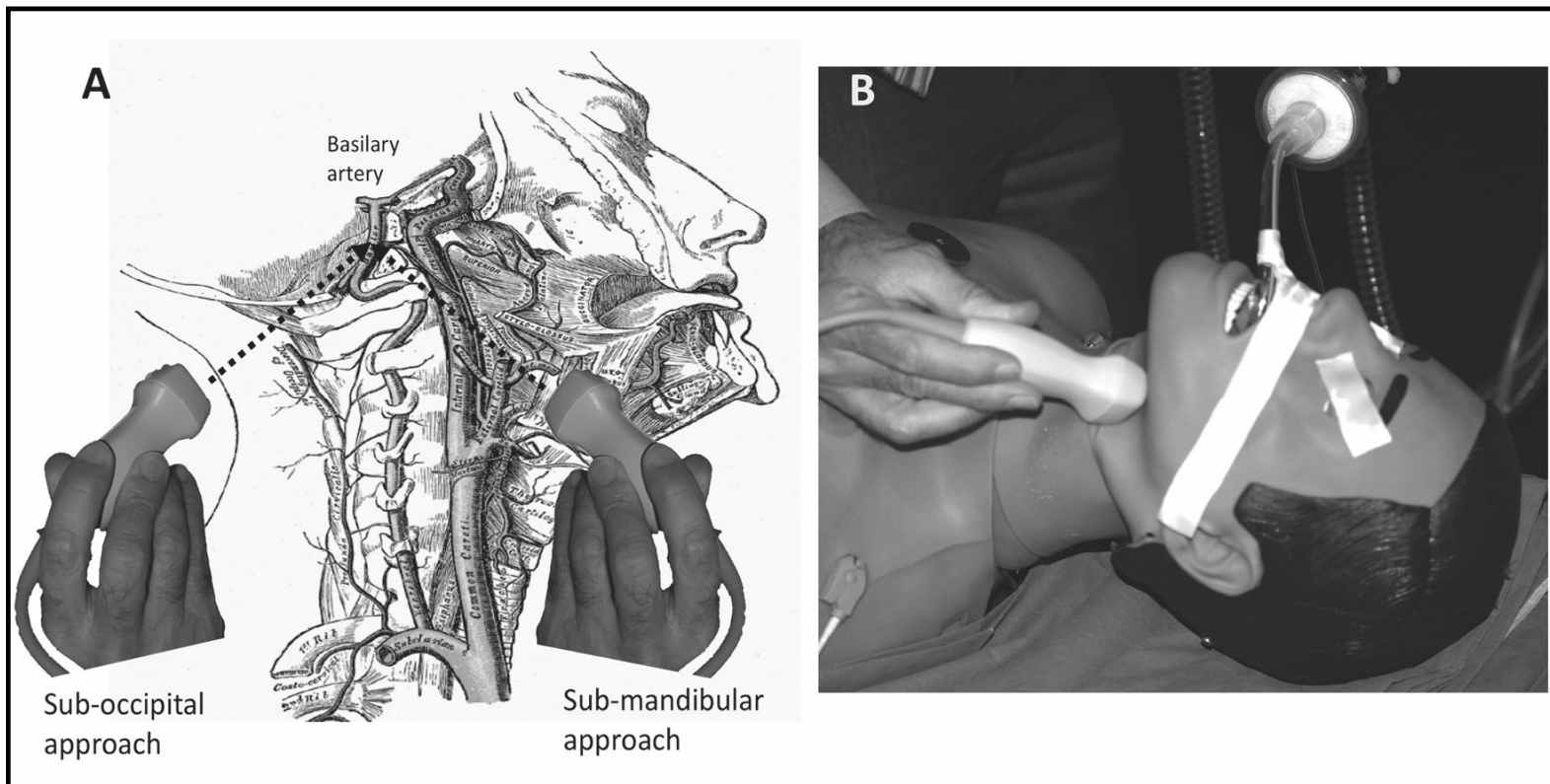
<https://www.semanticscholar.org>

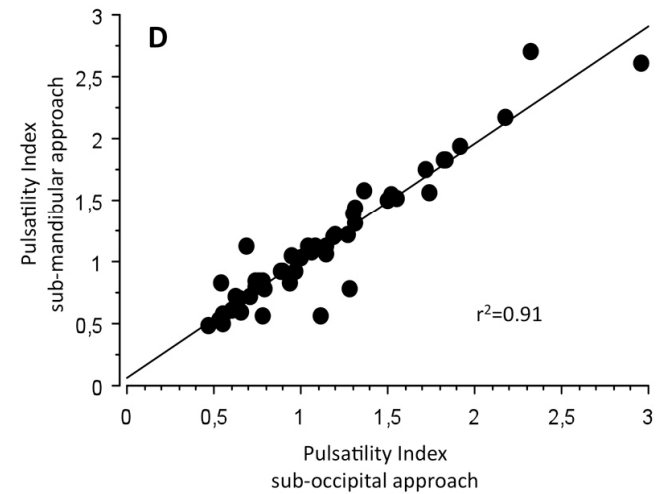
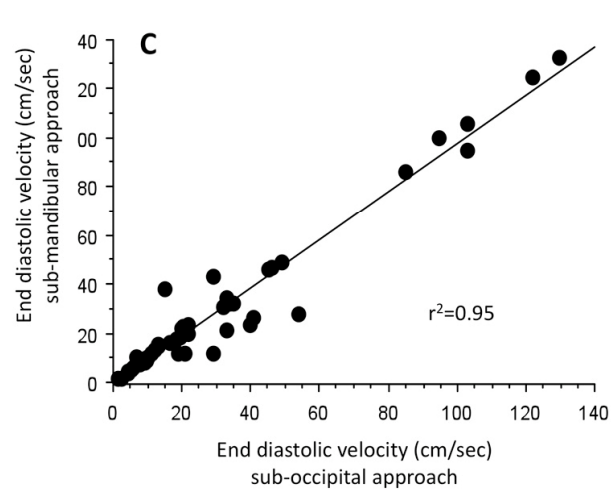
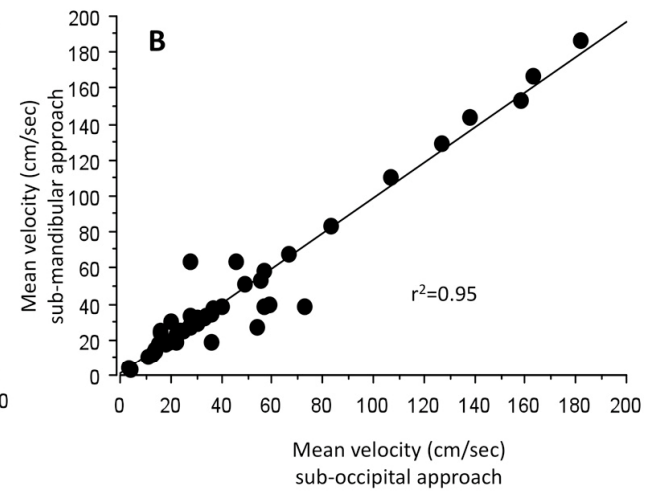
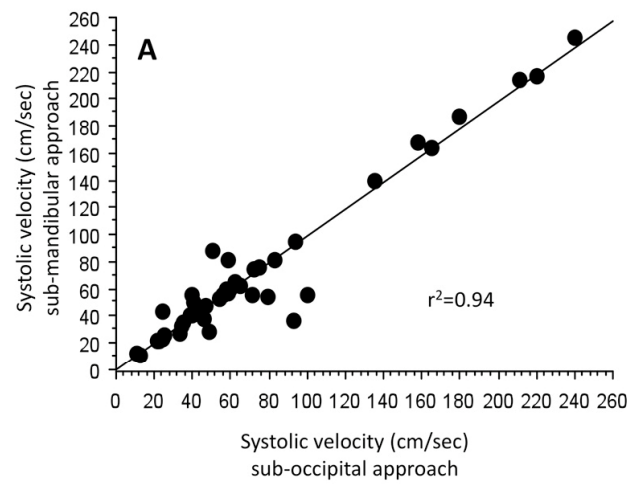
La fenêtre sous-occipitale



An Alternative Ultrasonographic Approach to Assess Basilar Artery Flow

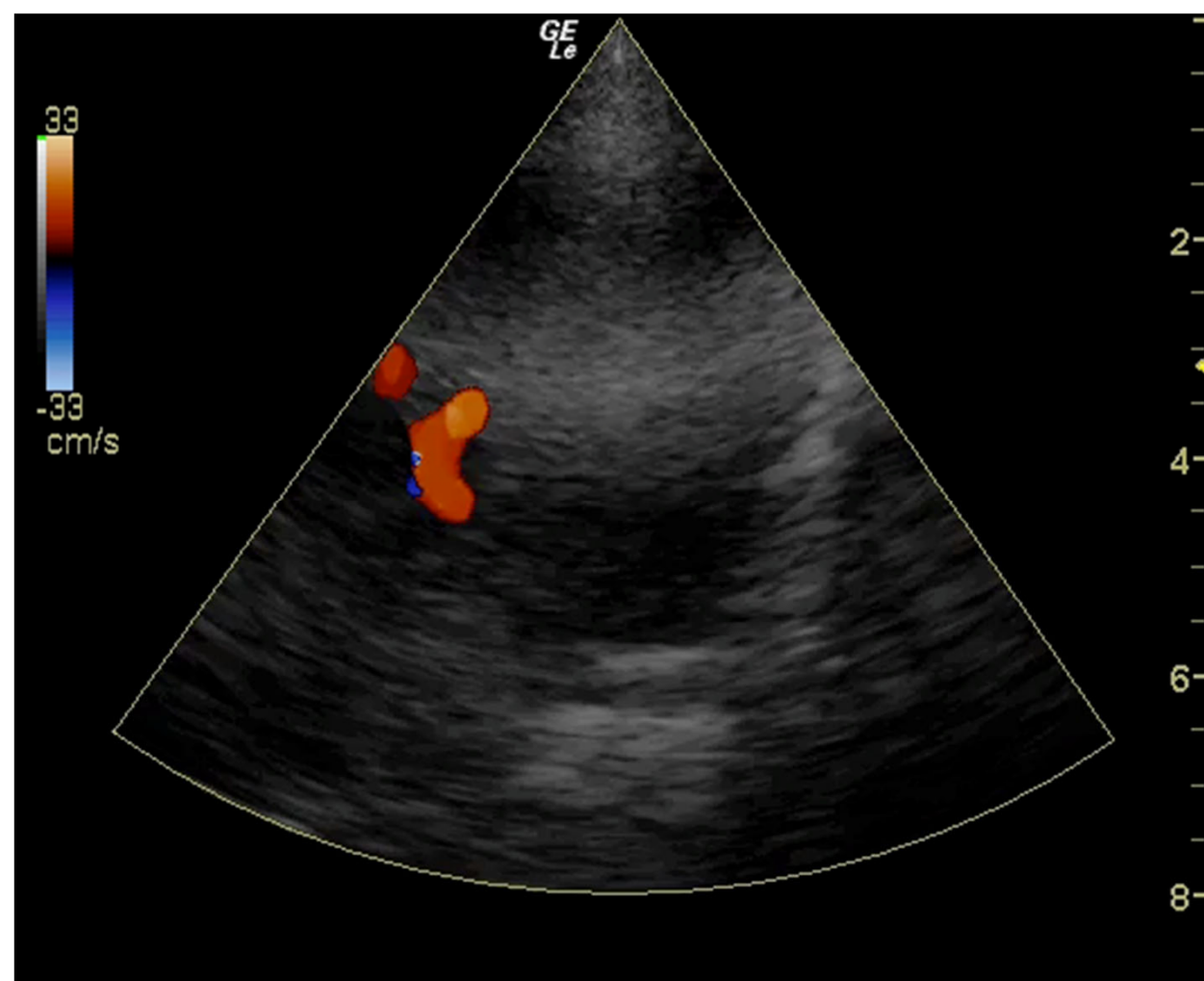
Thomas Geeraerts, MD, PhD
Wissam Thome, MD
Sébastien Tanaka, MD
Pierre Etienne Leblanc, MD
Jacques Duranteau, MD, PhD
Bernard Vigué, MD, PhD





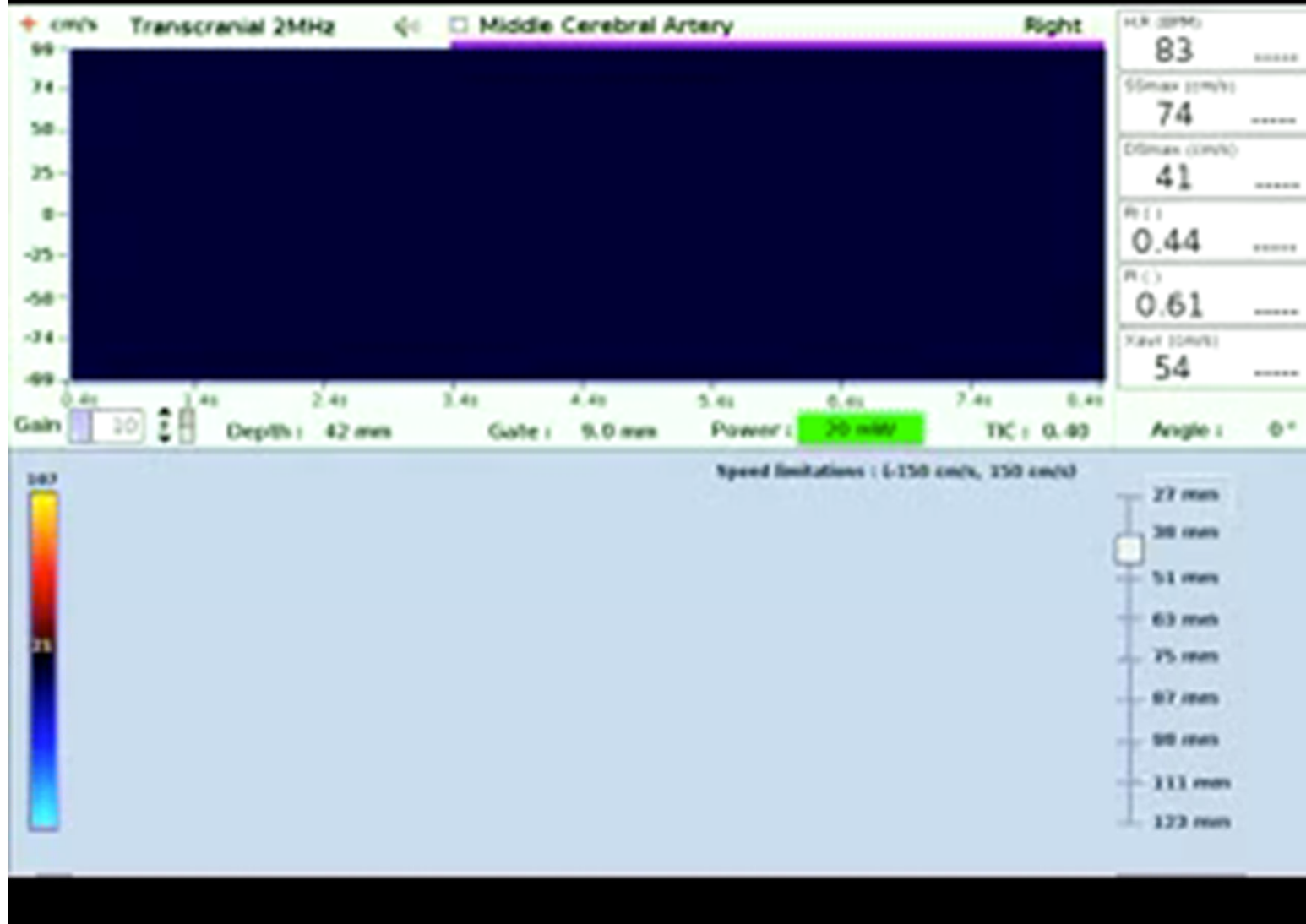
Deux méthodes

- Doppler pulsé conventionnel
- Doppler couleur 2D
 - Duplex (couplage échographie-Doppler pulsé)
 - Triplex (couplage échographie, Doppler couleur, Doppler pulsé)





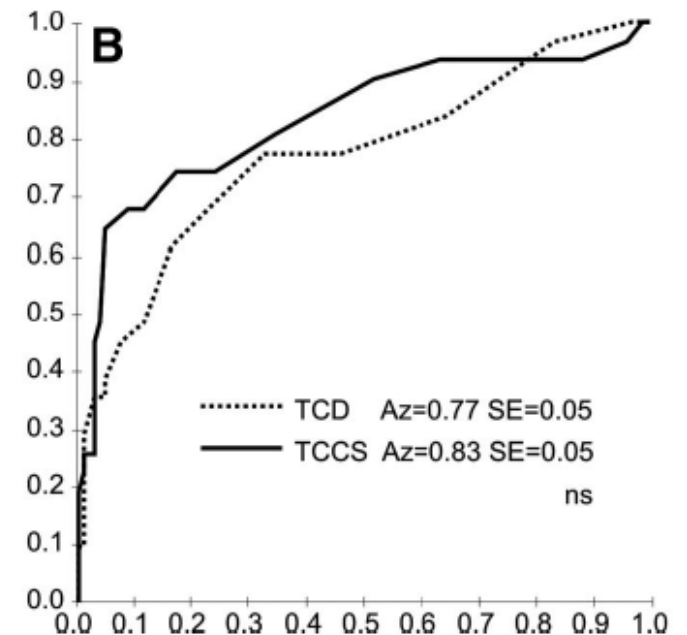




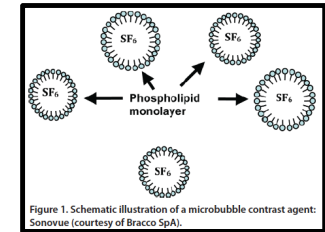
Doppler Couleur ou pulsé ?

Middle cerebral artery vasospasm: Transcranial color-coded duplex sonography versus conventional nonimaging transcranial Doppler sonography*

Maciej Swiat, MD; John Weigle, MD, PhD; Robert W. Hurst, MD; Scott E. Kasner, MD;
Mikolaj Pawlak, MD, PhD; Michal Arkuszewski, MD, PhD; Riyadh N. Al-Okaili, MD, PhD;
Miroslaw Swiercz, Dsc; Andrzej Ustymowicz, MD, PhD; Grzegorz Opala, MD, PhD;
Elias R. Melhem, MD, PhD; Jaroslaw Krejza, MD, PhD

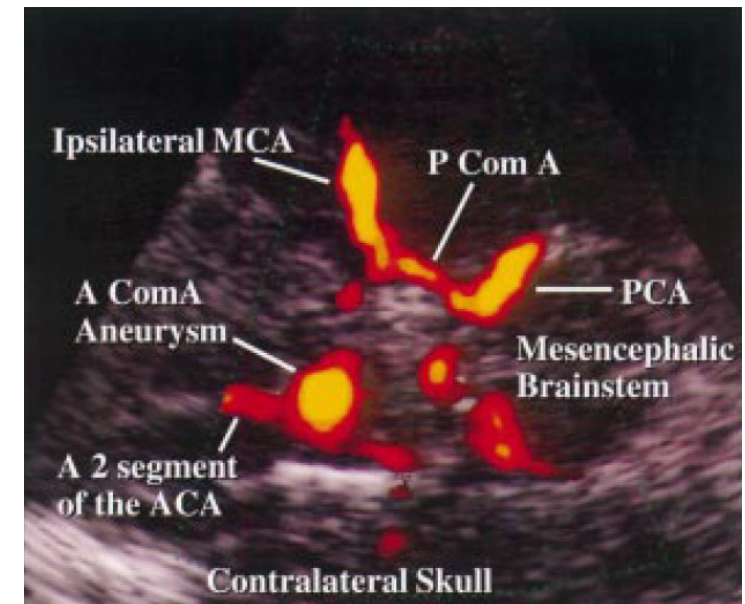


Doppler avec contraste



- Agent de contraste : microsphères lipidiques
- Augmente la précision du DTC

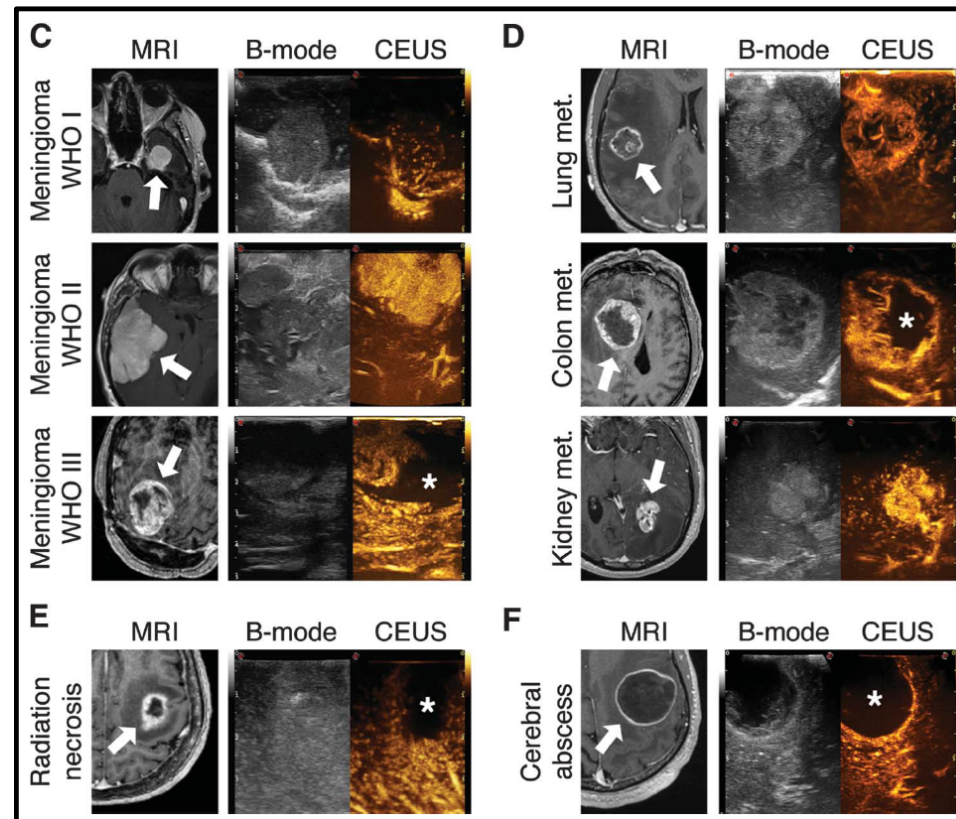
- Efficacité démontrée pour diagnostic
 - Anévrismes
 - MAV, FAV
 - FOP



- Sensibilisation pour confirmation de mort encéphalique ?

Intraoperative Contrast-Enhanced Ultrasound for Brain Tumor Surgery

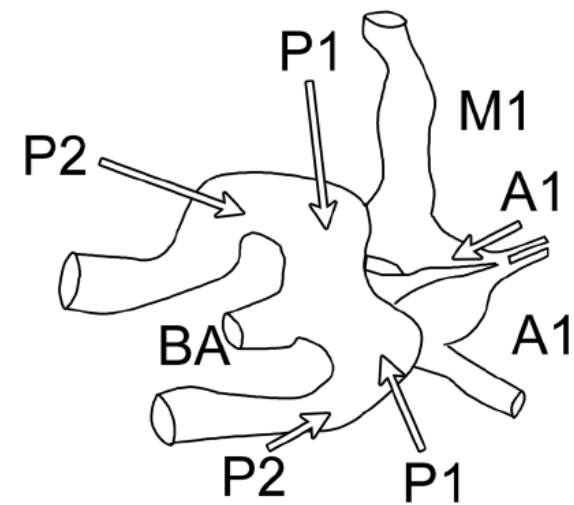
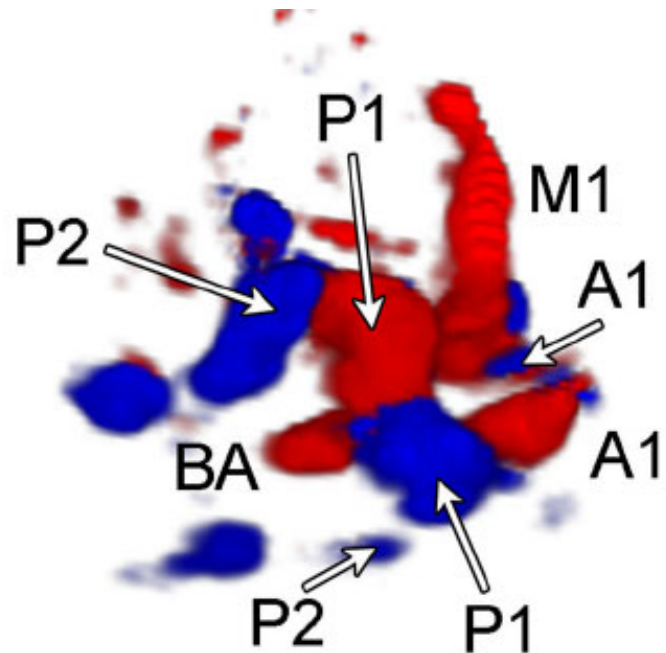
71 patients



Francesco Prada, MD*
 Alessandro Perin, MD, PhD*
 Alberto Martegani, MD‡
 Luca Aiani, MD‡
 Luigi Solbiati, MD§
 Massimo Lamperti, MD¶
 Cecilia Casali, MD*
 Federico Legnani, MD*
 Luca Mattei, MD*
 Andrea Saladino, MD*
 Marco Saini, MD*
 Francesco DiMeco, MD*‡§¶||

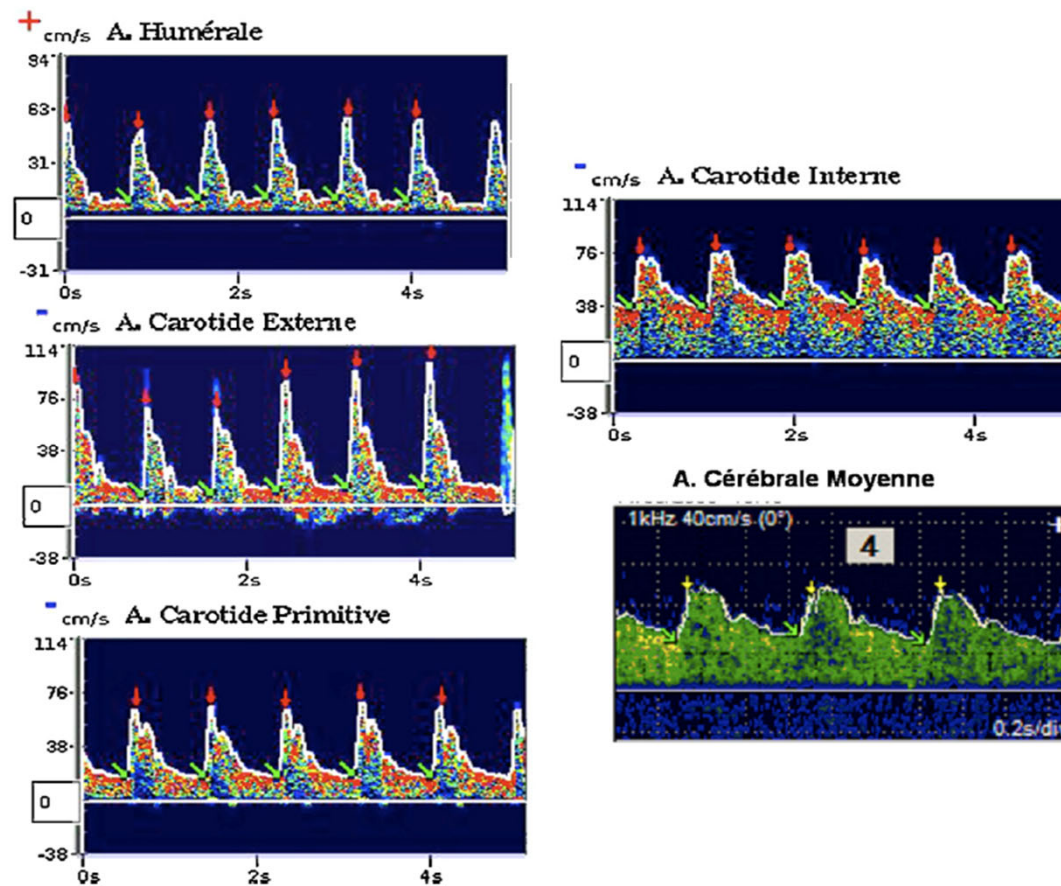
Real-Time 3D Contrast-Enhanced Transcranial Ultrasound and Aberration Correction

Nikolas M. Ivancevich^{*}, Gianmarco F. Pinton^{*}, Heather A. Nicoletto[†], Ellen Bennett[†], Daniel T. Laskowitz[†], and Stephen W. Smith^{*}



Ultrasound Med Biol. 2008 September ; 34(9): 1387–1395

Résistance artérielle



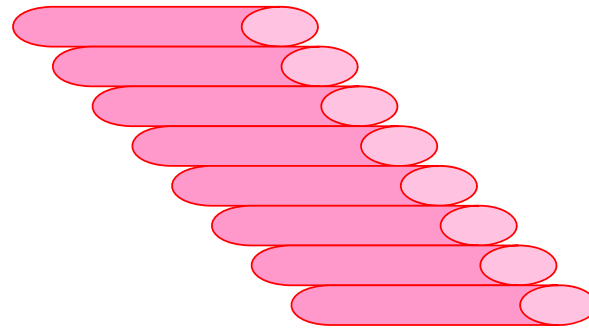
Geeraerts T, *Neurochirurgie*, 2008

40 % R



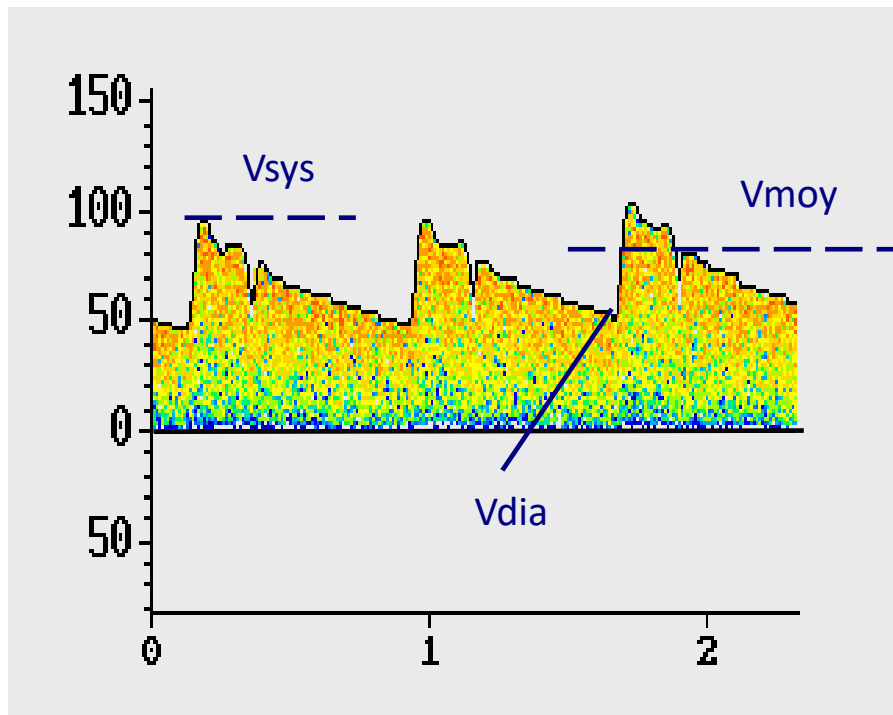
Gros tronc artériel

60 % R



Artéριοles

Indices



Index de pulsativité (Gosling)

$$IP = \frac{V_{sys} - V_{dia}}{V_{moy}}$$

Index de résistivity (Pourcelot)

$$IR = \frac{V_{sys} - V_{dia}}{V_{sys}}$$

Valeurs normales

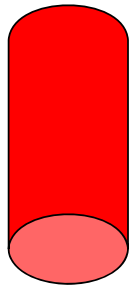
Tableau I – Vitesses circulatoires et index de pulsatilité : valeurs normales chez l'adulte.

Artère	Profondeur (mm)	Moyenne	Diastolique	Systolique	IR	IP
ACM	40-55	62 ± 12	45 ± 10	90 ± 16	0,4-0,7	0,90 ± 0,24
ACA	60-75	50 ± 13	35 ± 10	71 ± 18		0,83 ± 0,17
ACP	55-80	37 ± 10	26 ± 7	53 ± 11		0,88 ± 0,20
TB	85-100	39 ± 9	31 ± 9	52 ± 9		

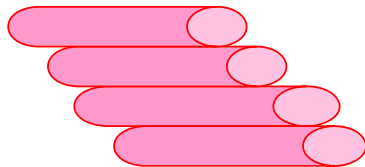
ACM : artère cérébrale moyenne ; ACA : artère cérébrale antérieure ; ACP : artère cérébrale postérieure ; TB : Tronc basilaire ; IR : index de résistance ; IP : index de pulsatilité

Extra-crânien

- Pressions systémiques
- Volémie
- Tachycardie ($\downarrow$ IP car $\downarrow$ relaxation diastolique)
- Modification de section dans les artères extra-crâniennes



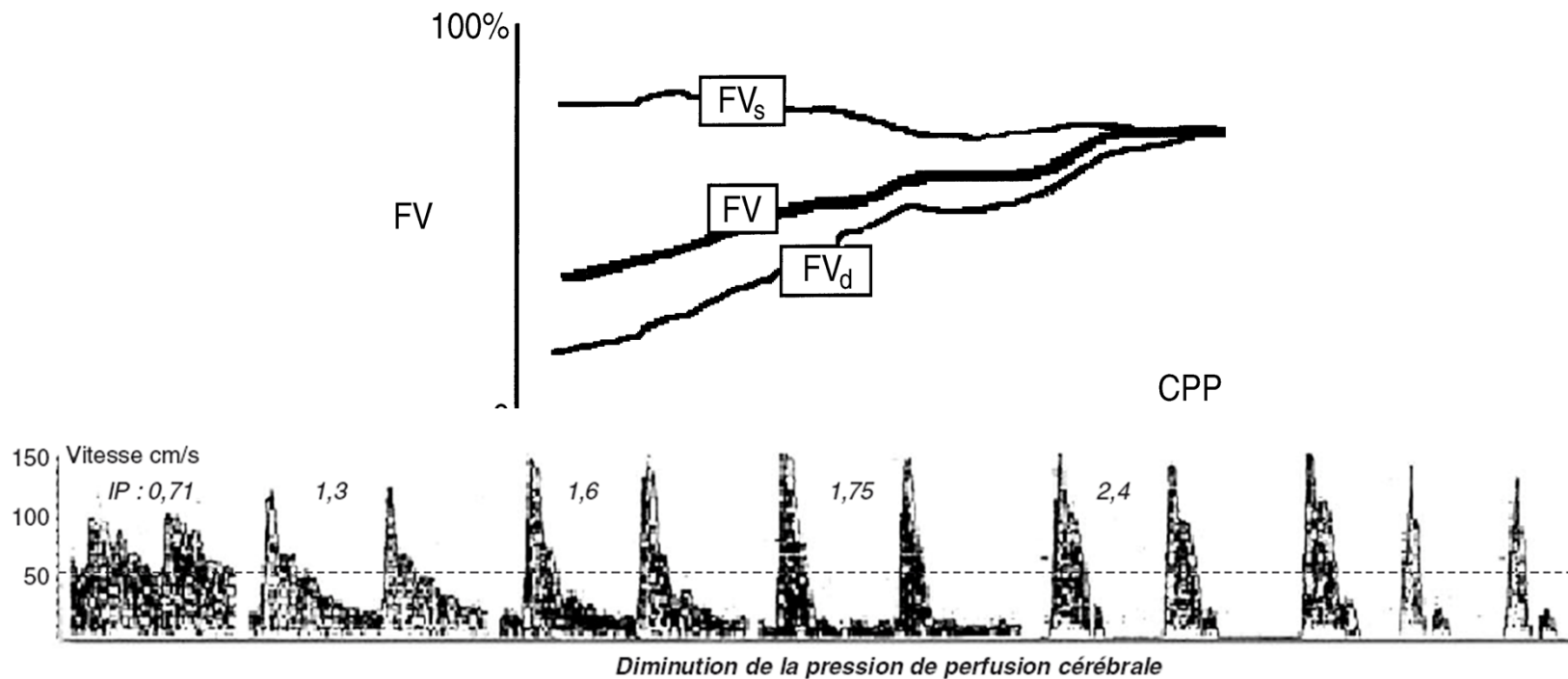
- Modification de diamètre
 - vasospasme
 - sténose, occlusion



Résistances artériolaires

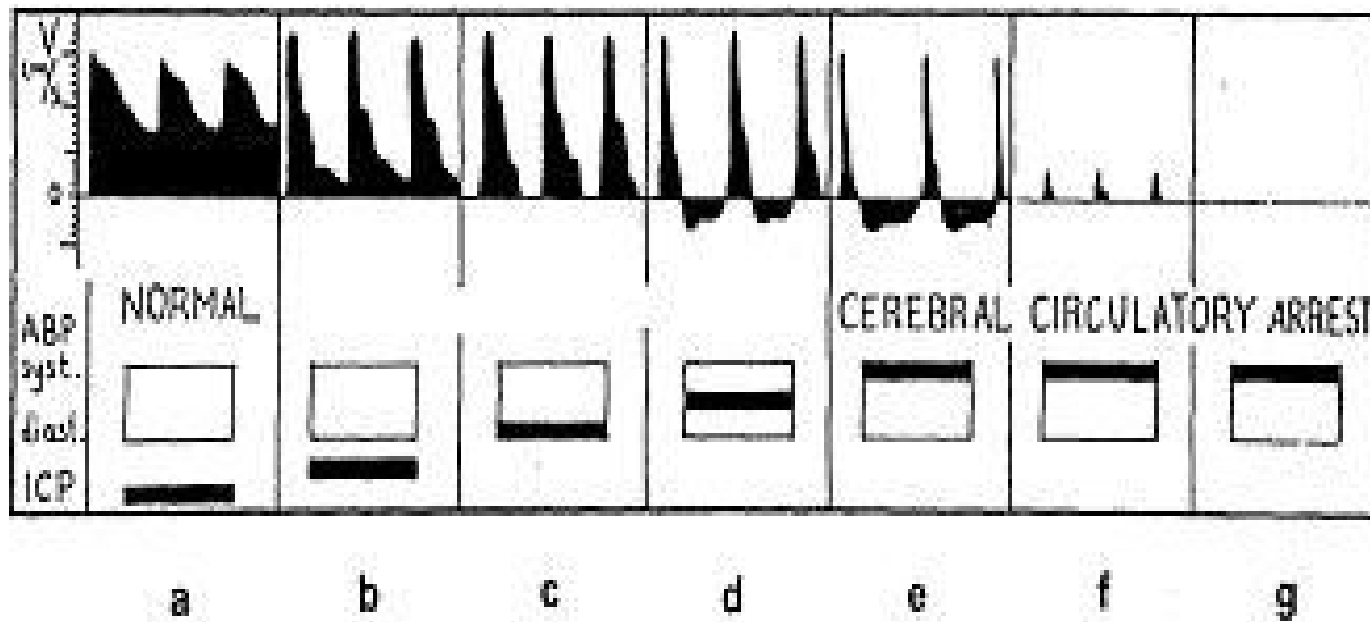
- Hypertension intracrânienne
 - Variations de capnie
 - Anémie
- ⇒ Vélocités diastoliques, IP

Diminution de la PPC



- Indépendant de l'angle d'insonation

Hypertension intracrânienne



Augmentation des résistances
↓ Vitesse diastolique ↑ IP

ITT : 0.4
 11-3L
 15 MAR 80
 09:36:15
 TRAIT 1/0/F/F3
 Dpt Anesthésie
 Hôpital SICETRE
 HP Carotide
 X

[Pe]

DRIN 65
 CCNP 45

3.6MHz

4cm

FENET
 LONG. 0.170
 61 68
 28

CP DROITE

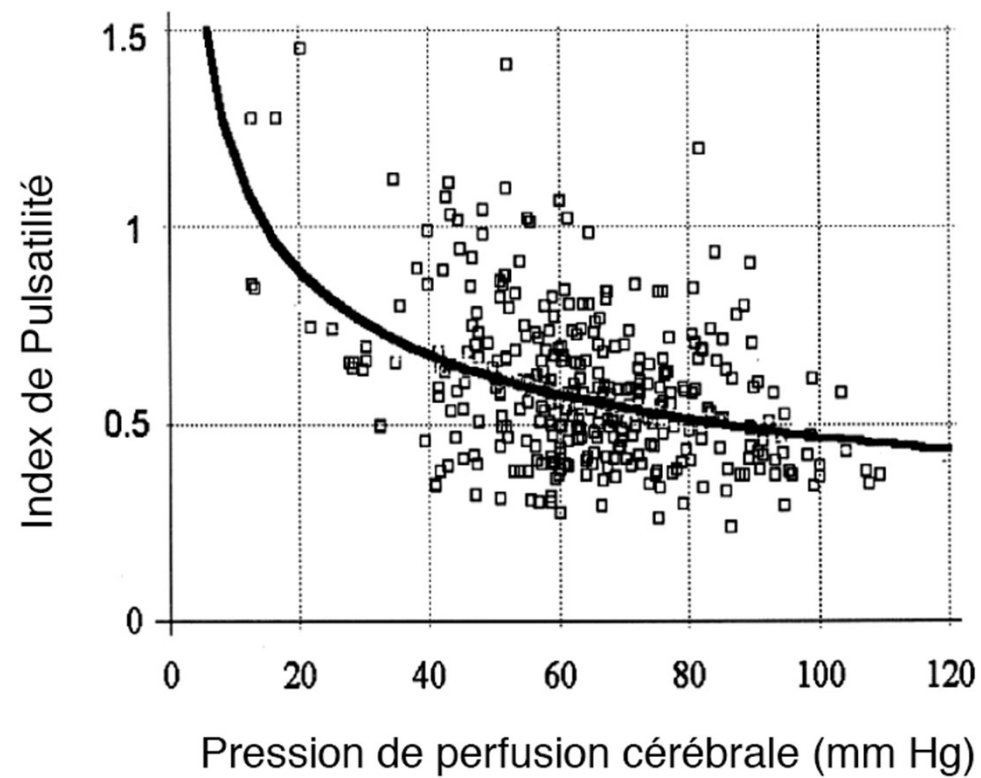
S

DS1
 GEL 20

MAX	118	cm/s
MIN	80	cm/s
MOY	90	cm/s
T. Acc.	11	s
VECTUS	18	cm/s
S/D	50	
ndPuls	4	
ndRes.	981	
MAX	104	cm/s
MIN	88	cm/s
MOY	93	cm/s
S/D	48	
ndPuls	1	
ndRes.	981	
MAX	81	cm/s
MIN	64	cm/s
MOY	70	cm/s
S/D	8	
ndPuls	1	
ndRes.	981	

cm/s

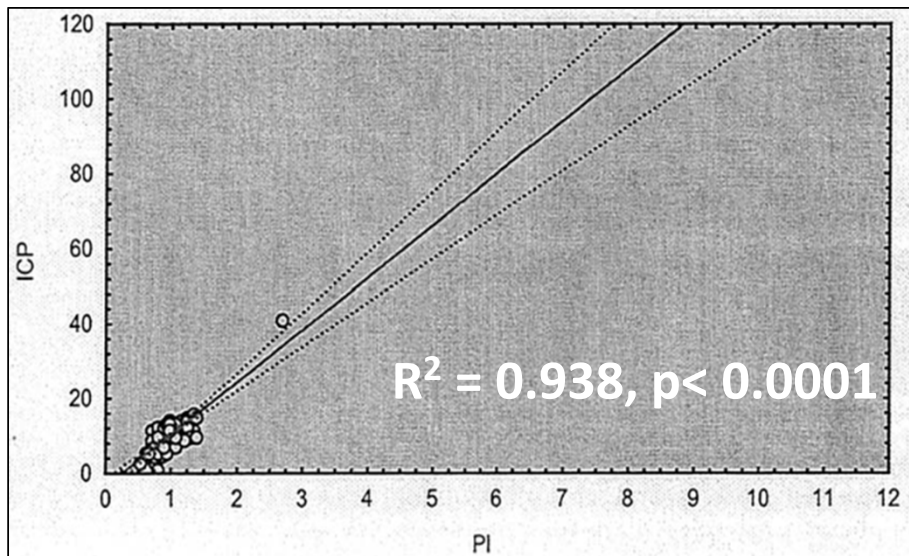
Pression de perfusion cérébrale ?



Czosnyka M, *J Neurosurg*, 1998

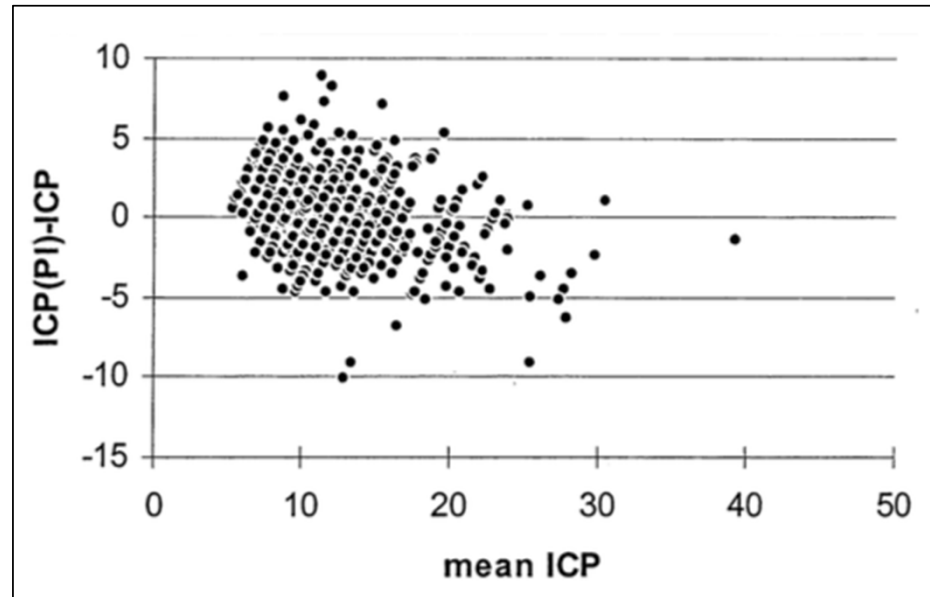
1- Diagnostic de ischémie cérébrale

- Prospective
- n=80 dont 60% HSA et ¼ TC, [2-79 ans]
- Détermination corrélation IP et PIC
 - => équation de droite de régression linéaire :
 $PIC_{prédite}$
 - Comparaison $PIC_{mesurée}$ et $PIC_{prédite}$



Bellner J, Surg Neurol 2004, 62

1- Diagnostic de ischémie cérébrale



$$PIC_{\text{prédite}} = PIC_{\text{mesurée}} \pm 4.2 \text{ mmHg}$$

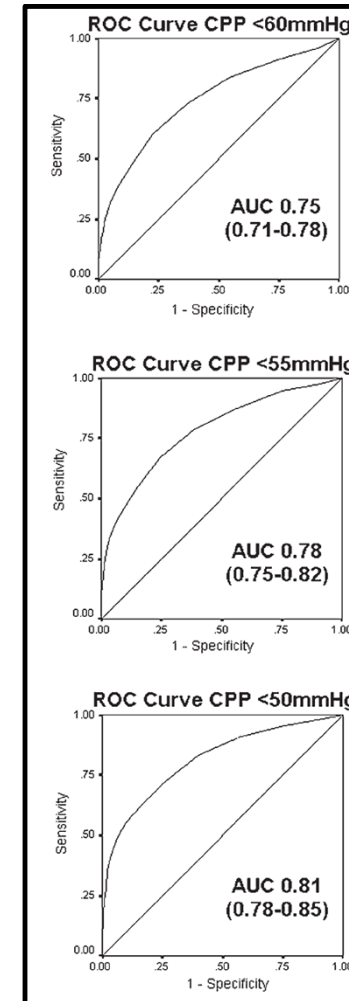
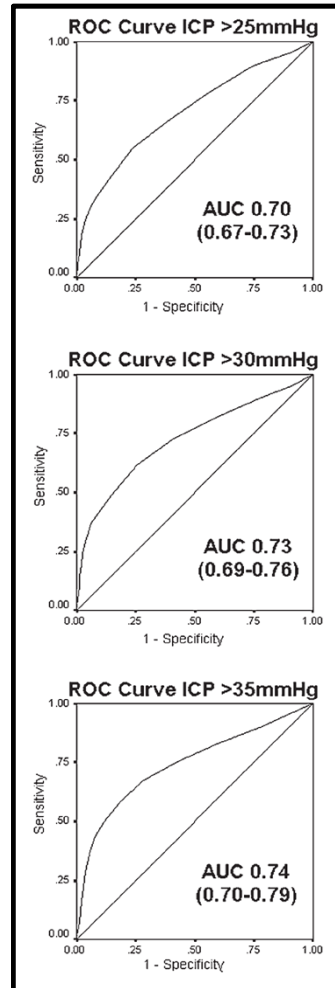
Dans 95% des cas (précision)

Bellner J, Surg Neurol 2004, 62

Reliability of the Blood Flow Velocity Pulsatility Index for Assessment of Intracranial and Cerebral Perfusion Pressures in Head-Injured Patients

Christian Zweifel, MD*
Marek Czosnyka, PhD*
Emmanuel Carrera, MD*
Nicolas de Riva, MD*
John D. Pickard, MD, FMedSci*
Peter Smielewski, PhD*

290 head-injured patients



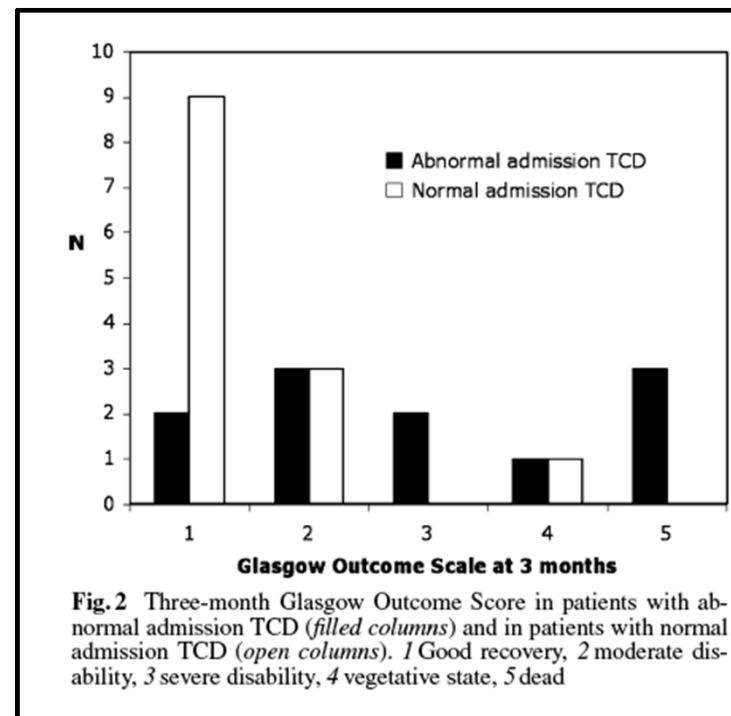
Neurosurgery 71:853-861, 2012

Catherine Ract
Sophie Le Moigno
Nicolas Bruder
Bernard Vigué

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

DTC considéré anormal si au moins 2 des 3 critères suivants:

- $V_m < 30$ cm/s,
- $V_d < 20$ cm/s,
- $IP > 1.4$.



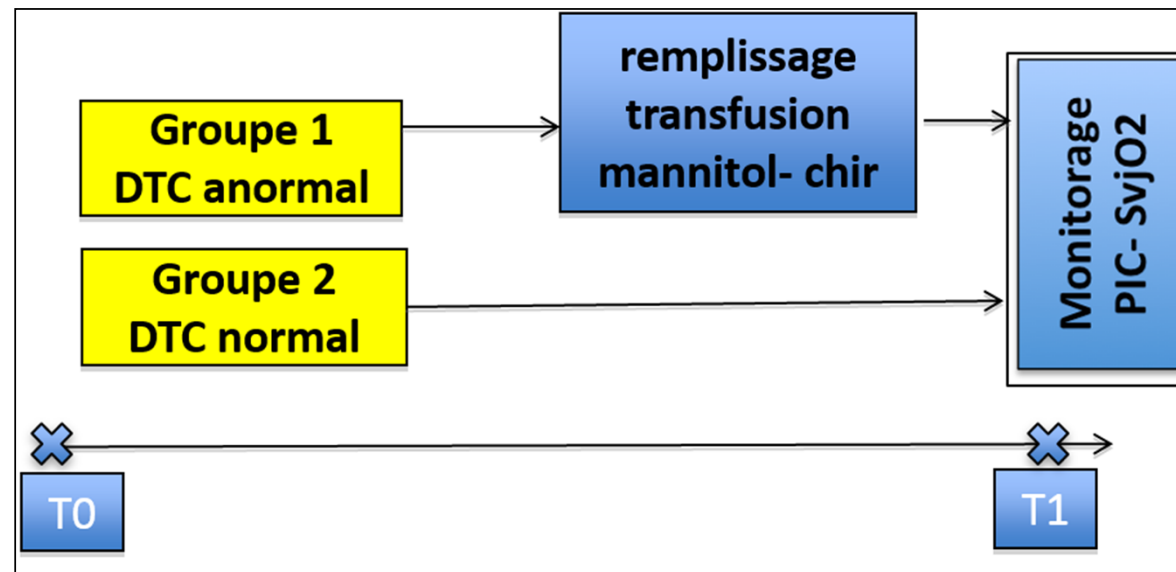
2- Triage et intensification du traitement

	Abnormal TCD (<i>n</i> = 9) Group 1		Normal TCD (<i>n</i> = 9) Group 2	
	In the field	At the trauma centre	In the field	At the trauma centre
Time from trauma (min)	68 ± 25	143 ± 50	61 ± 14	146 ± 57
Abnormal TCD (<i>n</i>)	9	4	0	0
Systolic velocity (cm/s)	67 ± 21	76 ± 23	79 ± 25	81 ± 17
Mean velocity (cm/s)	28 ± 10†	37 ± 12*,†	48 ± 14†	53 ± 9†
Diastolic velocity (cm/s)	9 ± 7†	18 ± 11*,†	33 ± 10†	38 ± 10†
Pulsatility index	2.2 ± 0.6†	1.7 ± 0.8*,†	0.9 ± 0.3†	0.8 ± 0.3†
MAP (mmHg)	93 ± 25	101 ± 32	72 ± 22	83 ± 19
Haemoglobin (g/dl)	14 ± 1		122	
Areactive mydriasis	4	2	0	0
Norepinephrine (<i>n</i>)	—	2	—	3
Mannitol (<i>n</i>)	—	7	—	0
Emergency neurosurgery (<i>n</i>)	—	3	—	0
48 h mortality (<i>n</i>)	—	6†	—	1†

- Normalisation par traitement intensif (faisabilité)
- Association doppler ⇔ gravité/pronostic
 - Pas de normalisation: 100% décès, différence entre 2 groupes
 - Doppler initial normal: 0% neurochirurgie

2- Triage et intensification du traitement

- Etude pilote: prospective, non randomisée, $GCS \leq 8$
- Objectifs: $FC < 120$, $PAM > 75$, $Hb > 10$
- Doppler considéré anormal (PPC basse):
 - $IP > 1,4$, $Vd < 20$ et $Vm < 30 \text{ cm.s}^{-1}$



Triage

Paul Jaffres
Julien Brun
Philippe Decléty
Jean-Luc Bosson
Bertrand Fauvage
Almuth Schleiermacher
Affif Kaddour
Daniel Anglade
Claude Jacquot
Jean-François Payen

Transcranial Doppler to detecton admission patients at risk for neurological deterioration following mild and moderate brain trauma

	Group 1	Group 2	<i>p</i>
TCD measurements (cm/s)			
FVm	43 (22–75)	36 (23–51)	0.37
FVs	75 (46–130)	77 (53–112)	0.93
FVd	27 (12–57)	26 (16–37)	0.30
Pulsatility index	1.28 (0.78–2.31)	1.64 (0.96–2.05)	0.05

2- Triage et intensification du traitement

- **Prospective, monocentrique, n=98 Trauma GCS [9-15]**
 - Marshall 1 et 2
 - doppler « patients stables » vs « dégradation neuro J7 »
 - dégradation: 21/98 (21.4%), 3 décès.

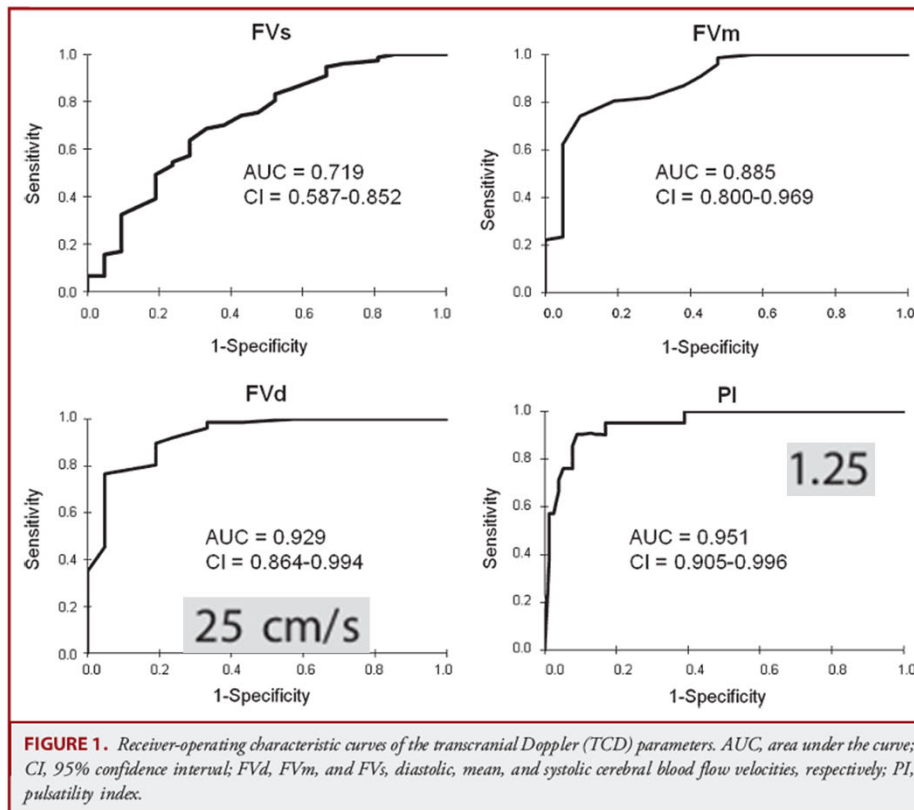
Status on Posttrauma Day 7: Patients With and Without Secondary Neurological Deterioration ^a			
	No SND (n = 77)	SND (n = 21)	P
FVm, cm/s	49 (31-80)	31 (18-60)	<.01
FVs, cm/s	84 (47-128)	69 (38-119)	<.01
FVd, cm/s	34 (18-64)	18 (11-36)	<.01
Pulsatility index	1.02 (0.66-1.83)	1.47 (1.07-2.33)	<.01
Injury-to-TCD time, min	215 (42-700)	300 (90-690)	.03

Prédiction: Se: 90% / Sp: 91%

Bouzat P, Neurosurgery 2011,68

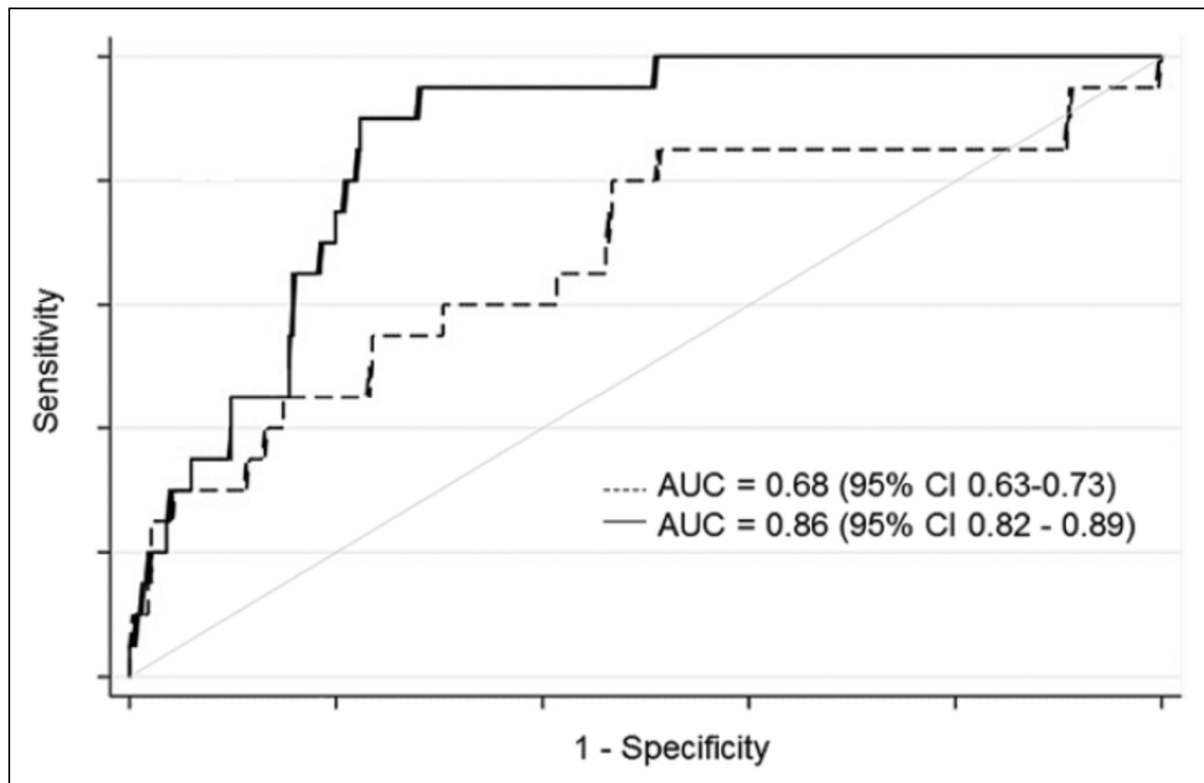
Transcranial Doppler to Screen on Admission Patients With Mild to Moderate Traumatic Brain Injury

Pierre Bouzat, MD*
 Gilles Francony, MD*
 Philippe Declety, MD*
 Céline Genty, BSc‡
 Affif Kaddour, MDS
 Pierre Bessou, MD¶
 Julien Brun, MD*
 Claude Jacquot, MD*
 Stephan Chabardes, MD, PhD||
 Jean-Luc Bosson, MD, PhD‡
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2- Triage et intensification du traitement

- **Prospective, multicentrique, n=356 MMTBI = GCS 9 à 15**
 - Marshall 2
 - Objectifs: validation **seuils IP 1.25 et Vd 25**
 - dégradation neuro <J7: 20 (6%), 4 décès.



VPN=98%

VPP= 18%

Bouzat P et al.,
Anesthesiology
2016

2- Triage et intensification du traitement



Recommandations Formalisées d'Experts 2016

R1.4 - Il faut probablement évaluer la gravité initiale des traumatisés crâniens à l'aide du Doppler transcrânien.

(GRADE 2+) Accord FORT

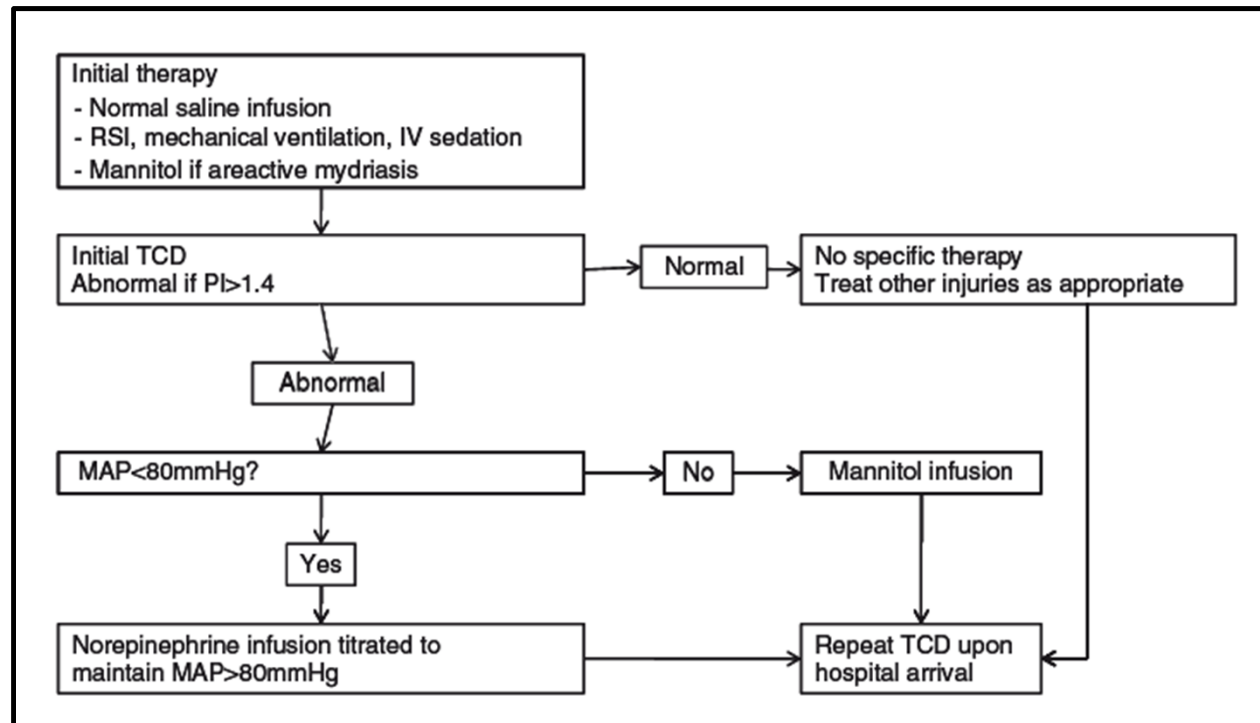
Argumentaire :

Chez les traumatisés crâniens, l'indice le plus sensible au Doppler transcrânien (DTC) pour détecter la baisse de Pression de Perfusion Cérébrale (PPC) est l'index de pulsatilité (IP)³⁹. Tant que l'on ne dispose pas d'un monitoring

Pre-hospital transcranial Doppler in severe traumatic brain injury: a pilot study

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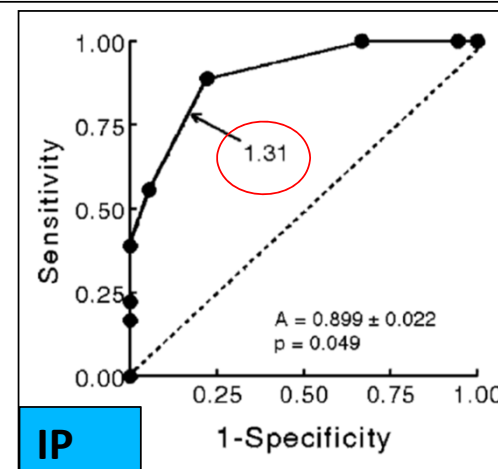
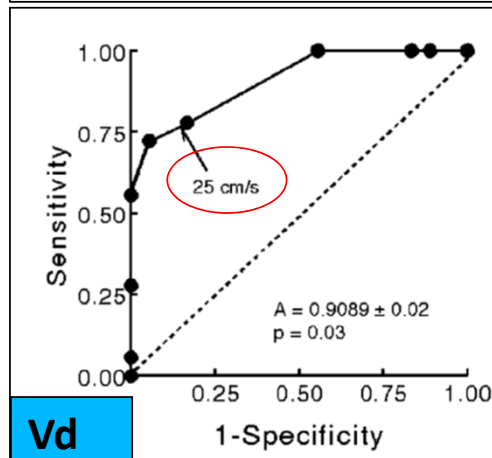
2- Triage et intensification du traitement

- Prospective monocentrique, n=36 [enfants](#)
- Traumatisme crânien sévère/modéré

Trabold F, Int Care Med
2004; 30

	Good prognosis GOS [1-2], n=18	Poor prognosis GOS [3-5], n=18
$V_{\max}$ (cm/s)	96±28	77±21
V_{ed} (cm/s)	38±11	16±11*
V_{mean} (cm/s)	56±18	35±13*
RI	0.59±0.09	0.79±0.10*
PI	1.08±0.31	1.97±0.73*

* $p < 0.05$ versus group 1 in univariate analysis



3- Dissection carotidienne

Critères de Denver	Critères de Memphis
-Fractures du rachis cervical -Déficit neurologique inexpliqué -Fr base au niveau du canal carotidien -Fr Lefort II et III -Hématome cervical -Souffle cervical < 50 ans -AVC ischémique -TCG avec score de GCS < 6 -pendaison	-Fractures du rachis cervical -Déficit neurologique inexpliqué par l'imagerie cérébrale -Fr base au niveau du canal carotidien -Fr Lefort II et III -Syndrome de CBH -Lésions des parties molles cervicales

3- Dissection carotidienne

- **Rétrospective**, dissection vs. contrôles appariés 1:4
- Profil doppler cas avec dissection confirmée/CTA

	TICAD	Controls 1	Controls 2	<i>p</i>
FVs (cm/s)	51 (22–92)	91 (57–123) ^a	80 (46–115) ^a	<0.01
FVm (cm/s)	36 (18–64)	53 (31–73) ^a	35 (25–64) ^b	<0.01
FVd (cm/s)	29 (15–53)	40 (18–55) ^a	25 (12–47) ^b	<0.01
PI	0.70 (0.18–1.45)	0.98 (0.60–1.75) ^a	1.36 (0.84–3.09) ^{a, b}	<0.01
PI < 0.80 (<i>n</i>)	10	4	0	<0.01
FVs asymmetry (%)	47 (7–60)	12 (0–22) ^a	12 (0–41) ^a	<0.01
FVm asymmetry (%)	37 (4–51)	12 (0–29) ^a	15 (0–36) ^a	<0.01
FVd asymmetry (%)	29 (0–40)	14 (0–24)	16 (0–52)	0.18
PI asymmetry (%)	46 (16–85)	9 (1–39) ^a	13 (0–53) ^a	<0.01
FVs asymmetry >25% (<i>n</i>)	9	0	5	<0.01
PI ≤ 0.80 and FVs asymmetry >25% (<i>n</i>)	9	0	0	<0.01

- ↘ **vélocités et IP homolatérale à la dissection**
- ↑ **assymétrie des vélocités si dissection**

3- Dissection carotidienne



Recommandations Formalisées d'Experts 2016

R3.2 - Il faut probablement faire précocement une exploration des troncs supra-aortiques et des vaisseaux intracrâniens par angiotomodensitométrie chez les patients présentant des facteurs de risque.

(GRADE 2+) Accord FORT

Conclusion

- Progrès techniques certains
- Taux de succès augmente
- Anatomie cérébrale et Doppler transcrânien

- Développement futur pour l'anesthésie réanimation
 - Contraste
 - 3D
- Attention à la toxicité des ultrasons

Je vous remercie de votre attention

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