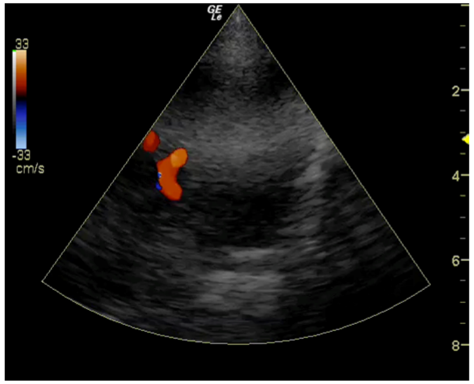
UNIVERSITÉ TOULOUSE III PAUL SABATIER

Université de Toulouse

Hôpitaux de Toulouse

Echo-Doppler transcrânien
Aspects techniques



Pr Thomas GEERAERTS

Pôle Anesthésie Réanimation

CHU de Toulouse

Conflits d'intérêt

- Aucun

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 Goffi[2], Thomas Geeraerts[3], Danilo Cardim[4], Gabriele Via[5], Marek Czosnyka[6], Soojin Park[7], Aarti Sarwal[8], Llewellyn Padayachy[9], Frank Rasulo[10] and Giuseppe Citerio[11]

Take-home message

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

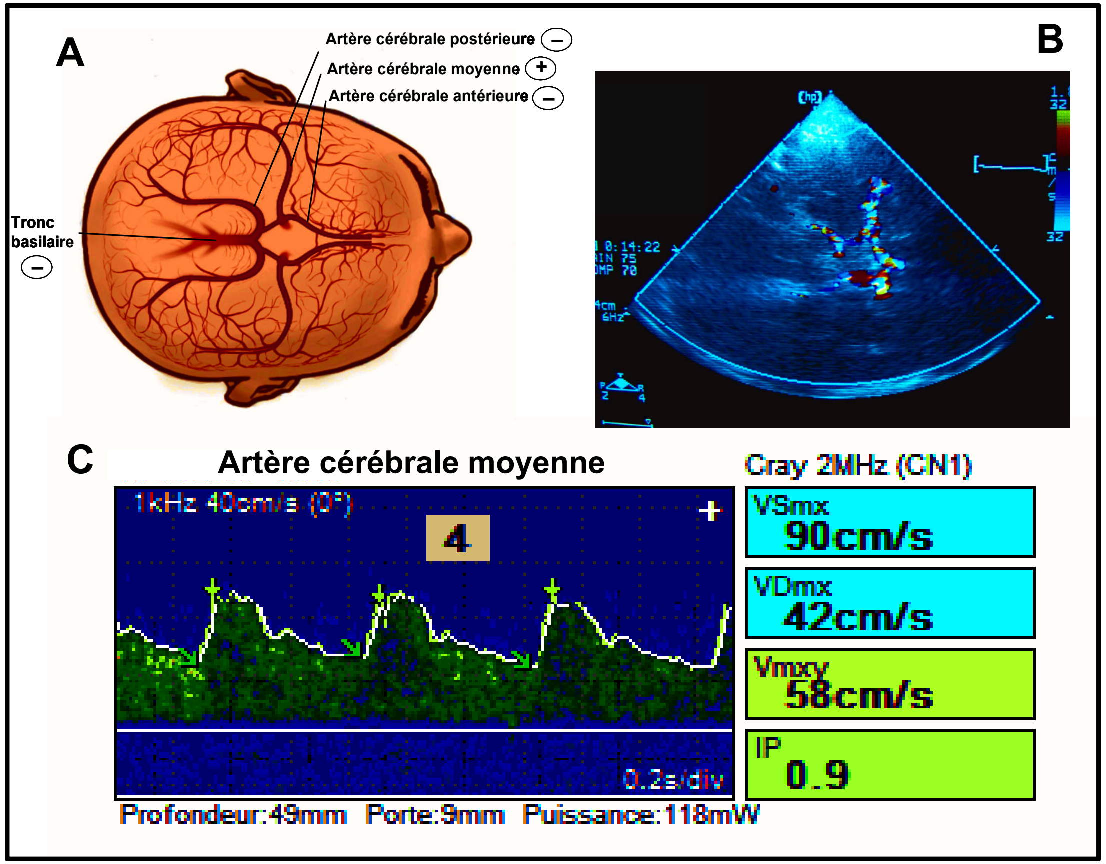
Brain ultrasonography can be performed using commonly used ultrasound systems, through four main acoustic windows (transtemporal, occipital, submandibular and transorbital).

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.

Intensive Care Med
https://doi.org/10.1007/s00134-019-05610-4

Doppler transcrânien



The British Journal of Radiology, 75 (2002), 615–619

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

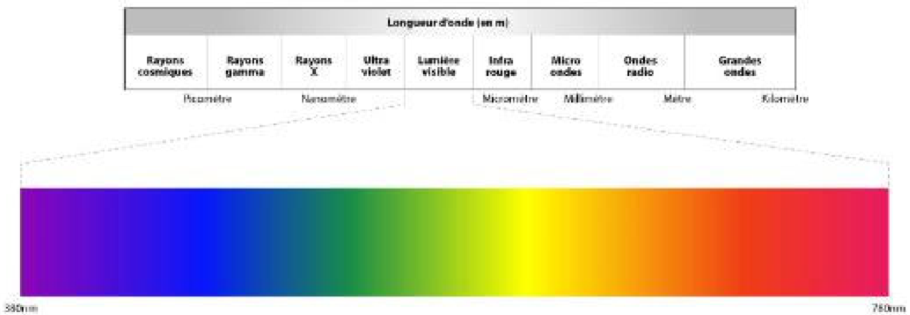


Figure 1. Christian Johann Doppler (1803–1853).

Doppler pulsé

Effet Doppler

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

$$\Delta f = 2 \,.\, Fo.\, V/C.\, \cos\theta$$

Δf : variation de fréquence de l'onde

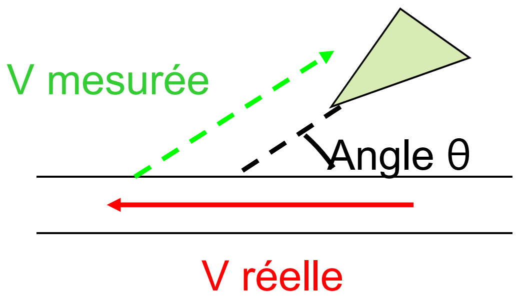
Fo: fréquence de l'onde émise

V: vitesse du flux sanguin

C: vitesse du son dans le tissu

Cosθ: angle sonde et vaisseau

Angle d'insonation



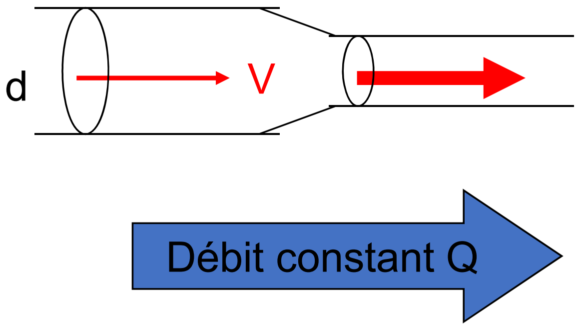
- La vitesse mesurée dépend du cosinus de l'angle d'insonation

  V mesurée=cos θ x V réelle

- On sous-estime donc forcément les vélocités…

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

  V= const. X Q / d²



Vitesse n'est pas débit
La Garonne

Toulouse

Débit moyen
200 m³/sec

Bordeaux

Débit moyen
700 m³/sec

Q = V x section

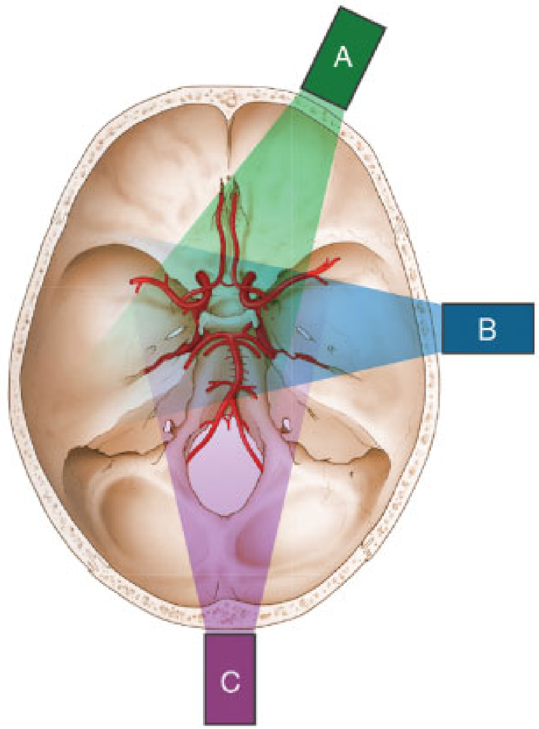
Chez l’adulte, il y a un os…

- 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/cm^2

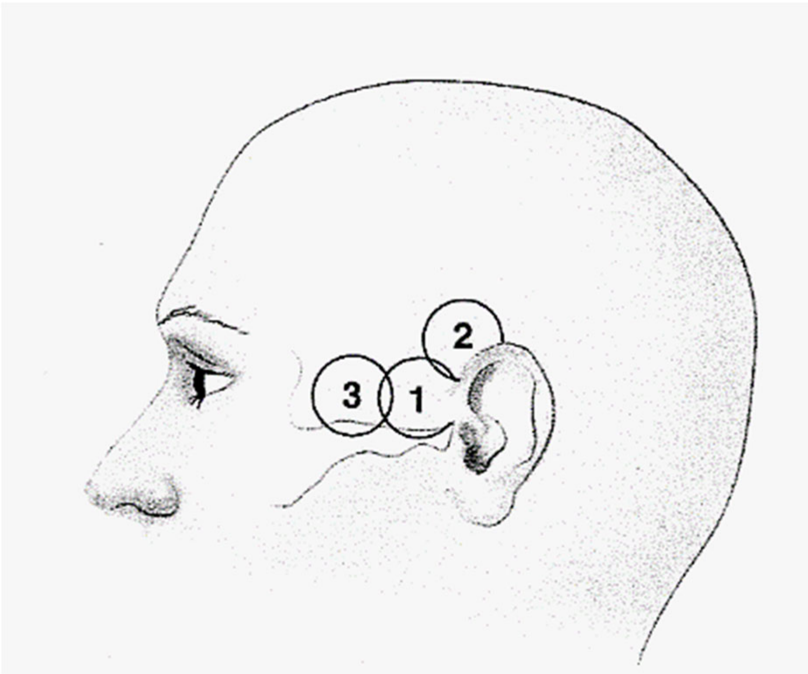
Les fenêtres osseuses

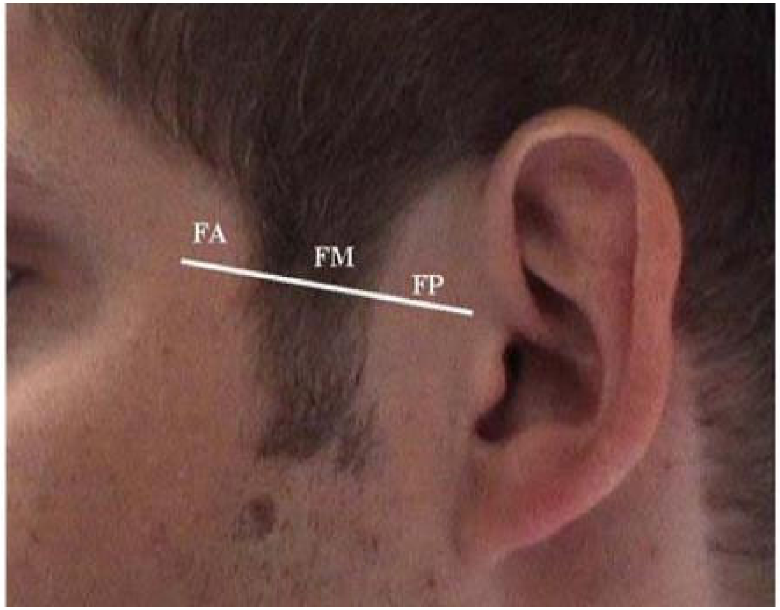
- Transtemporal
- Transorbital
- Sousoccipital
  - Transforamenal
- Sousmandibulaire



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

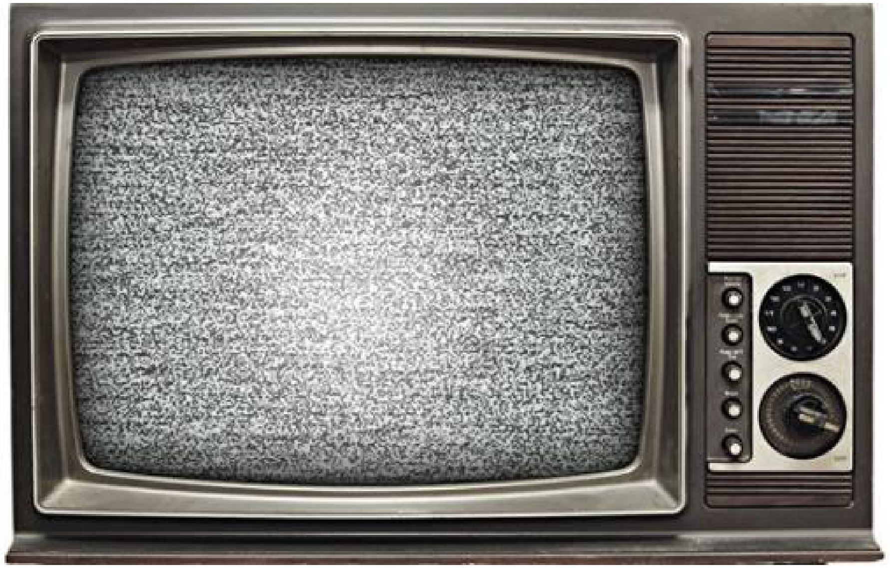
Doppler recordings of bilateral MCA blood flow velocities were obtained in all 50 subjects. However,

J Neurosurg 57:769–774, 1982

Parfois la fenêtre reste fermée

- Jusqu'à 18% dans les études d'AVC

- Femme
- Age
- Ethnie « non-blanche »



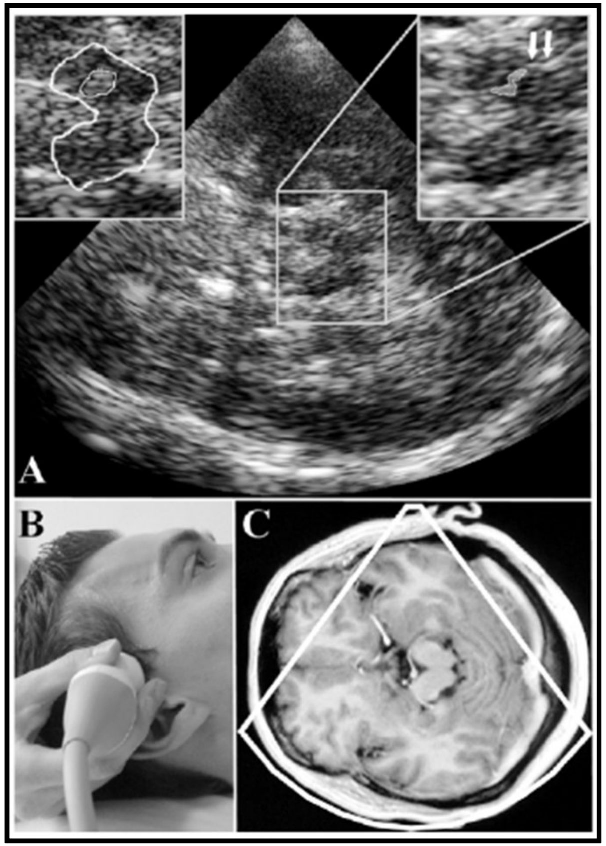
Grolimund P. Transmission of ultrasound through the temporal bone. In: Aaslid R, ed. Transcranial Doppler sonography. Wien/New York: Springer Verlag, 1985:10–18.

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

Uwe Walter*

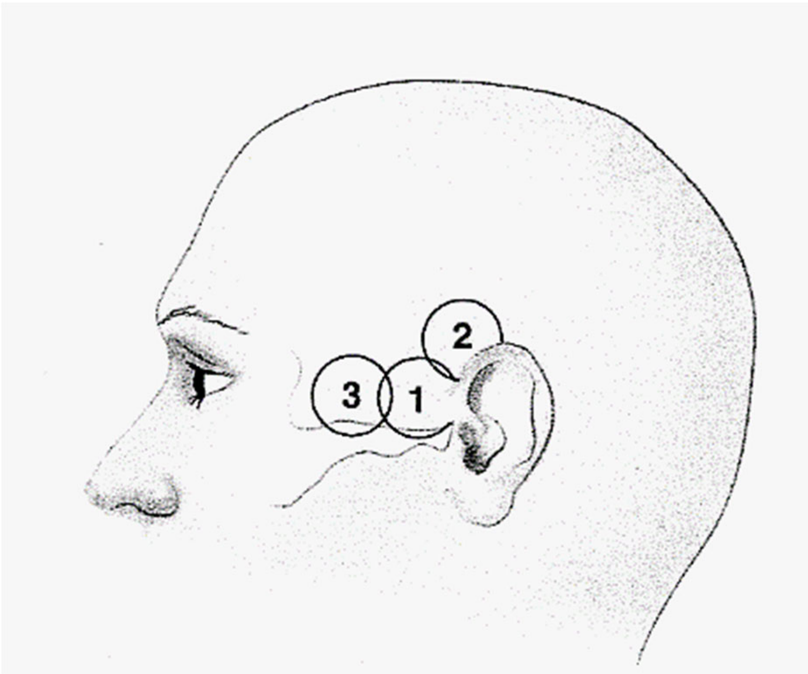
Table 1 Ultrasound system settings for transcranial sonography.

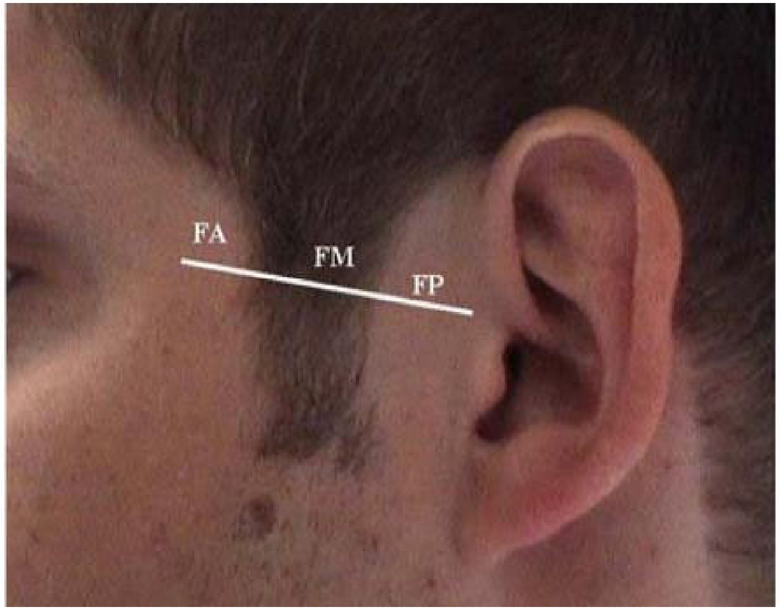
Parameter	Settings
Ultrasound system	
Penetration depth	Start with 14—16 cm, reduce if needed
Dynamic range	45—55 dB
Postprocessing function	Moderate suppression of low echo signals
Time gain compensation	Adjust manually as needed, or use the 'tissue optimization' function if available
Image brightness	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



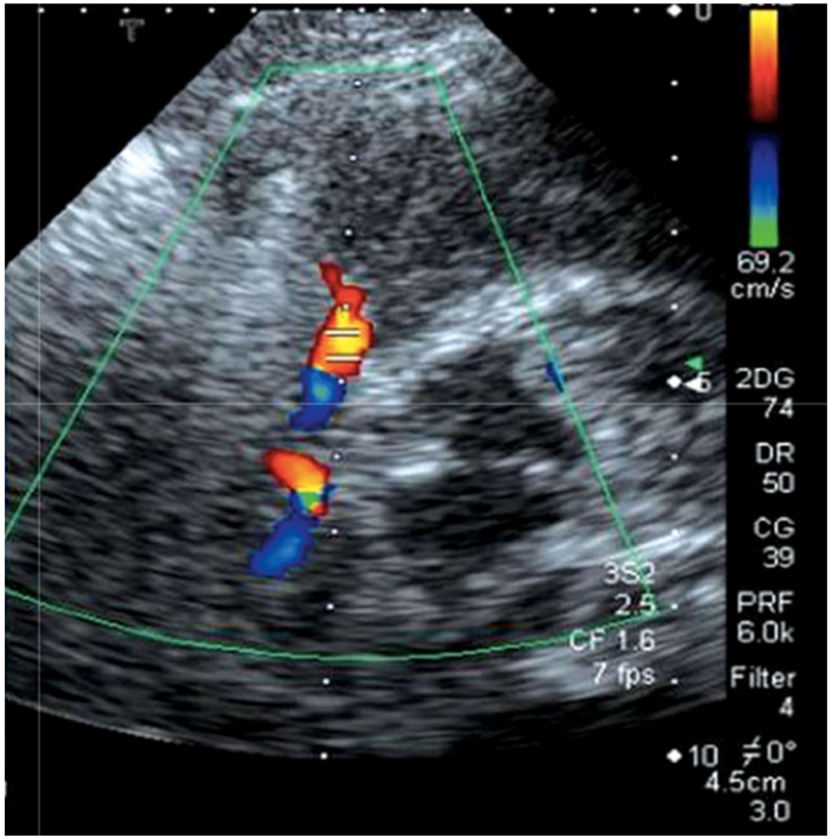
Perspectives in Medicine (2012) 1, 334—343

La fenêtre temporale

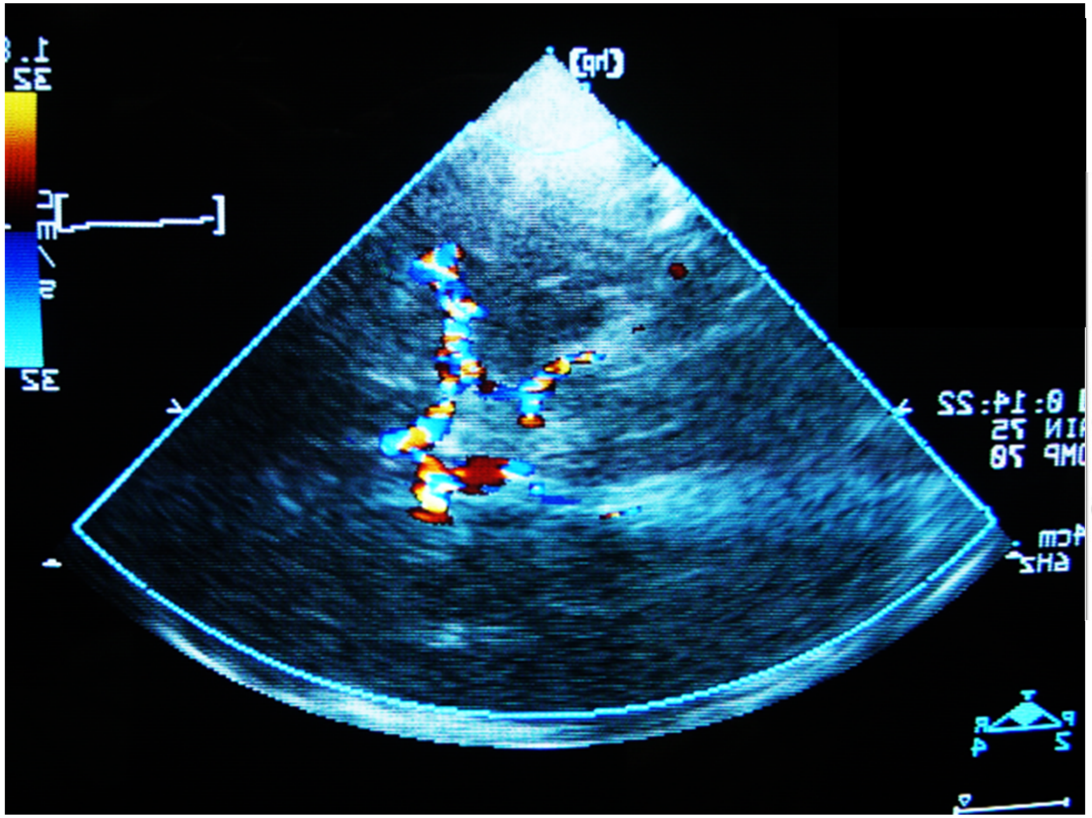


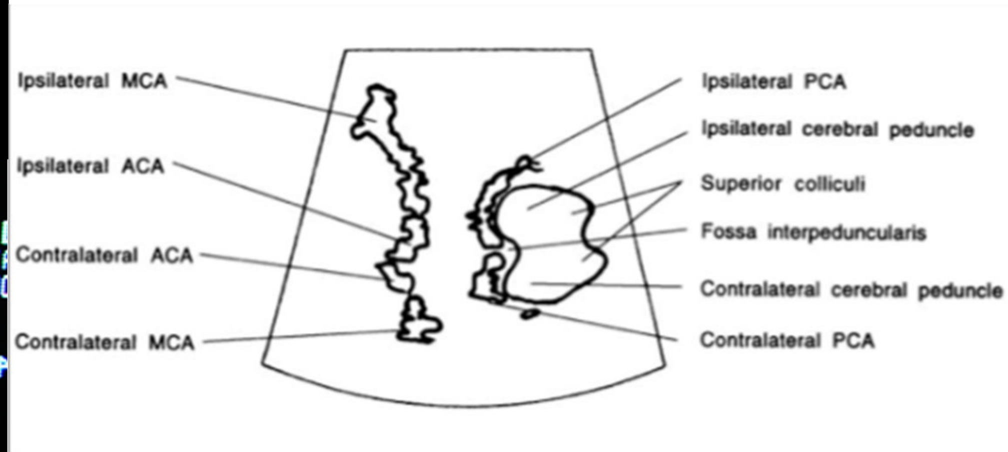


Visualiser le mesencéphale

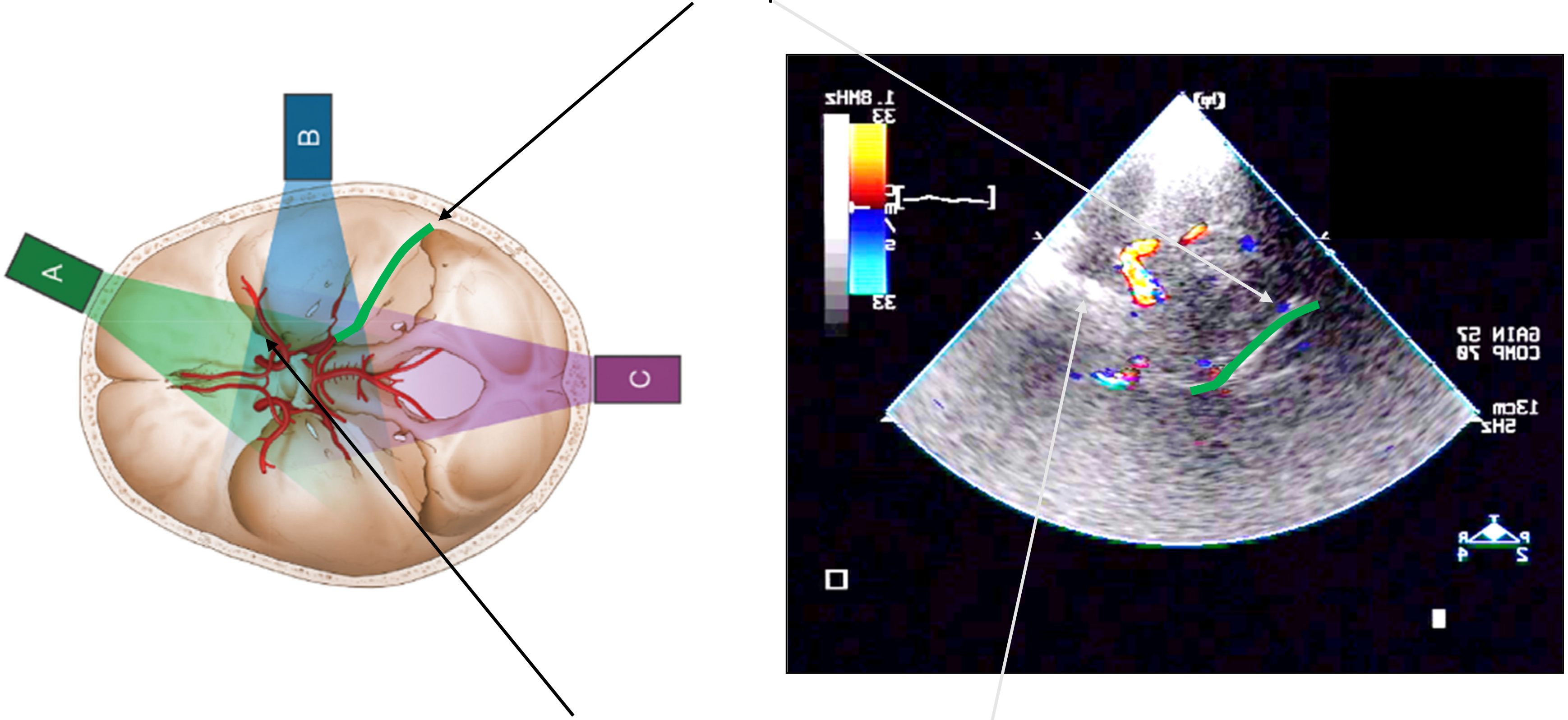


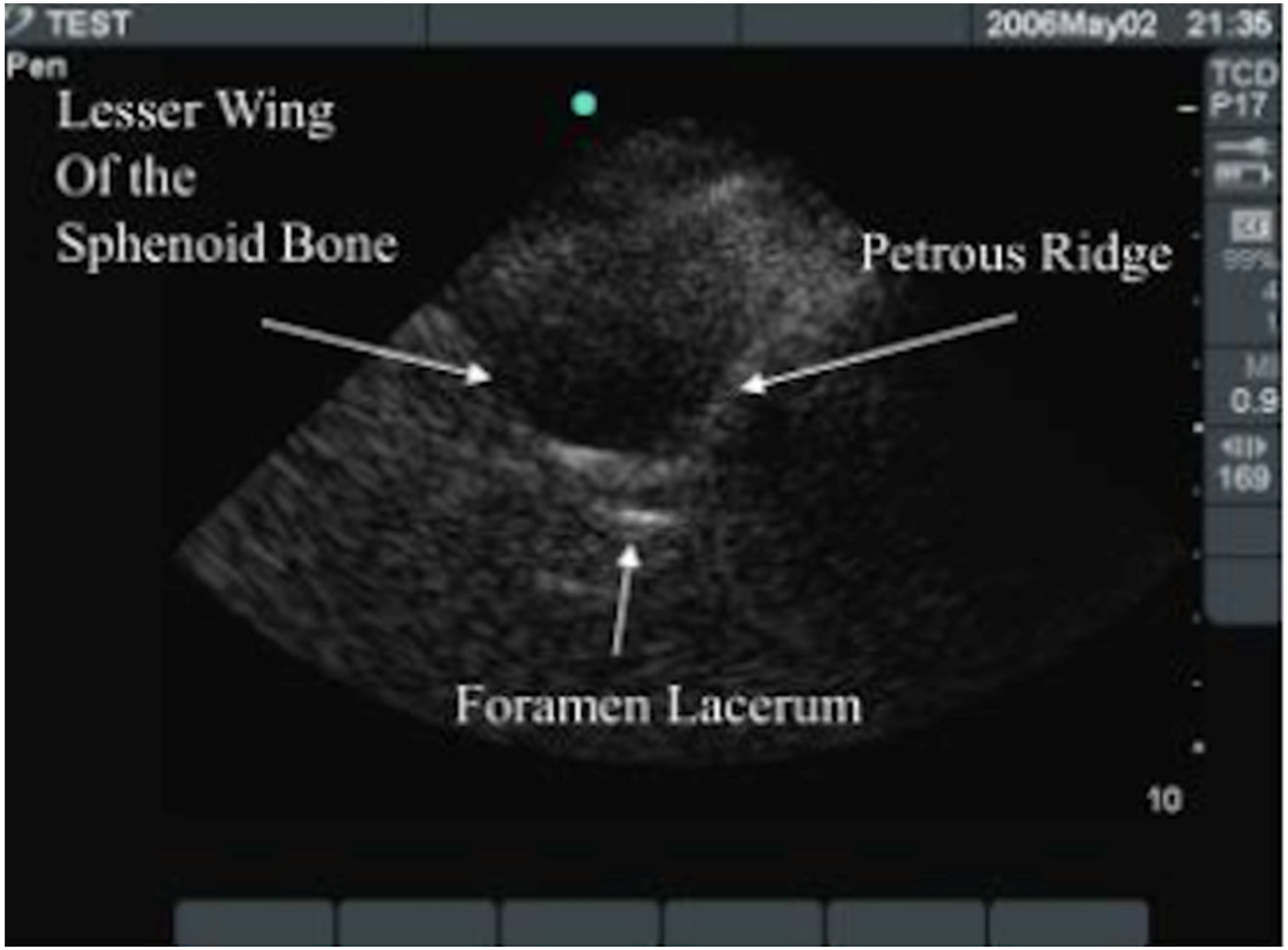
Polygone de Willis

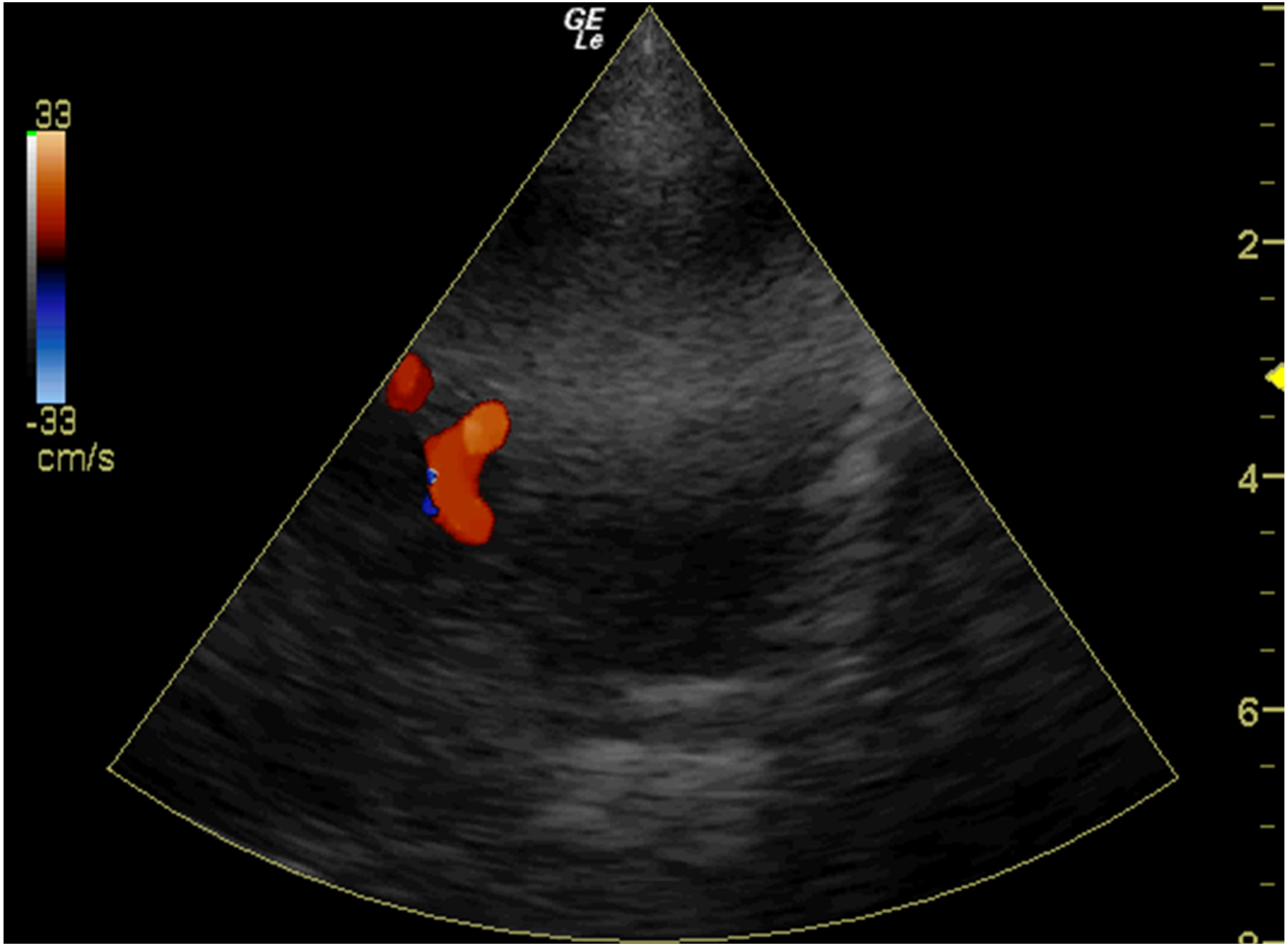




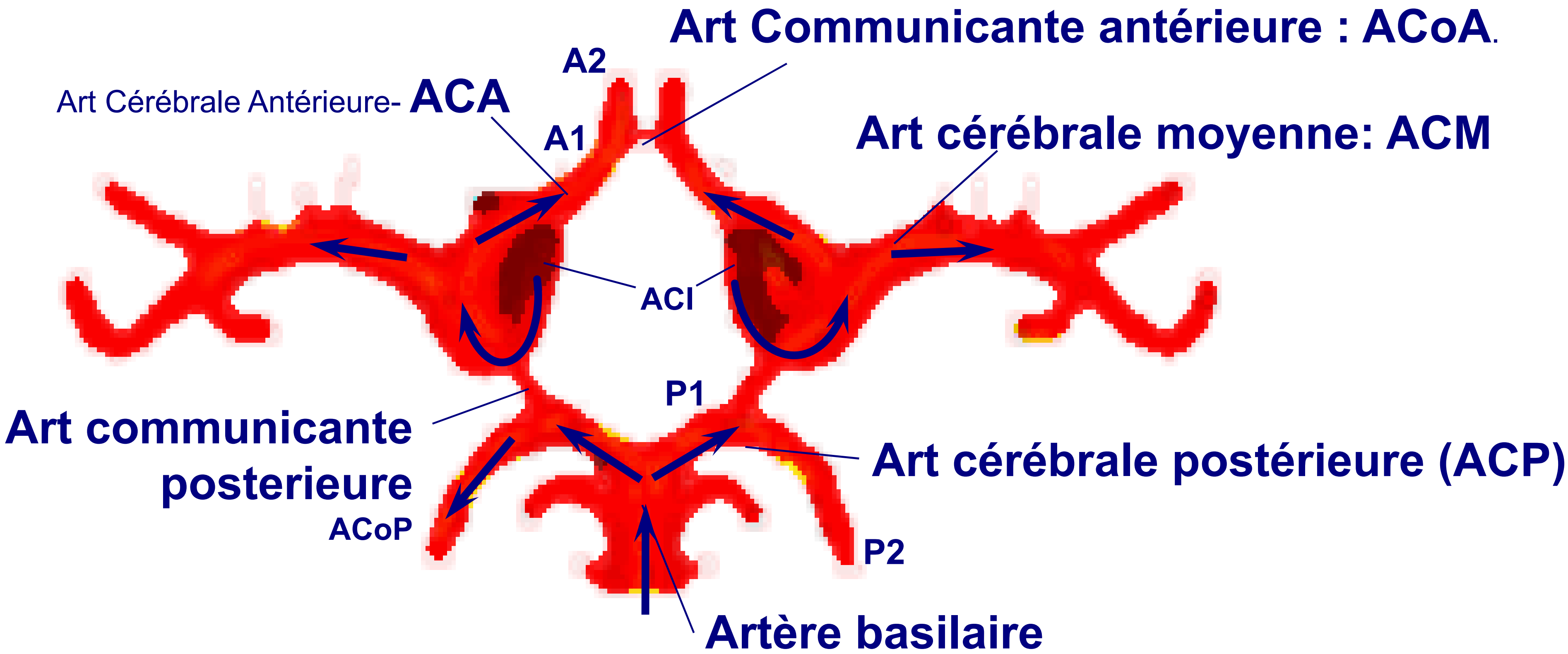
Repères osseux




TEST
2006May02 21:36
Pen
TCD
P17
Lesser Wing
Of the
Sphenoid Bone
Petrous Ridge
MI
0.9
169
Foramen Lacerum
10


GE
Le
33
-33
cm/s
2
4
6

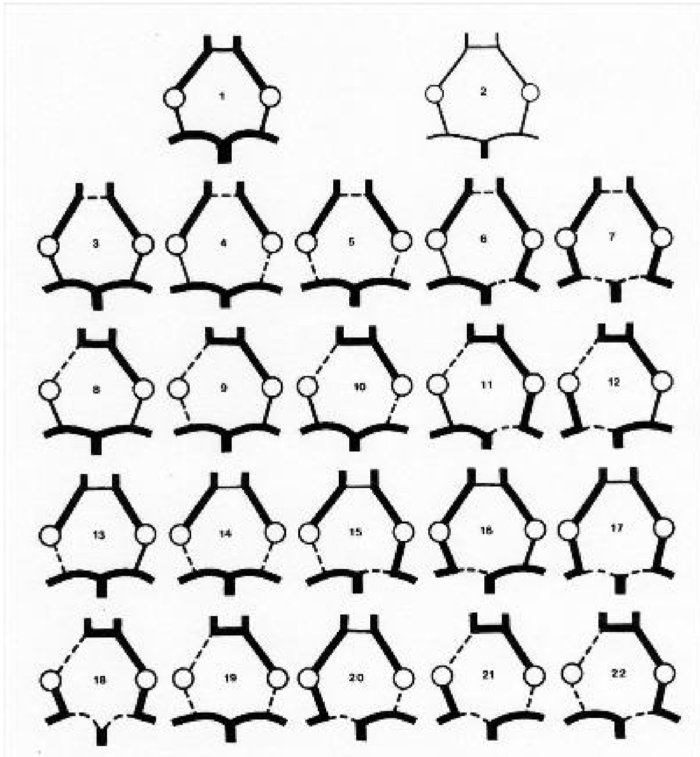
Polygone de Willis



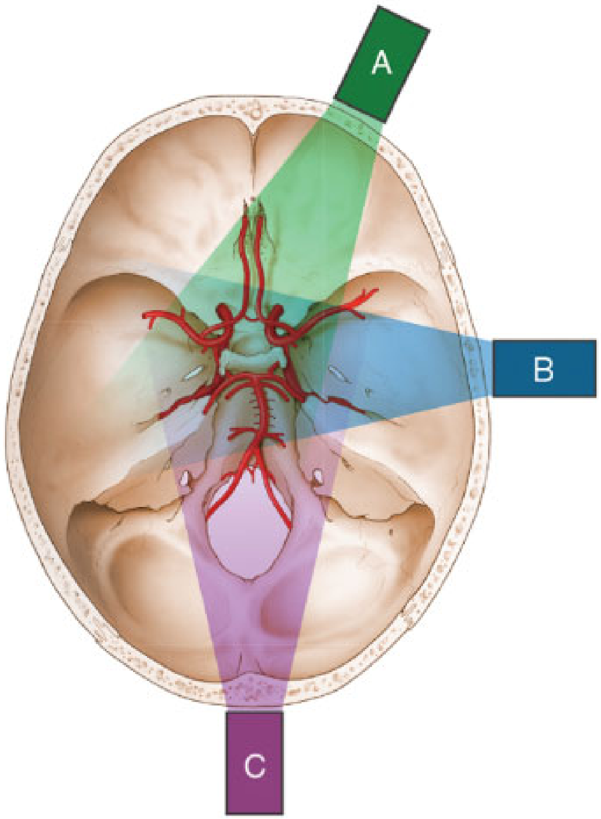
Variantes anatomiques du polygone

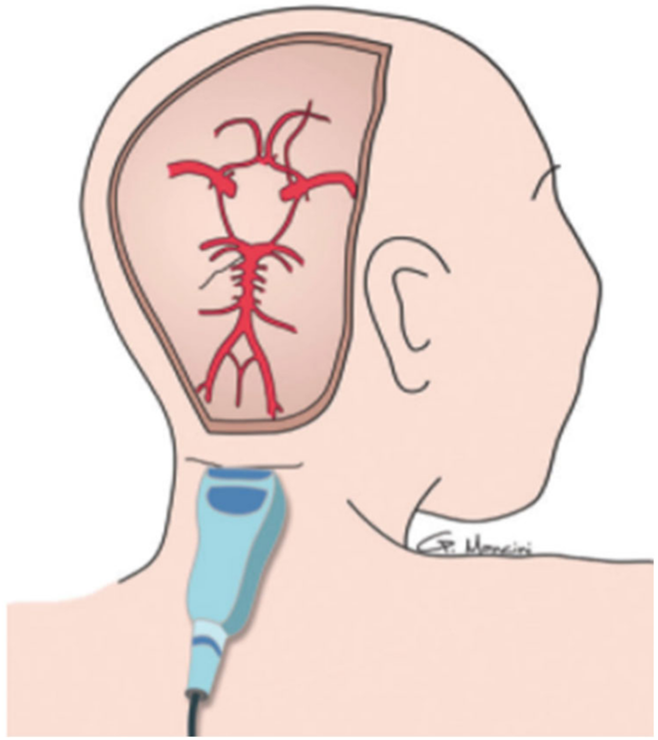
- Environ 20% de la population possède un polygone parfait

- 22 variantes



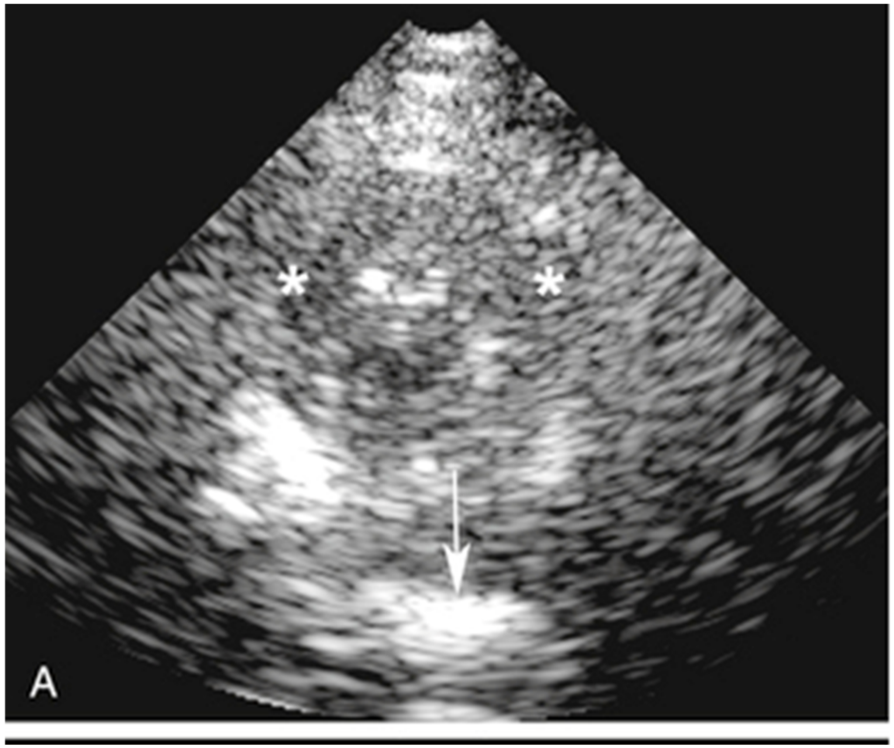
La fenêtre sous-occipitale

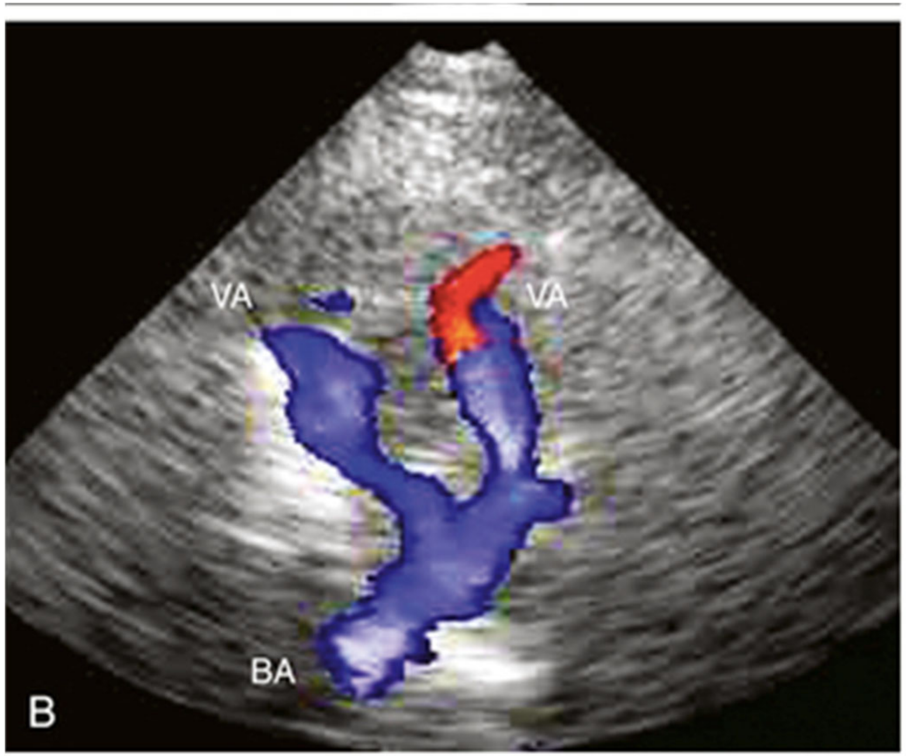




https://www.semanticscholar.org

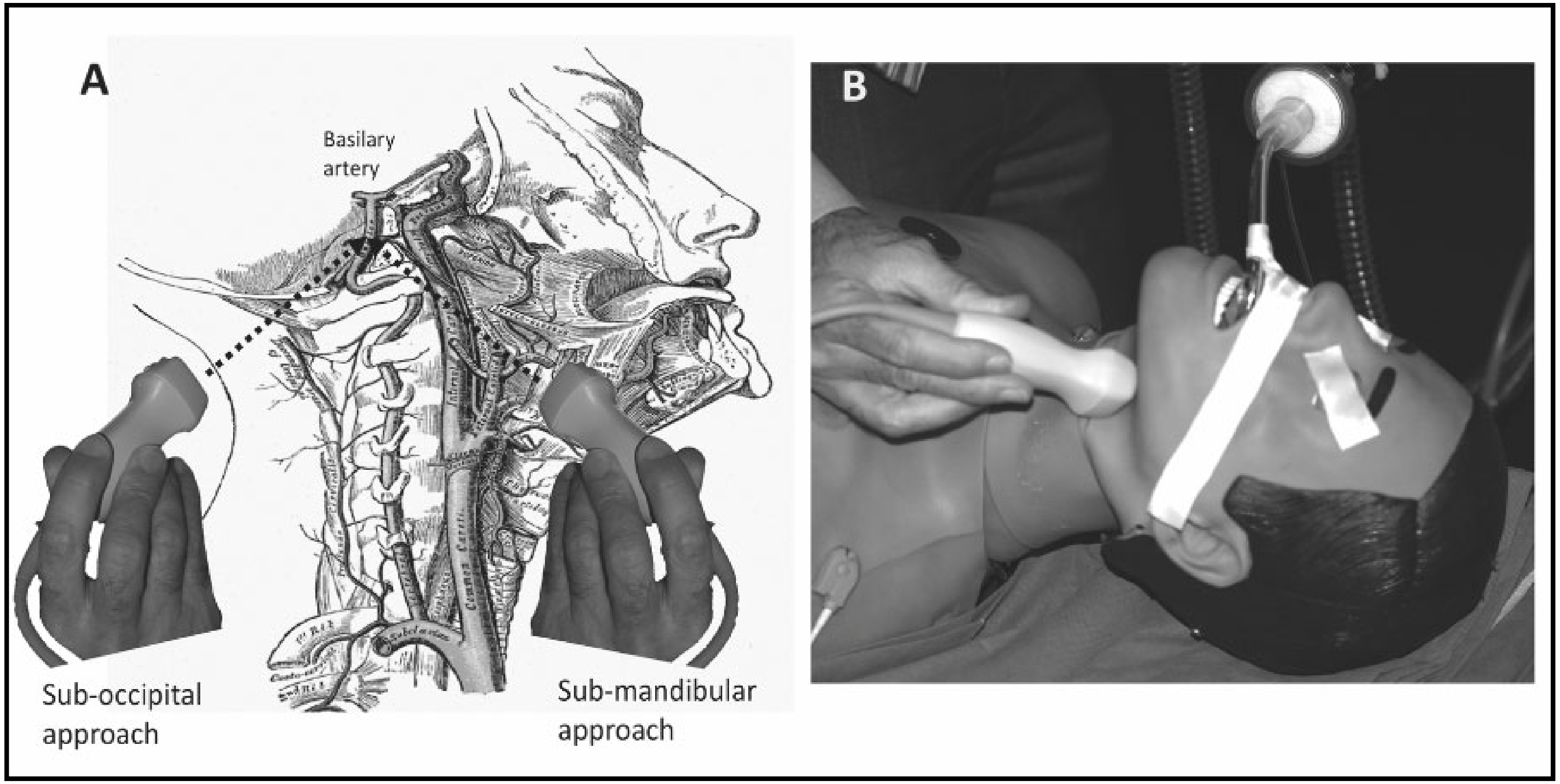
La fenêtre sous-occipitale



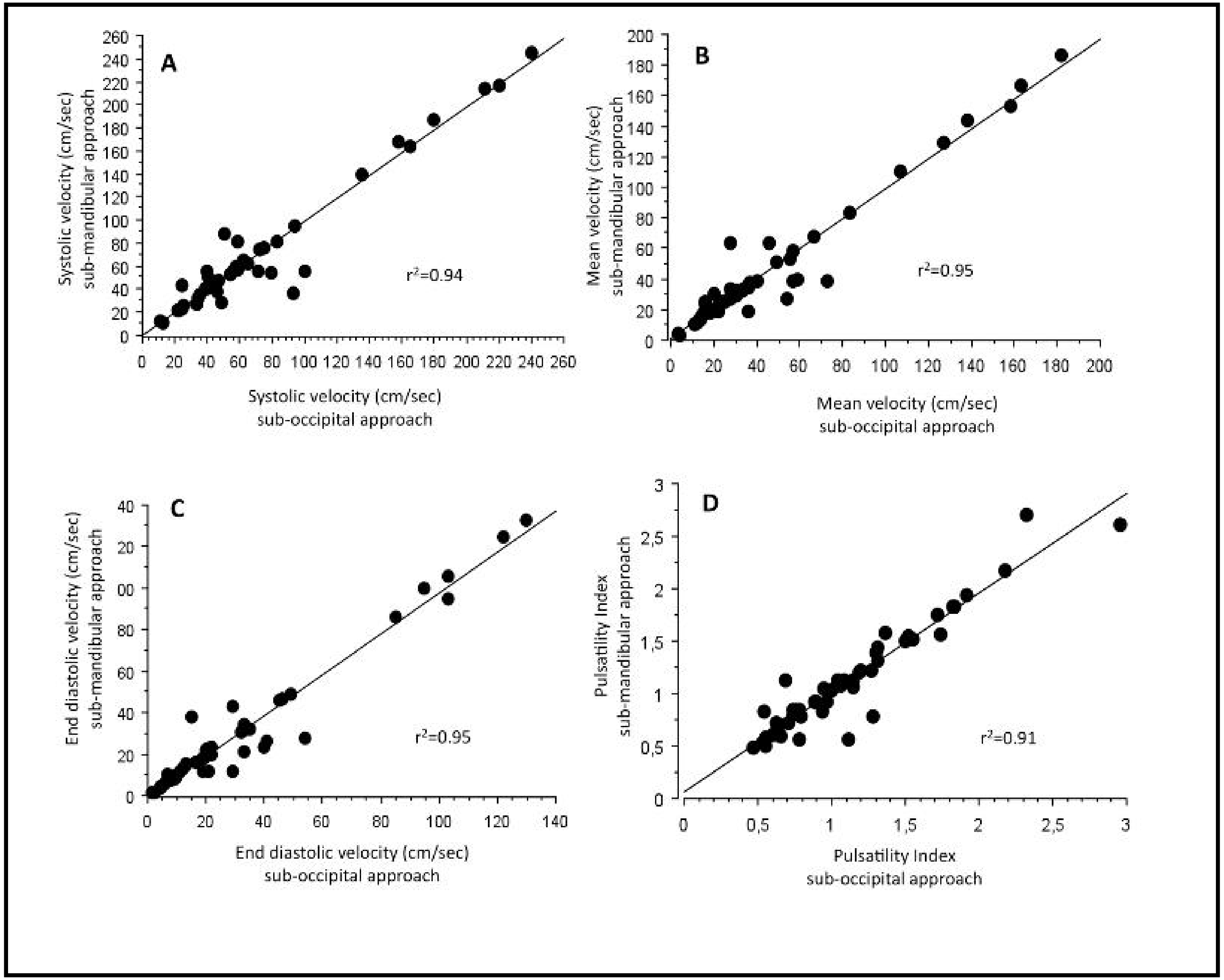


An Alternative Ultrasonographic Approach to Assess Basilar Artery Flow

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



Neurosurgery 68[ONS Suppl 2]:ons276–ons281, 2011

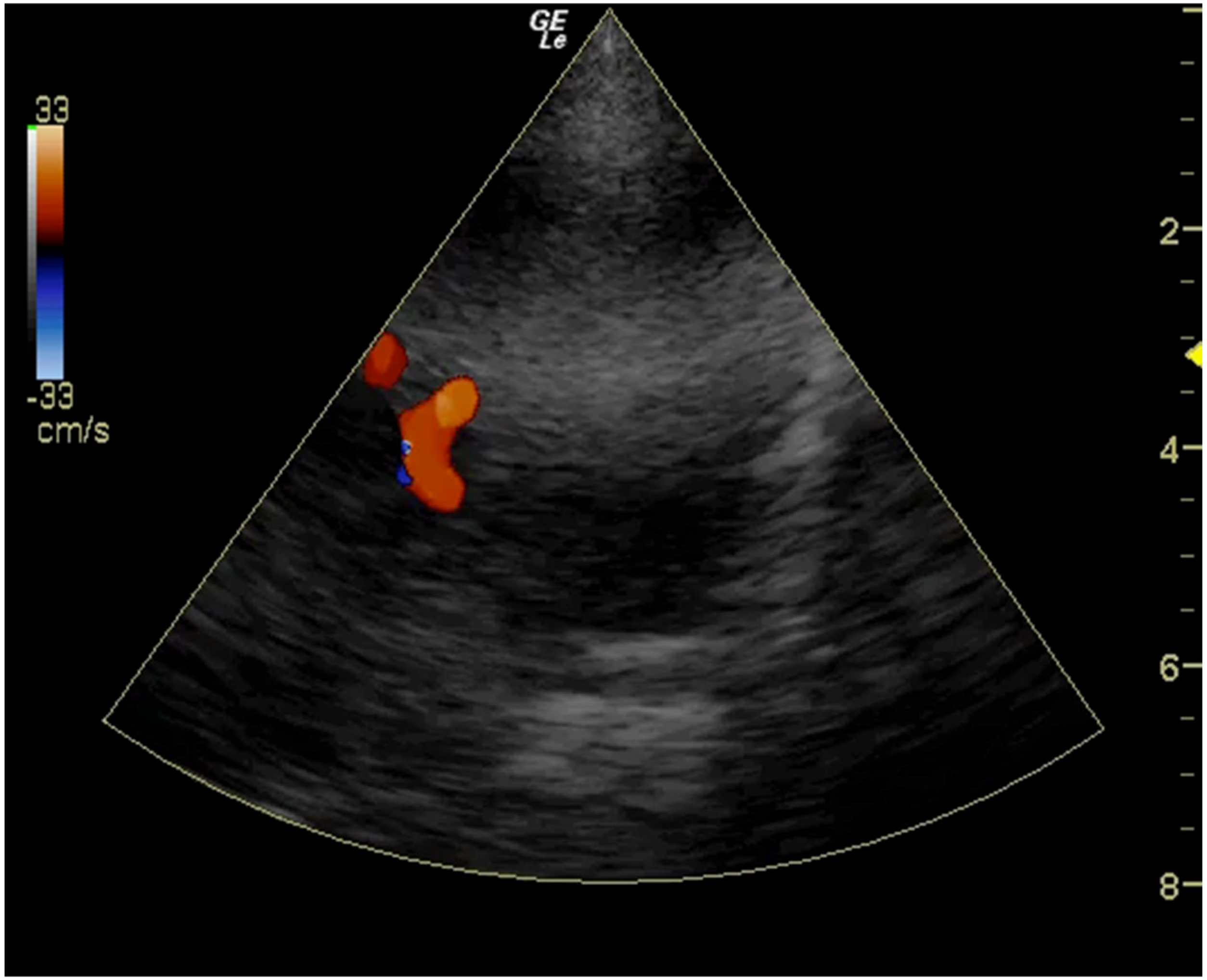


A
r²=0.94
Systolic velocity (cm/sec)
sub-mandibular approach
Systolic velocity (cm/sec)
sub-occipital approach
B
r²=0.95
Mean velocity (cm/sec)
sub-mandibular approach
Mean velocity (cm/sec)
sub-occipital approach
C
r²=0.95
End diastolic velocity (cm/sec)
sub-mandibular approach
End diastolic velocity (cm/sec)
sub-occipital approach
D
r²=0.91
Pulsatility Index
sub-mandibular approach
Pulsatility Index
sub-occipital approach

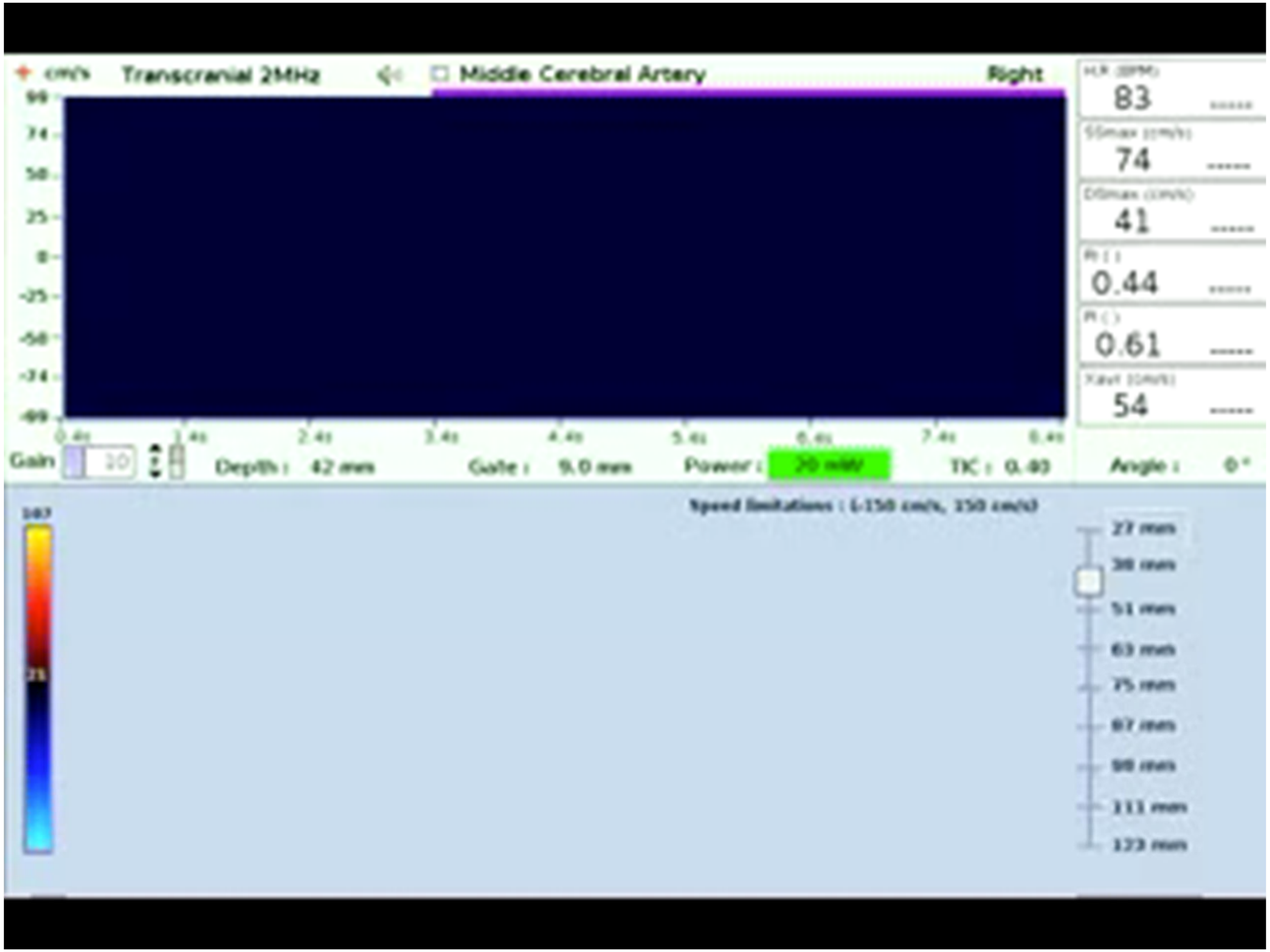
Deux méthodes

- Doppler pulsé conventionnel

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


GE
Le
33
-33
cm/s
2
4
6
8


LOOKI
Atys

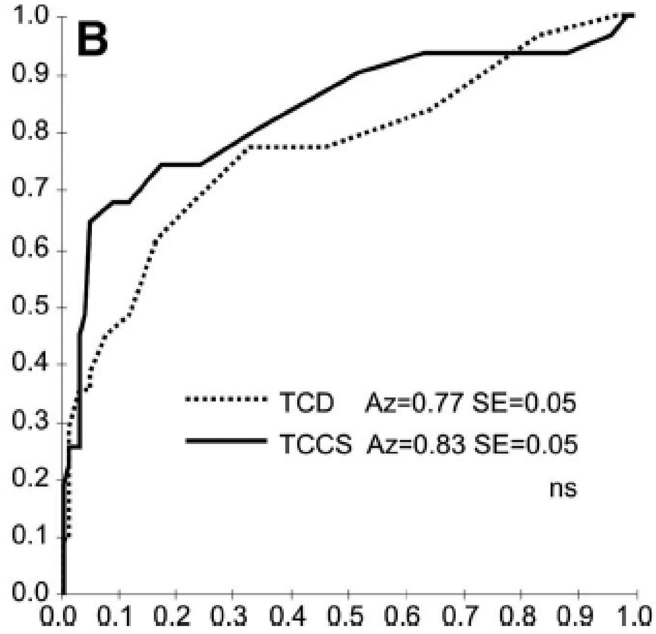


cm/s
Transcranial 2MHz
Middle Cerebral Artery
Right
83
74
41
0.44
0.61
54
Gain
Depth : 42 mm
Gate : 9.0 mm
Power :
Angle :

Doppler Couleur ou pulsé ?

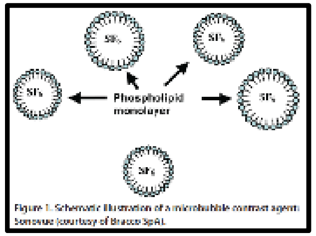
Middle cerebral artery vasospasm: Transcranial color-coded duplex sonography versus conventional nonimaging transcranial Doppler sonography*

Maciej Swiat, MD; John Weigele, 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



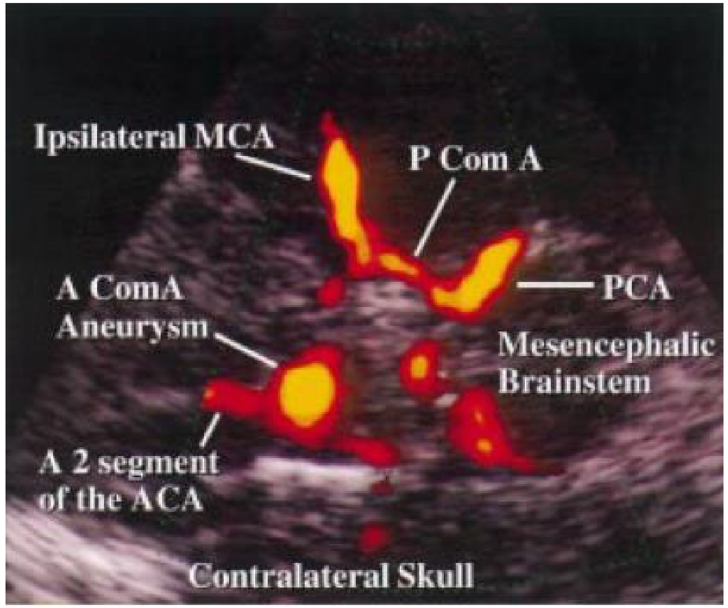
Crit Care Med 2009 Vol. 37, No. 3

Doppler avec contraste



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

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

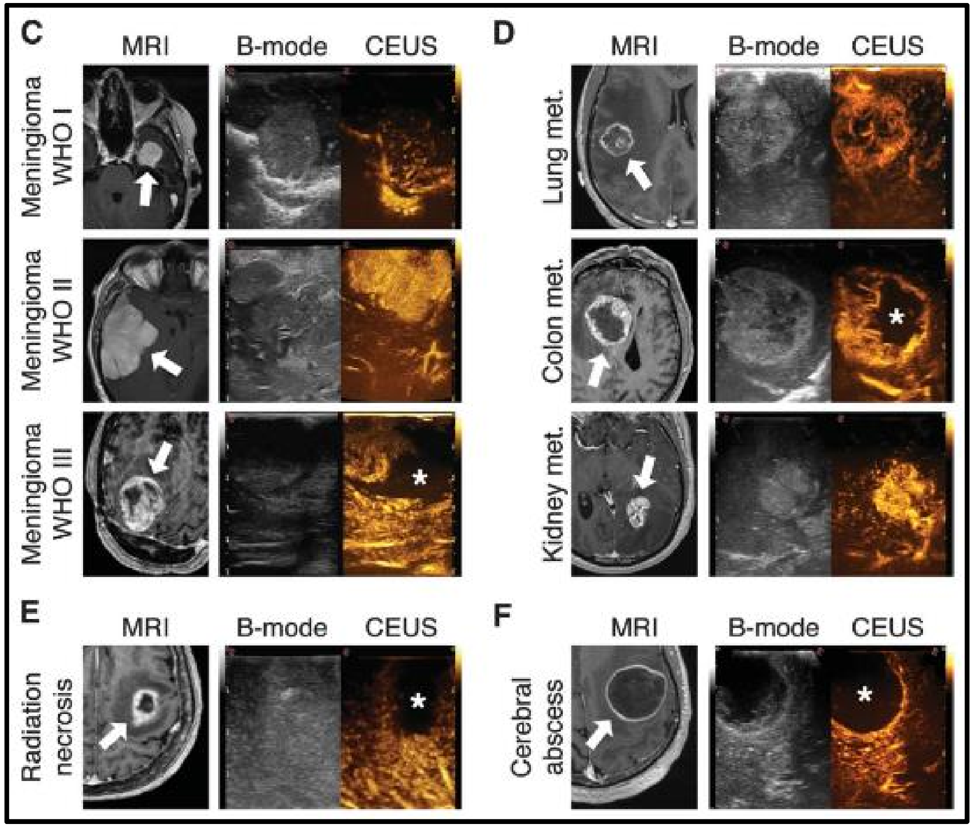


- Sensibilisation pour confirmation de mort encéphalique ?

Intraoperative Contrast-Enhanced Ultrasound for Brain Tumor Surgery

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*‡§¶||

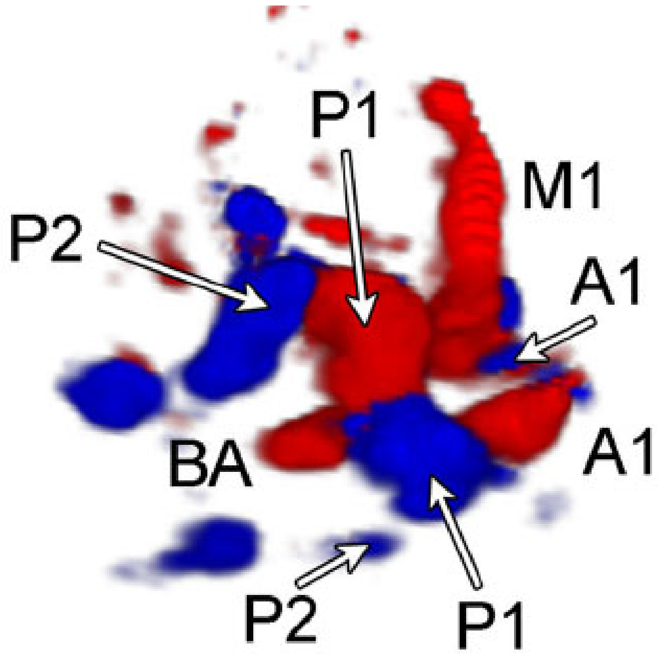
171 patients

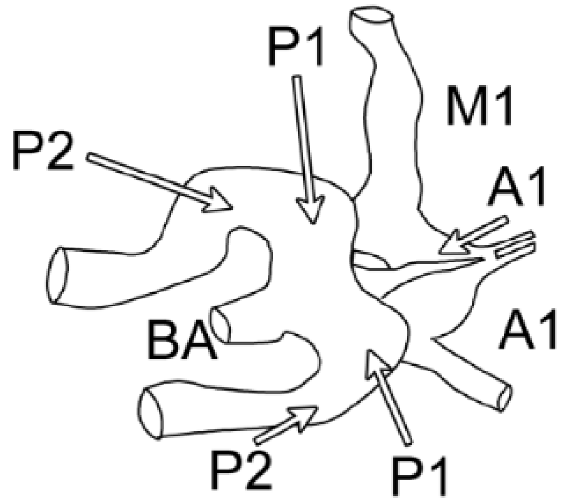


Neurosurgery 74:542–552, 2014

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

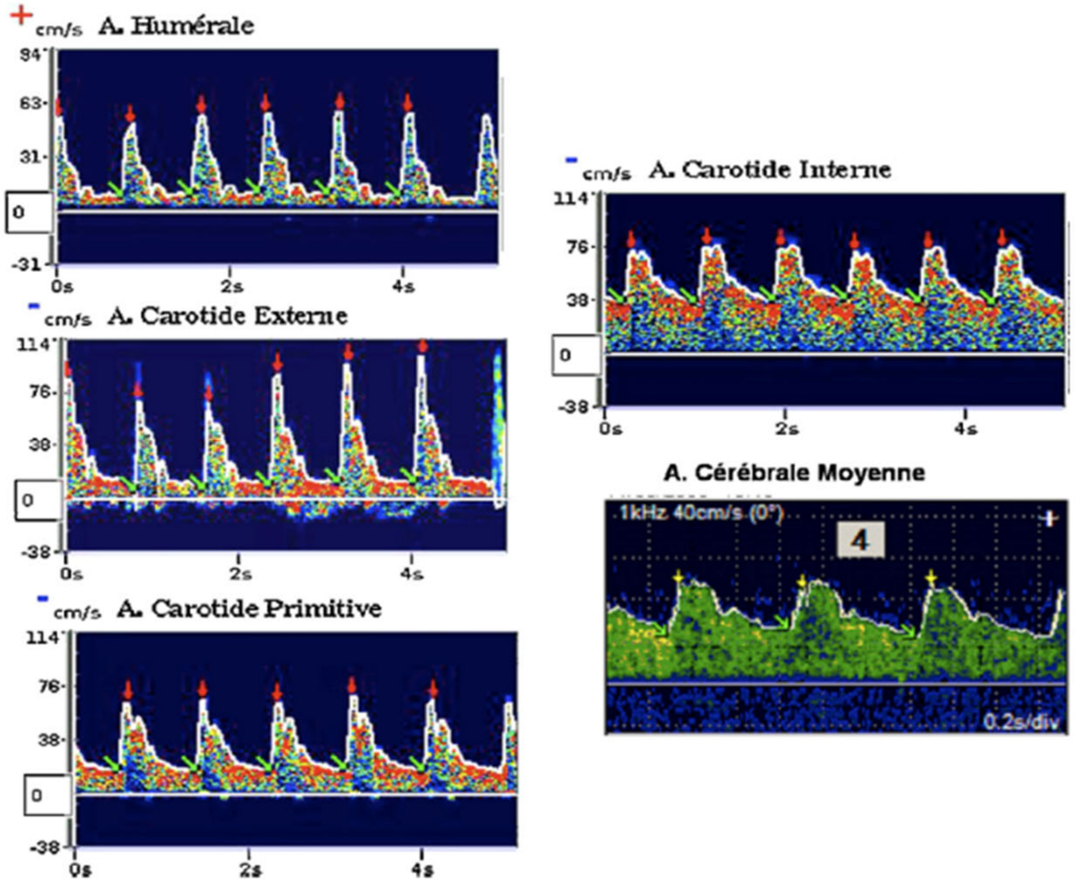
Nikolas M. Ivancevich*, Gianmarco F. Pinton*, Heather A. Nicoletto†, Ellen Bennett†, Daniel T. Laskowitz†, and Stephen W. Smith*





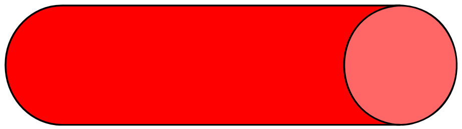
Ultrasound Med Biol. 2008 September ; 34(9): 1387–1395

Résistance artérielle



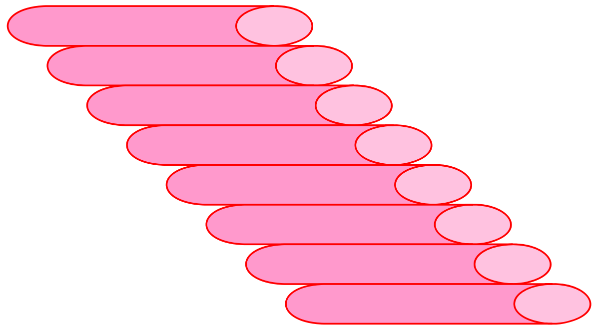
Geeraerts T, *Neurochirurgie, 2008*

40 % R



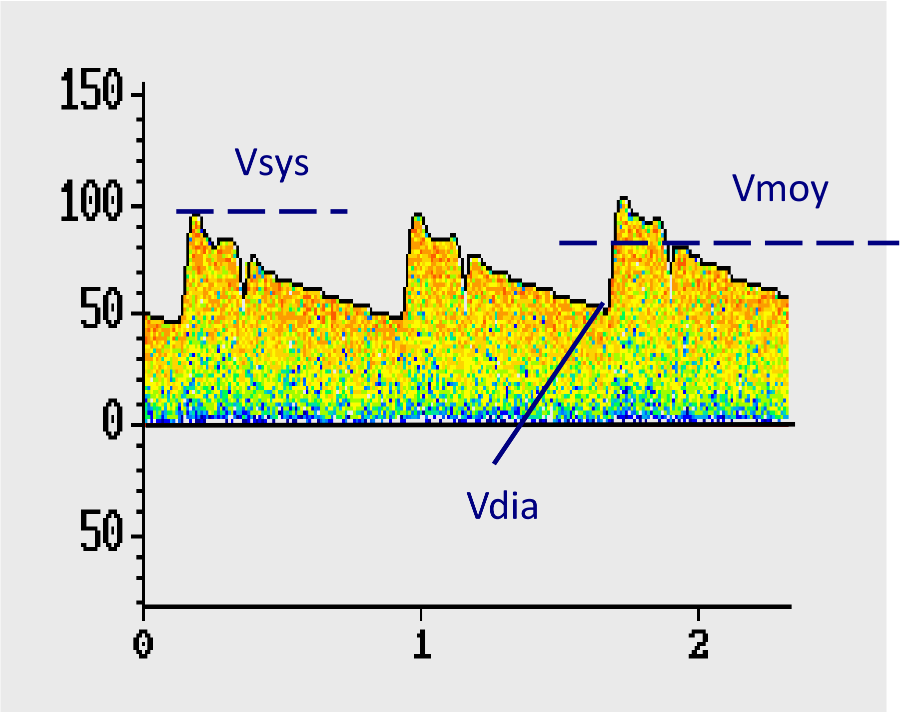
Gros tronc artériel

60 % R



Artérioles

Indices



Index de pulsatilité (Gosling)

$$IP = \frac{Vsys\text{-}Vdia}{Vmoy}$$

Index de résistivity (Pourcelot)

$$IR = \frac{Vsys\text{-}Vdia}{Vsys}$$

Valeurs normales

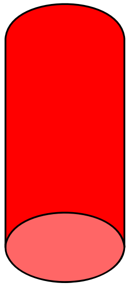
Tableau I – Vitesses circulatoires et index de pulsatilité : valeurs normales chez l'adulte.

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		

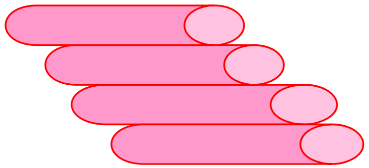
ACM : artère cérébrale moyenne ; ACA : artère cérébrale antérieure ; ACP : artère cérébrale postérieure ; TB : Tronc basilaire ; IR : index de résistance ; IP : index de pulsatilité

Extra-crânien

- Pressions systémiques
- Volémie
- Tachycardie (↓IP car ↓ralaxation distolique)
- Modification de section dans les artères extra-crâniennes



- Modification de diamètre
    - vasospasme
    - sténose, occlusion

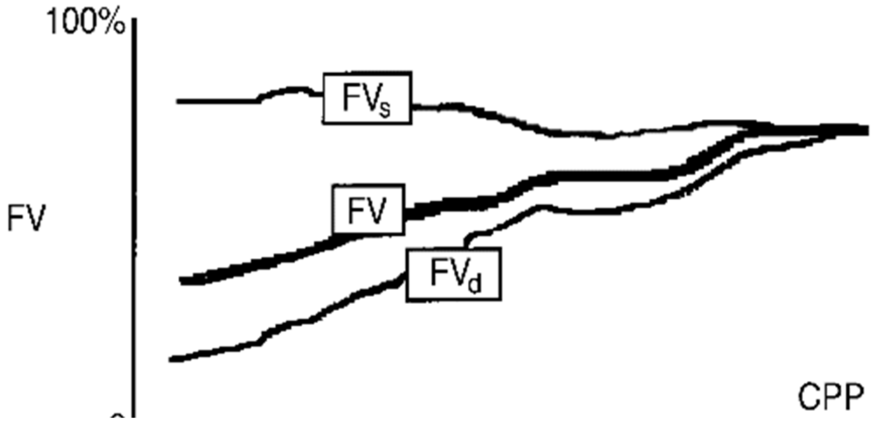


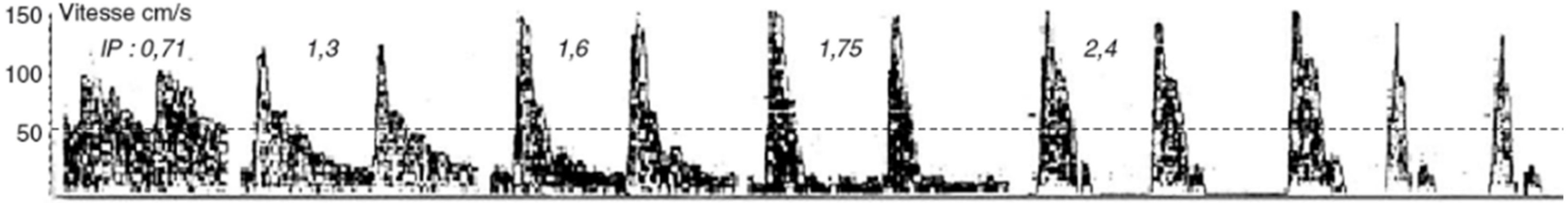
Résistances artériolaires

- Hypertension intracrânienne
- Variations de capnie
- Anémie

⇨ Vélocités diastoliques, IP

Diminution de la PPC





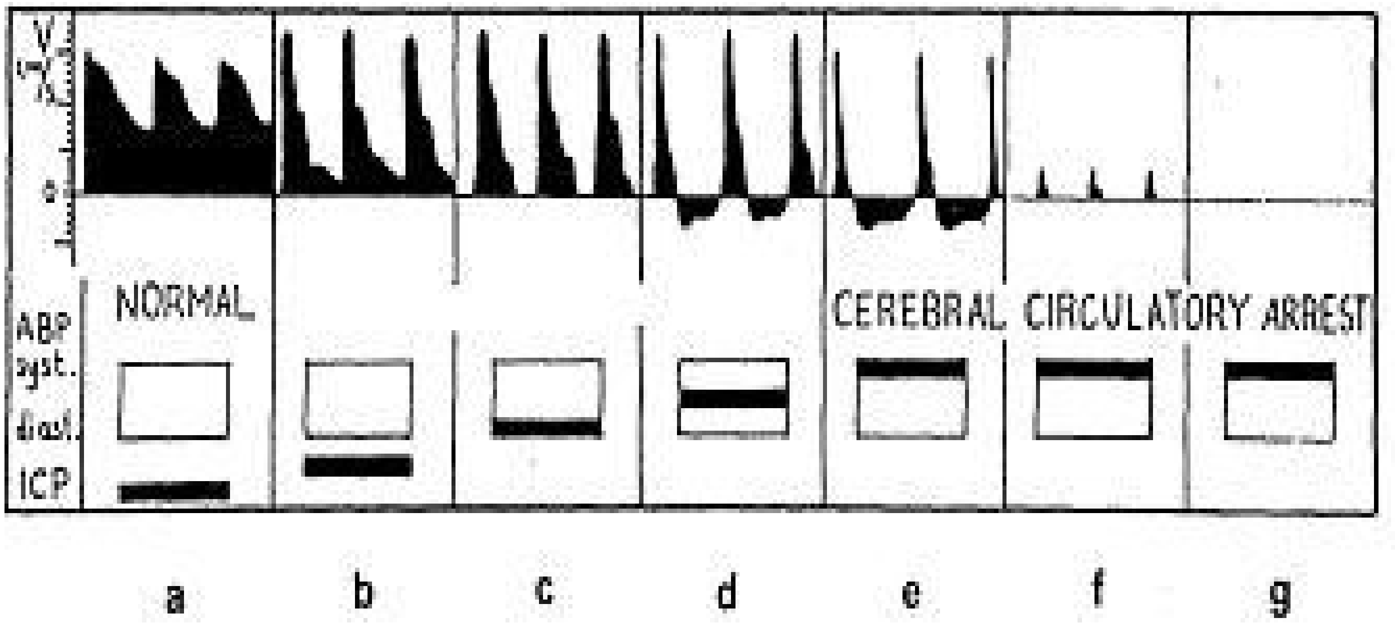
Diminution de la pression de perfusion cérébrale

- Indépendant de l´angle d´insonation

Kirpatrik P, ***Head Trauma*****,** 2000

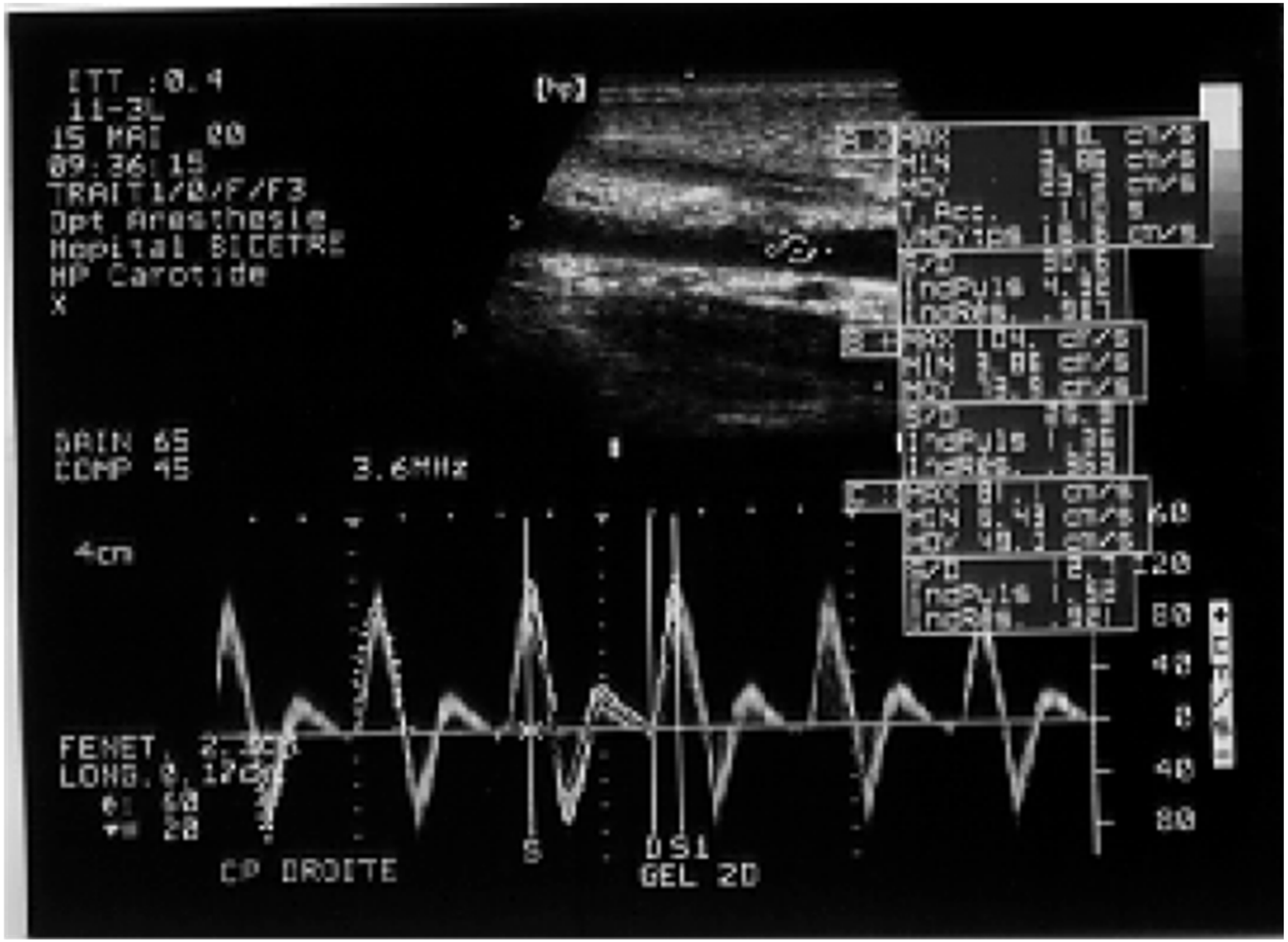
Bruder N, *EMC,* 2006

Hypertension intracrânienne



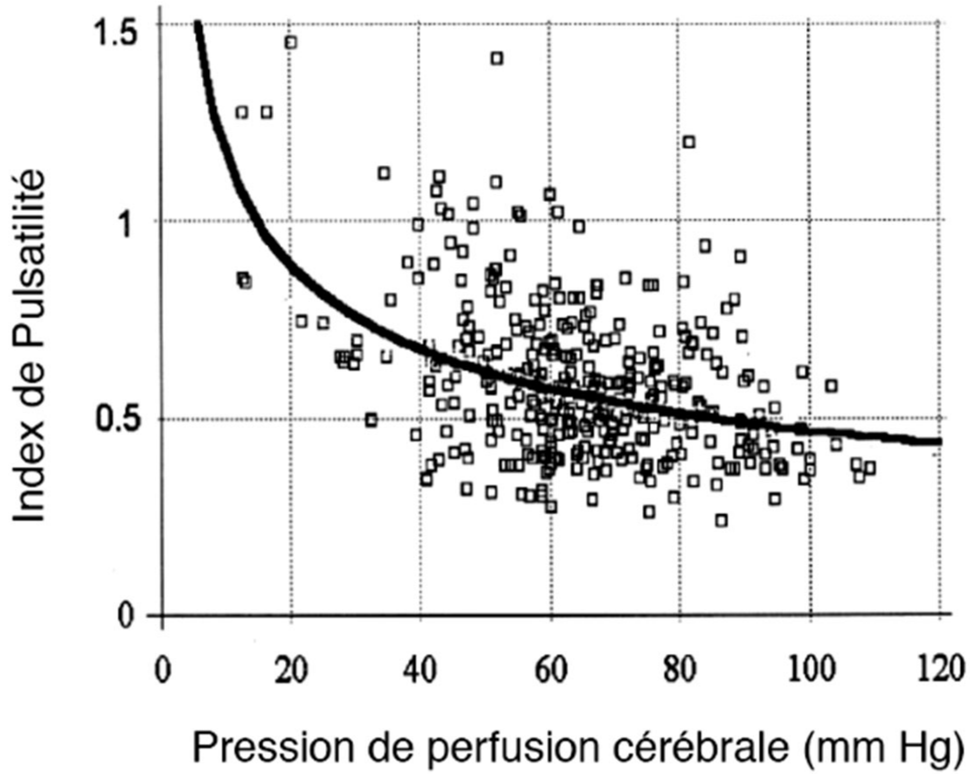
Augmentation des résistances

↓ Vélocité diastolique ↑ IP



ITT :0.4
11-3L
15 MAI 00
09:36:15
TRAIT1/0/F/F3
Dpt Anesthesie
Hopital BICETRE
HP Carotide
GAIN 65
COMP 45
3.6MHz
4cm
FENET.
LONG.
CP DROITE
GEL 2D

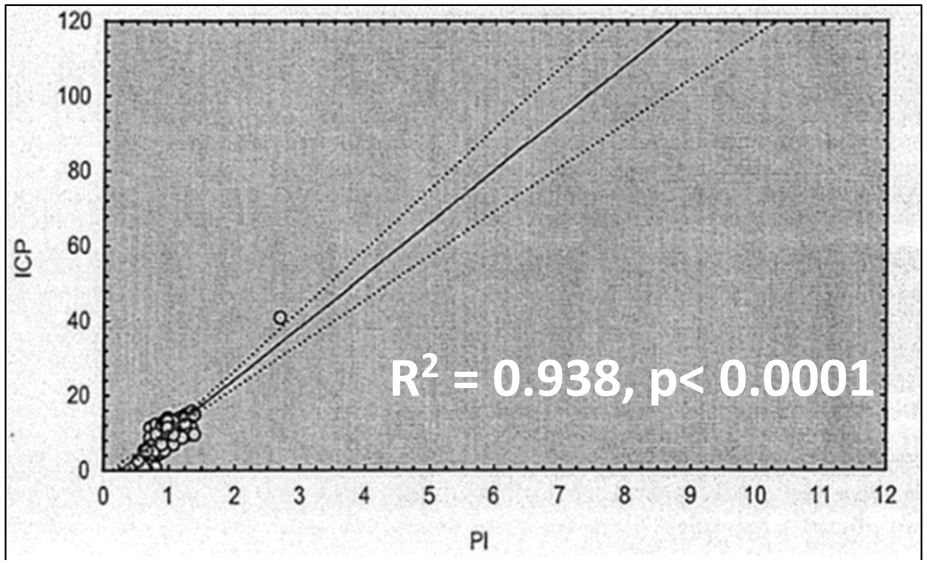
Pression de perfusion cérébrale ?



Czosnyka M, *J Neurosurg, 1998*

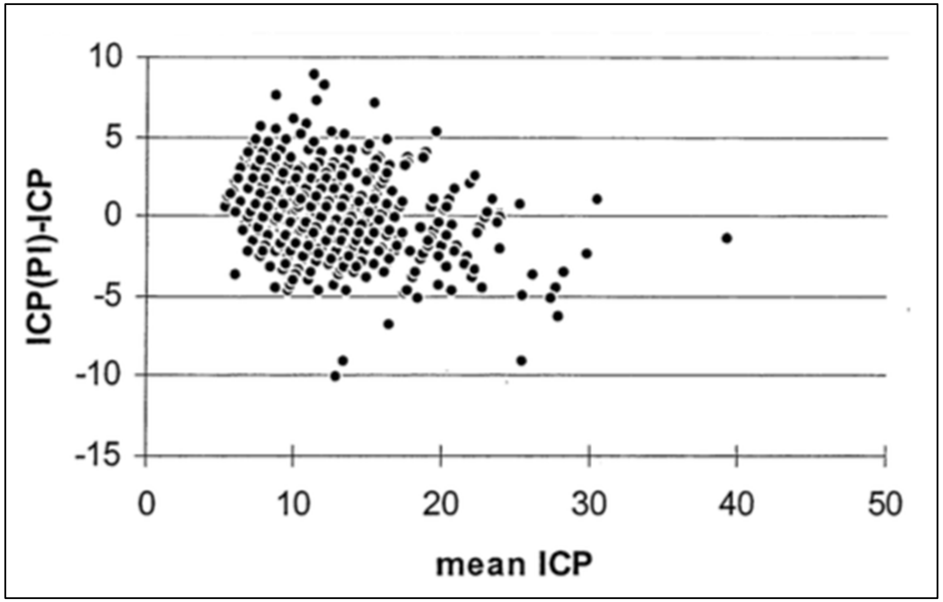
1- Diagnostic de ischémie cérébrale

- 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



$PIC_{prédite}$ = PIC mesurée +/- 4.2 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

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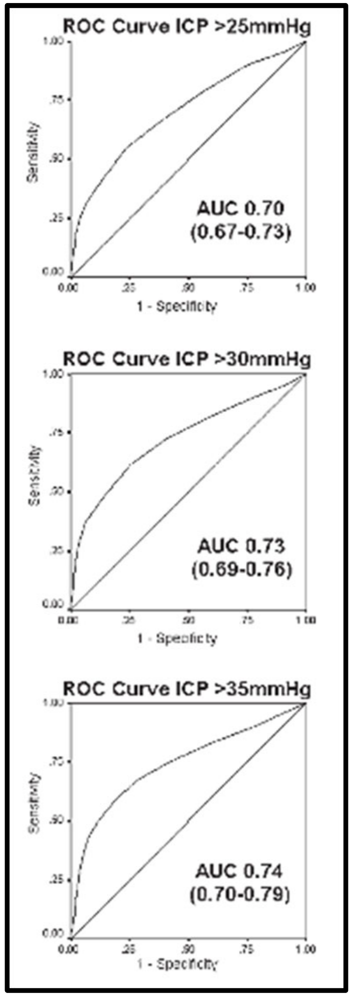
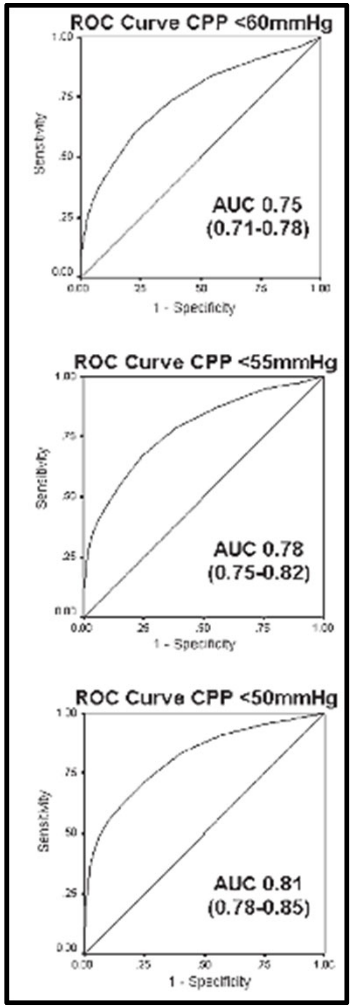
Peter Smielewski, PhD*

290 head-injured patients





Neurosurgery 71:853–861, 2012

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

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

- Vm < 30 cm/s,
- Vd < 20 cm/s,
- IP > 1.4.

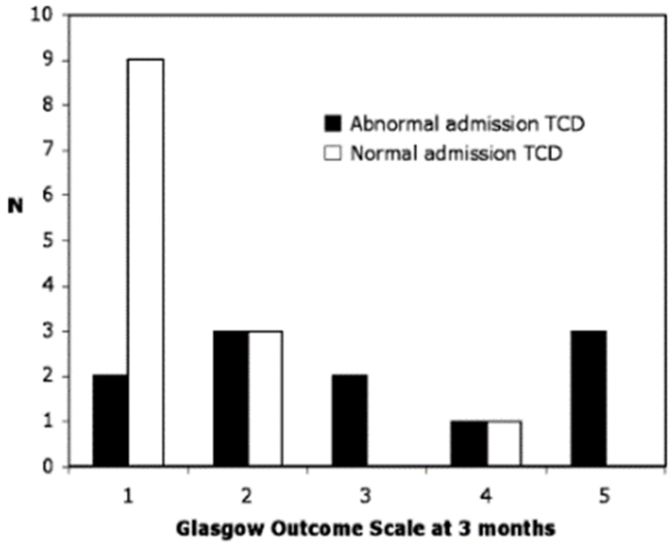


Fig. 2 Three-month Glasgow Outcome Score in patients with abnormal admission TCD (*filled columns*) and in patients with normal admission TCD (*open columns*). *1* Good recovery, *2* moderate disability, *3* severe disability, *4* vegetative state, *5* dead

2- Triage et intensification du traitement

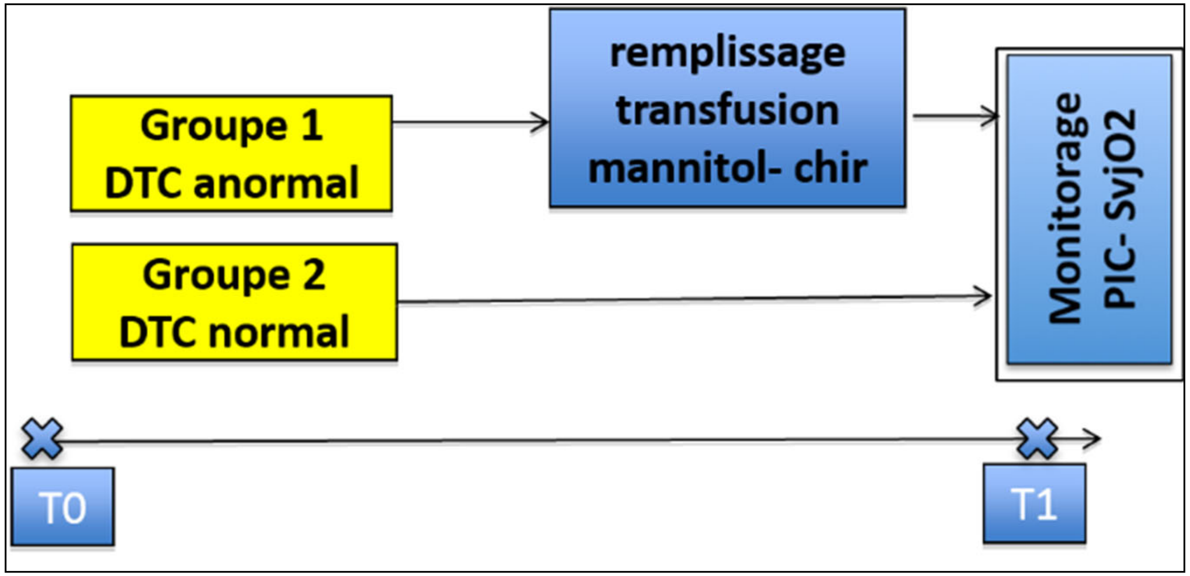
	Abnormal TCD ($n = 9$) Group 1		Normal TCD ($n = 9$) Group 2	
	In the field	At the trauma centre	In the field	At the trauma centre
Time from trauma (min)	68 ± 25	143 ± 50	61 ± 14	146 ± 57
Abnormal TCD (*n*)	9	4	0	0
Systolic velocity (cm/s)	67 ± 21	76 ± 23	79 ± 25	81 ± 17
Mean velocity (cm/s)	28 ± 10†	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 (*n*)	–	2	–	3
Mannitol (*n*)	–	7	–	0
Emergency neurosurgery (*n*)	–	3	–	0
48 h mortality (*n*)	–	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**

Tazarourte K, Acta Anesth Scand 2011

2- Triage et intensification du traitement

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



Ract C, Int Care Med 2007, 33:645-51

Triage

Intensive Care Med (2005) 31:785–790
DOI 10.1007/s00134-005-2630-4

ORIGINAL

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

	Group 1	Group 2	*p*
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, <u>monocentrique</u>, 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

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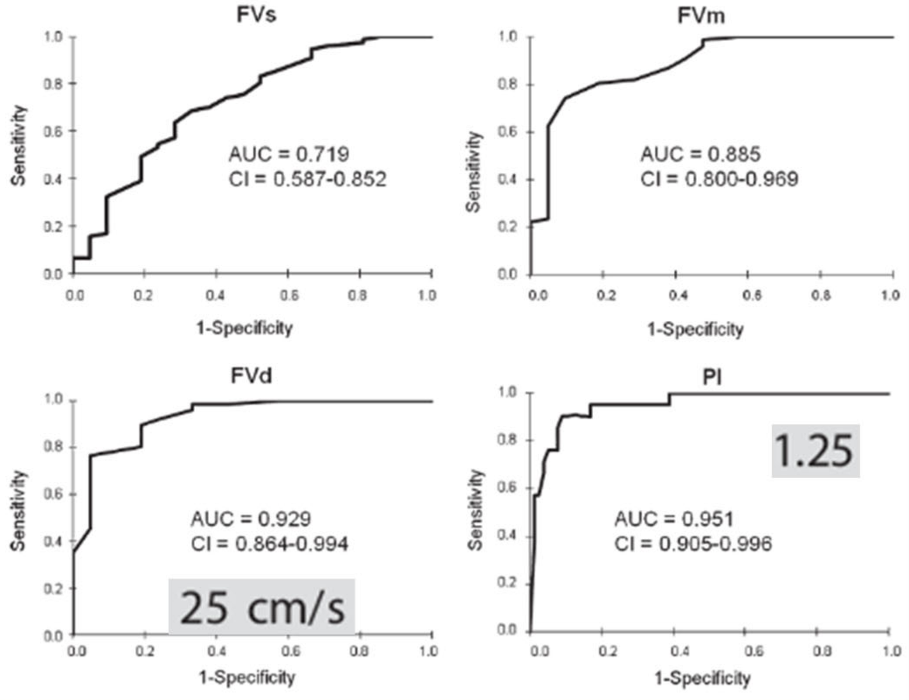
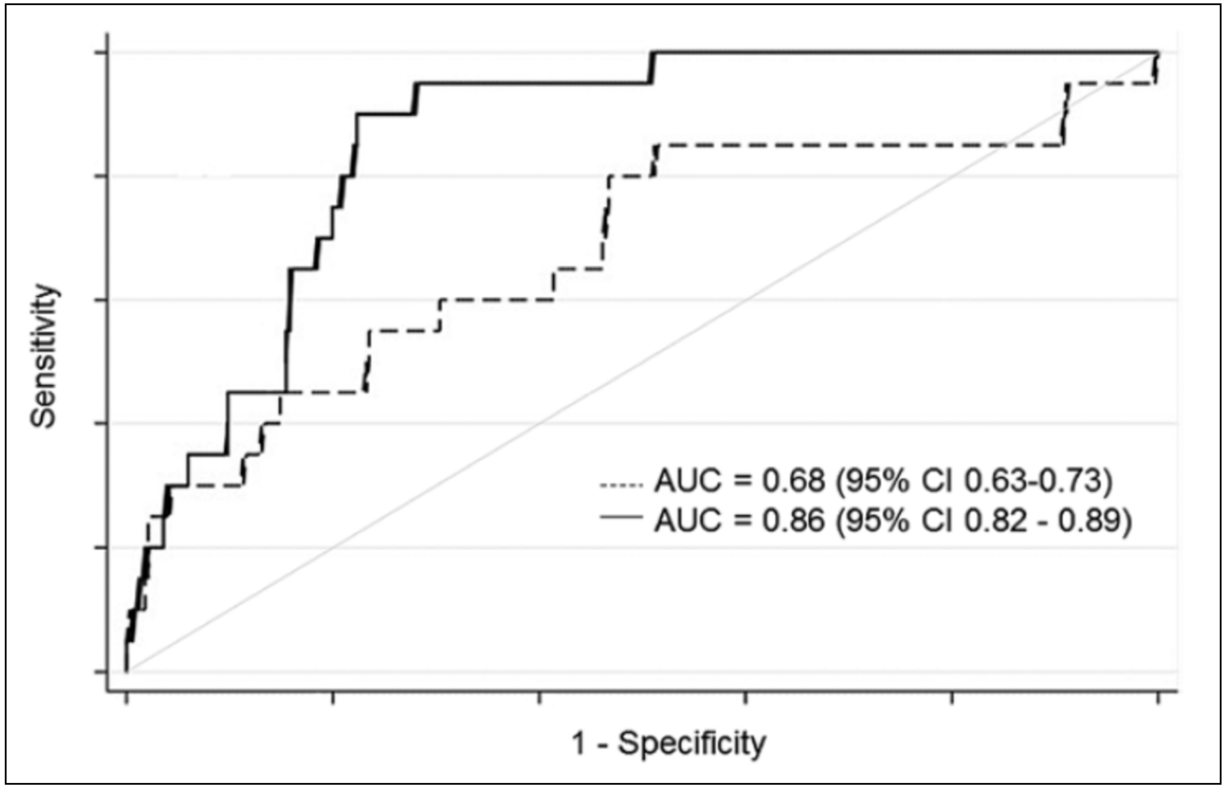


FIGURE 1. *Receiver-operating characteristic curves of the transcranial Doppler (TCD) parameters. AUC, area under the curve; CI, 95% confidence interval; FVd, FVm, and FVs, diastolic, mean, and systolic cerebral blood flow velocities, respectively; PI, pulsatility index.*

2- Triage et intensification du traitement

- **Prospective, <u>multicentrique</u>, 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

SFAR

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 monitorage

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

K. Tazarourte[1,2], A. Atchabahian[3], J.-P. Tourtier[1], J.-S. David[1], C. Ract[2], D. Savary[1], M. Monchi[1] and B. Vigué[2]
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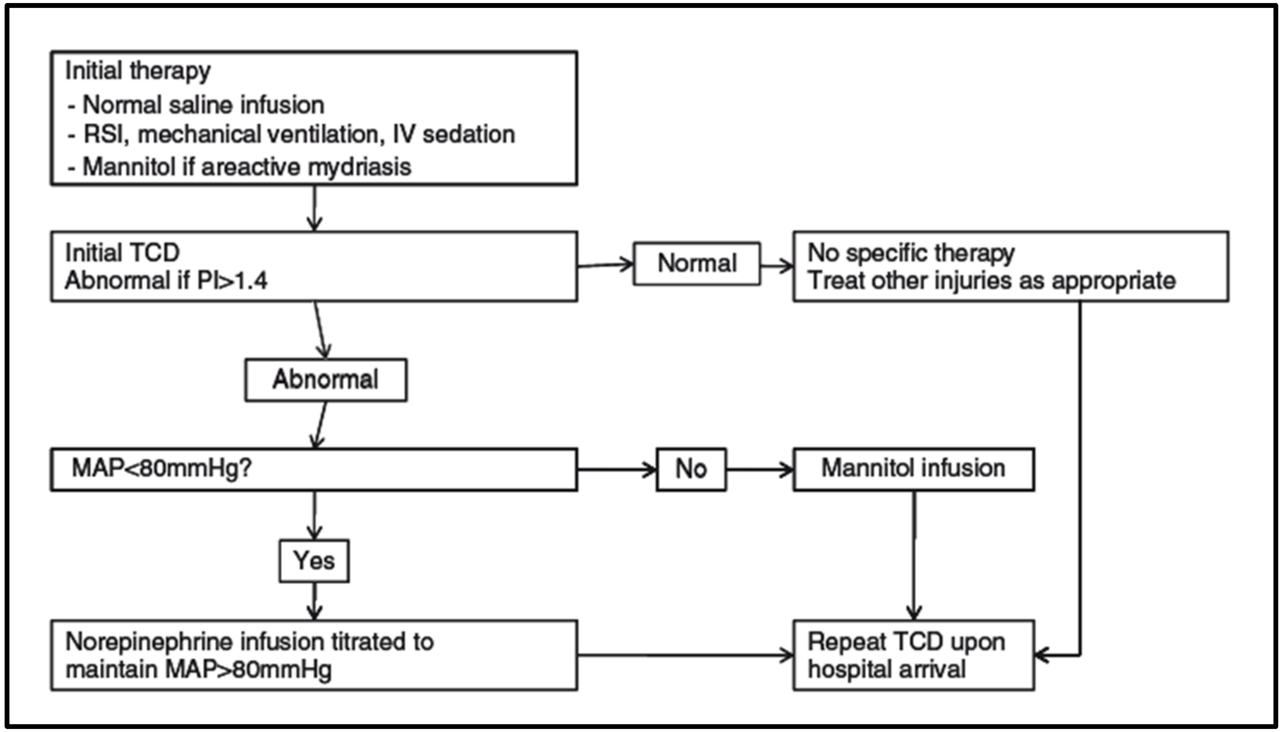


Acta Anaesthesiol Scand 2011; **55**: 422–428

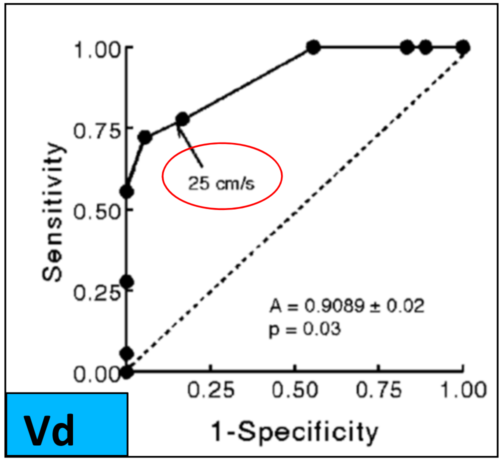
2- Triage et intensification du traitement

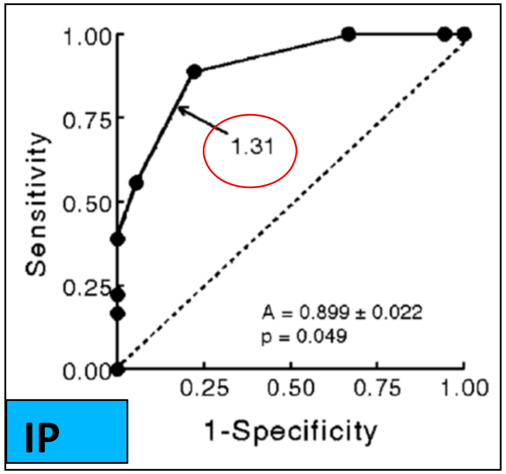
- Prospective monocentrique, n=36 **enfants**
- Traumatisme crânien sévère/modéré

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

Cothren CC, Clinics 2005

3- Dissection carotidienne

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

	TICAD	Controls 1	Controls 2	p
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 $\leq$ 0.80 (n)	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% (n)	9	0	5	<0.01
PI $\leq$ 0.80 and FVs asymmetry >25% (n)	9	0	0	<0.01

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

Bouzat P, Int. Care Med. 2010

3- Dissection carotidienne

SFAR

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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