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XXVI CONGRESSO NAZIONALE SINV:
SINERGIE INTERDISCIPLINARI NEL PAZIENTE NEUROLOGICO CRITICO

14/12/2017

Misurazione non invasiva della pressione di perfusione cerebrale e della pressione intracranica
Non-invasive assessment of intracranial pressure

Lecce, 1-2 dicembre 2017

Piergiorgio Lochner

Intracranial hypertension

Intracranial hypertension (IH) is an important cause of secondary brain injury, and its association with poor outcome has been extensively demonstrated (1).

Monitoring of intracranial pressure (ICP) is invaluable in the management of neurosurgical and neurological critically ill patients.

Invasive measurement of ventricular or parenchymal pressure is considered the *gold standard* for accurate measurement of ICP but is not always possible due to certain risks.

1) MARMAROU A. Impact of ICP instability and hypotensionon outcome in patients with severe head trauma. J Neurosurg 1991;75:S59–66.

N Engl J Med. 2012 December 27; 367(26): 2471–2481. doi:10.1056/NEJMoa1207363.

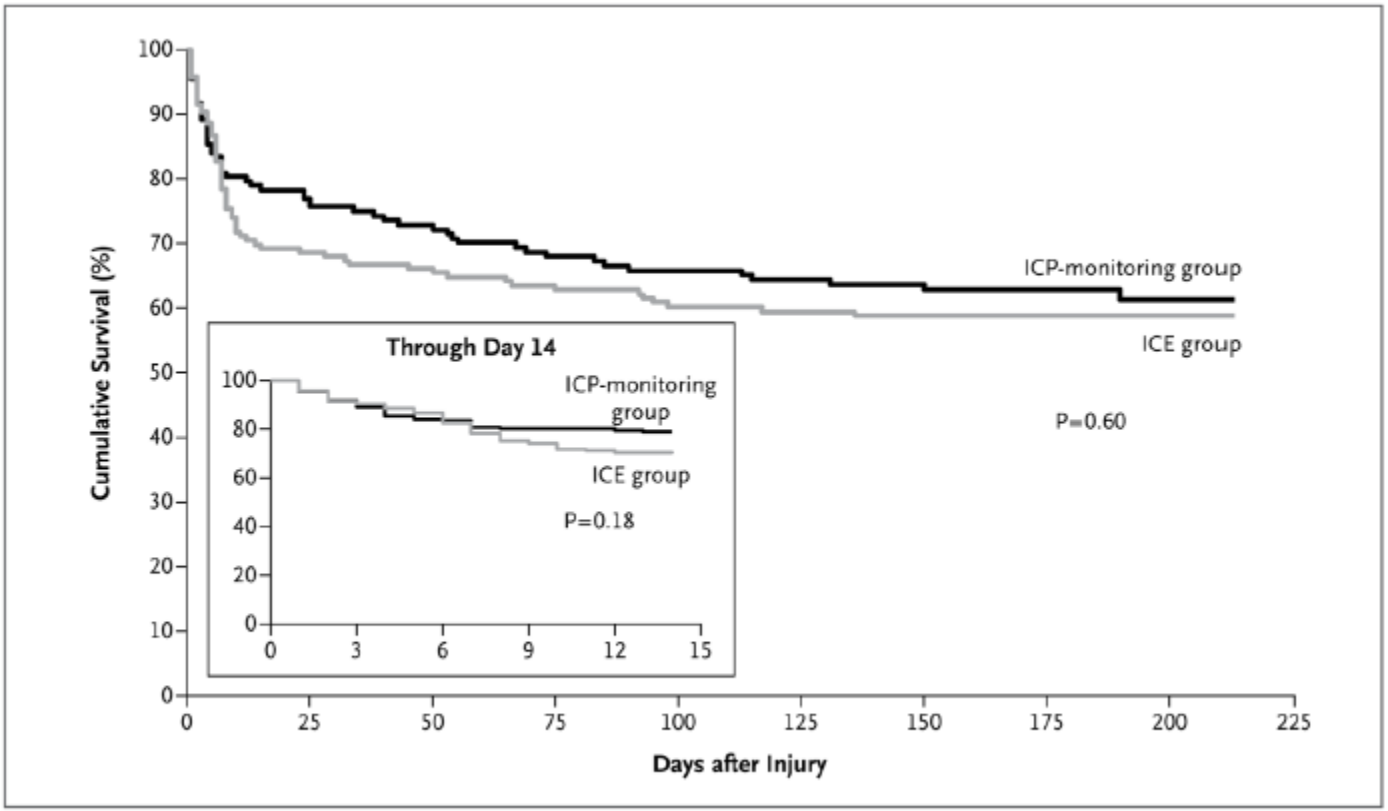
A Trial of Intracranial-Pressure Monitoring in Traumatic Brain Injury

Methods—We conducted a multicenter, controlled trial in which 324 patients 13 years of age or older who had severe traumatic brain injury and were being treated in intensive care units (ICUs) in Bolivia or Ecuador were randomly assigned to one of two specific protocols: guidelines-based management in which a protocol for monitoring intra-parenchymal intracranial pressure was used (pressure-monitoring group) or a protocol in which treatment was based on imaging and clinical examination (imaging–clinical examination group). The primary outcome was a composite of survival time, impaired consciousness, and functional status at 3 months and 6 months and neuropsychological status at 6 months; neuropsychological status was assessed by an examiner who was unaware of protocol assignment. This composite measure was based on performance across 21 measures of functional and cognitive status and calculated as a percentile (with 0 indicating the worst performance, and 100 the best performance).

Results—There was no significant between-group difference in the primary outcome, a composite measure based on percentile performance across 21 measures of functional and cognitive status (score, 56 in the pressure-monitoring group vs. 53 in the imaging–clinical examination group; P = 0.49). Six-month mortality was 39% in the pressure-monitoring group and 41% in the imaging–clinical examination group (P = 0.60). The median length of stay in the ICU was similar in the two groups (12 days in the pressure-monitoring group and 9 days in the imaging–clinical examination group; P = 0.25), although the number of days of brain-specific treatments (e.g., administration of hyperosmolar fluids and the use of hyperventilation) in the ICU was higher in the imaging–clinical examination group than in the pressure-monitoring group (4.8 vs. 3.4, P = 0.002). The distribution of serious adverse events was similar in the two groups.

N Engl J Med. 2012 December 27; 367(26): 2471–2481. doi:10.1056/NEJMoa1207363.

A Trial of Intracranial-Pressure Monitoring in Traumatic Brain Injury



Indications for noninvasive ICP measurement

- **ICP monitoring isnot immediately available**
- **contraindicated,as in cases of coagulopathy**

HOLLOWAY KL,. J Neurosurg 1996;:419–24
BRATTON SL, J Neurotrauma 2007;24 Suppl 1:S37–44.

Methods for noninvasive ICP measurement

Morphological

- MRI
- computed tomography
- Ultrasound
- Fundoscopy

Physiological

- Transcranial and ophthalmic Doppler
- Tympanometry
- *Near-infrared spectroscopy*
- Electroencephalography
- Visual-evoked potentials
- Otoacoustic emissions assessment

Characteristics

- Availability
- Operator dependency
- Temporal/Spatial resolution
- Suitable in Emergency
- Risk of Infections/hemorrhage
- Cost

Characteristics of the nICP methods

Method	Availability	Operator dependency	Temporal resolution	Suitable in Emergency	Risk of Infections/ hemorrhage	Cost
Radiological findings CT	High	No	poor	Yes	None	Medium
MRI	Medium	No	poor	No	None	High
ONSD US	High	Yes	good	Yes	None	Low
ONSD CT	High	No	poor	Yes	None	Low
ONSD MRI	Medium	No	poor	No	None	High
TMD	High	Yes	poor	No	None	Low
Fundoscopy	High	Yes	poor	No	None	Low
Arteriosus TCD	High	Yes	good	Yes	None	Low
Venous TCD	High	Yes	poor	Yes	None	Low
Ophthalmic artery	Low	Yes	poor	Yes	None	Low
NIRS	Medium	Yes	good	No	None	Low
EEG	Low	Yes	good	No	None	Low
VEP	Low	Yes	good	No	None	Low
EOAEs	Low	Yes	poor	No	None	Low
Time of flight	Low	Yes	poor	No	None	Low

Brain imaging techniques

magnetic resonance (MR),

computed tomography (CT),

optic nerve sheath diameter (ONSD assessment)

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Computed tomography

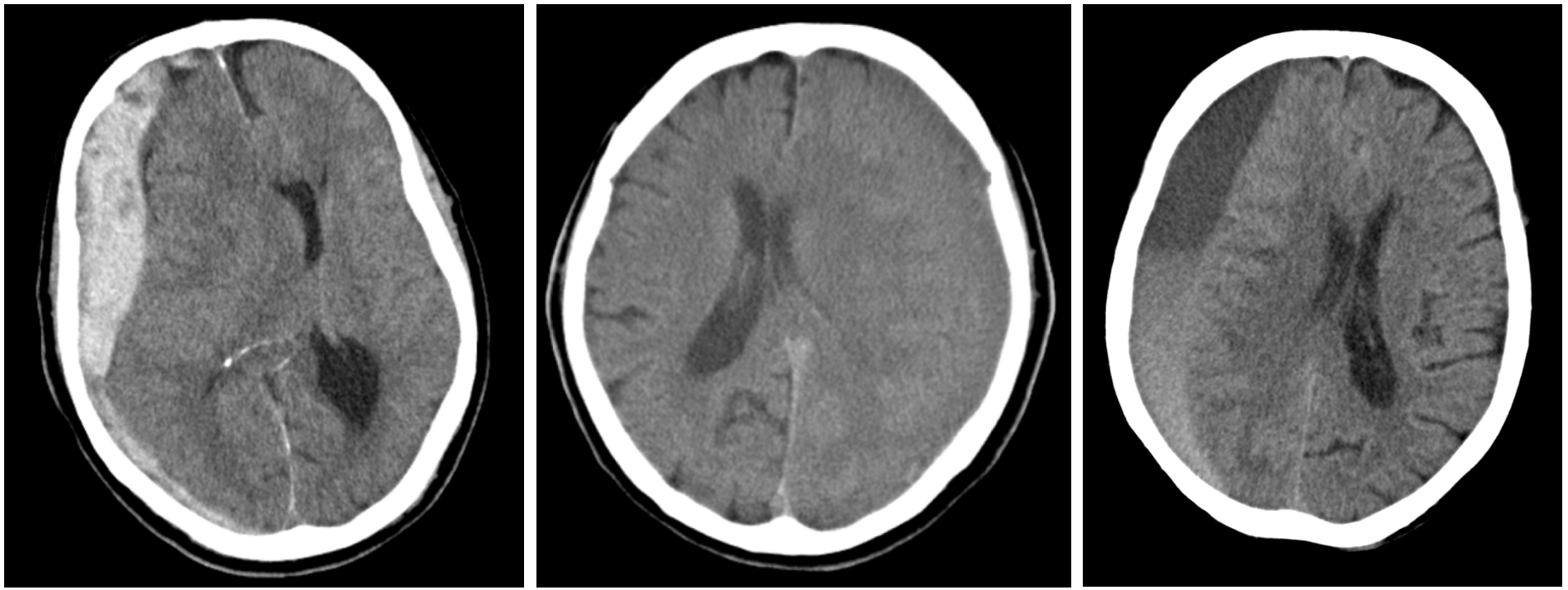
ICP estimation through imaging

- midline shift
- size of sulci
- morphology of cisterns
- intracerebral hematoma size
- presence of contusions
- subarachnoidal blood

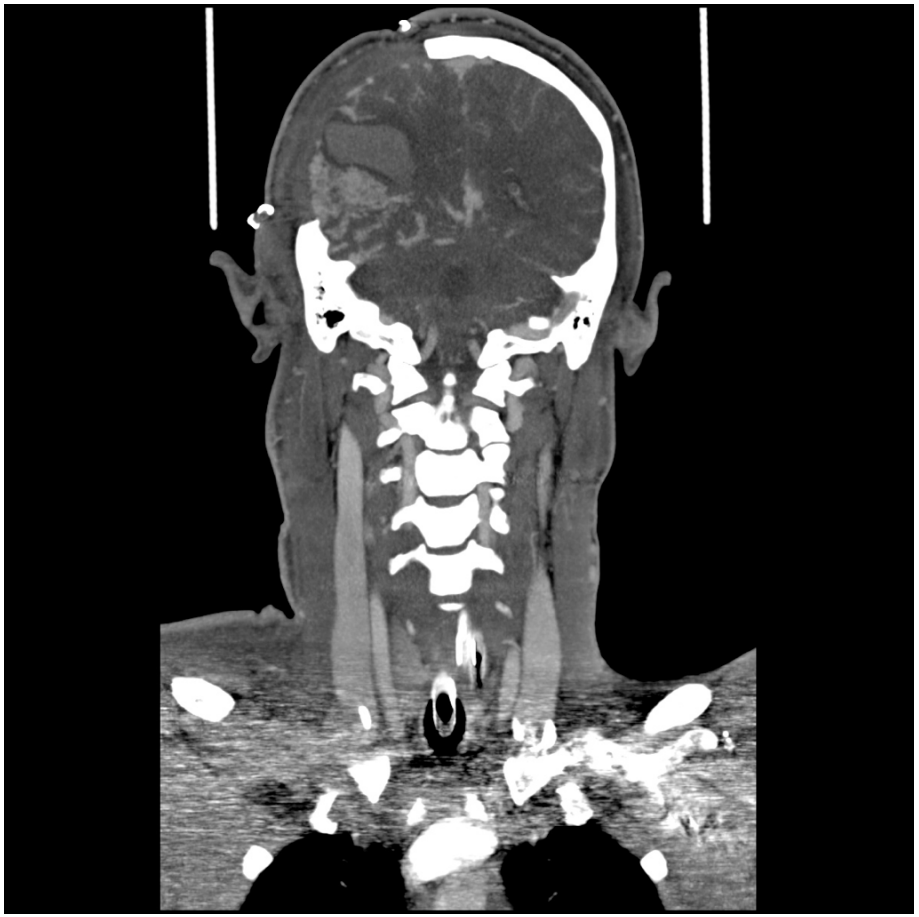
Valuable clinical tool for quickly diagnosing
if used alone its low specificity is a major limitation.

KISHORE. AJR AmJ Roentgenol 1981;137(4):829–33.
TEASDALE E,. J Neurol Neurosurg Psychiatry1984;47(6):600–3.

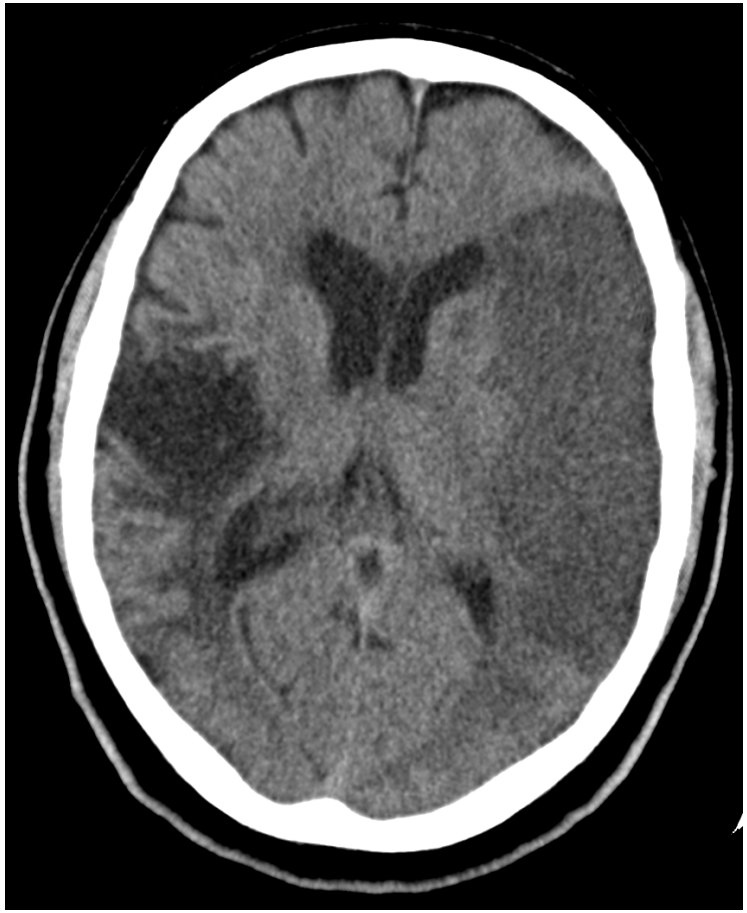
Misurazione non invasiva della pressione di perfusione cerebrale e della pressione intracranica



Misurazione non invasiva della pressione di perfusione cerebrale e della pressione intracranica

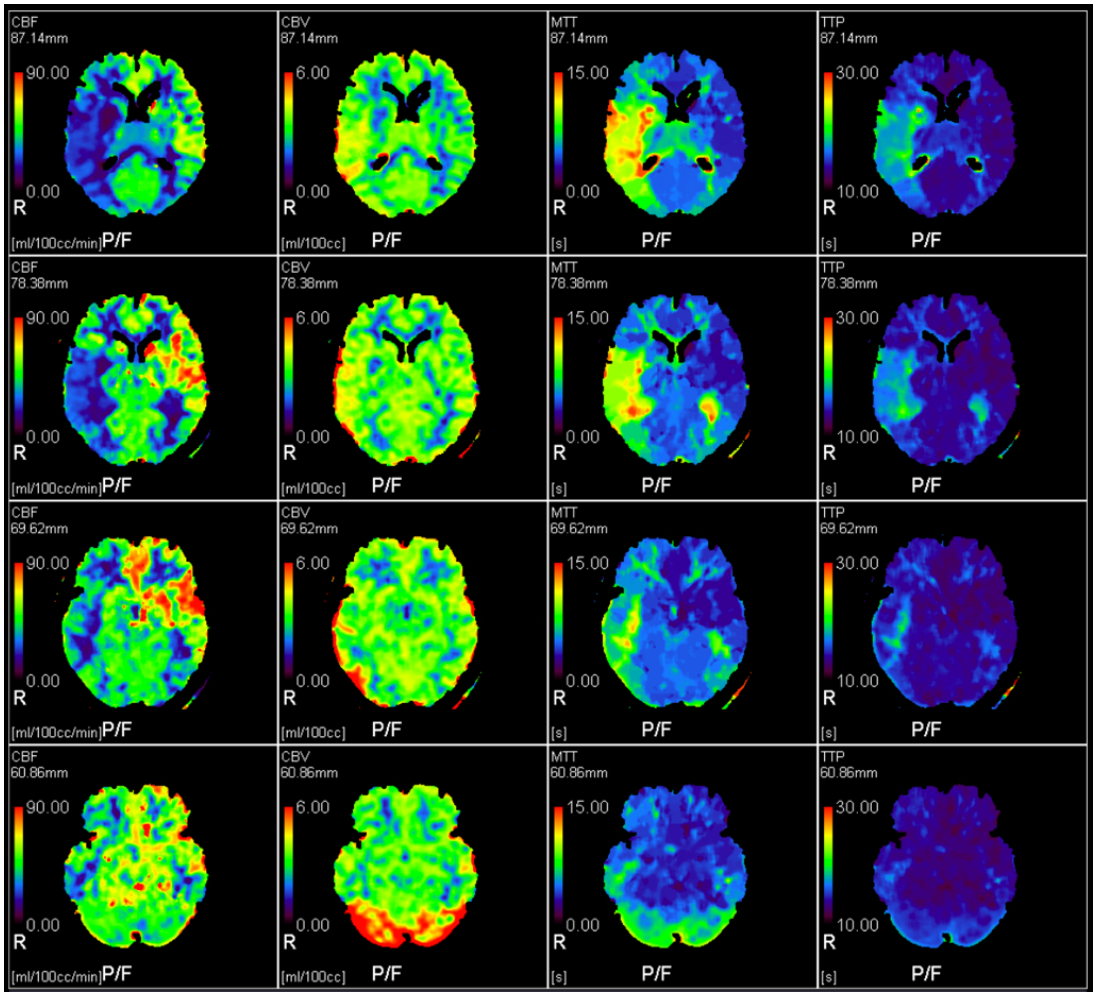


25-jähriger Patient: Plötzliche Bewusstlosigkeit, dann komatös



Stroke

Misurazione non invasiva della pressione di perfusione cerebrale e della pressione intracranica



Accuracy of CT

Technique	Author	Number of pts and disease	Sens %	Spec %	PPV %
Radiological findings	Eisenberg et al., (6)	45 TBI pts			50
	Holliday et al., (13)	17 TBI pts			41
	Kishore et al., (14)	150 TBI pts			2
	O'Sullivan et al., (16)	8 TBI pts			17
	Sadhu et al., (17)	21 TBI pts			88
	Sekhon et al., (120)	57 TBI pts			0
	Kim et al., (135)	221 pts with HDK			

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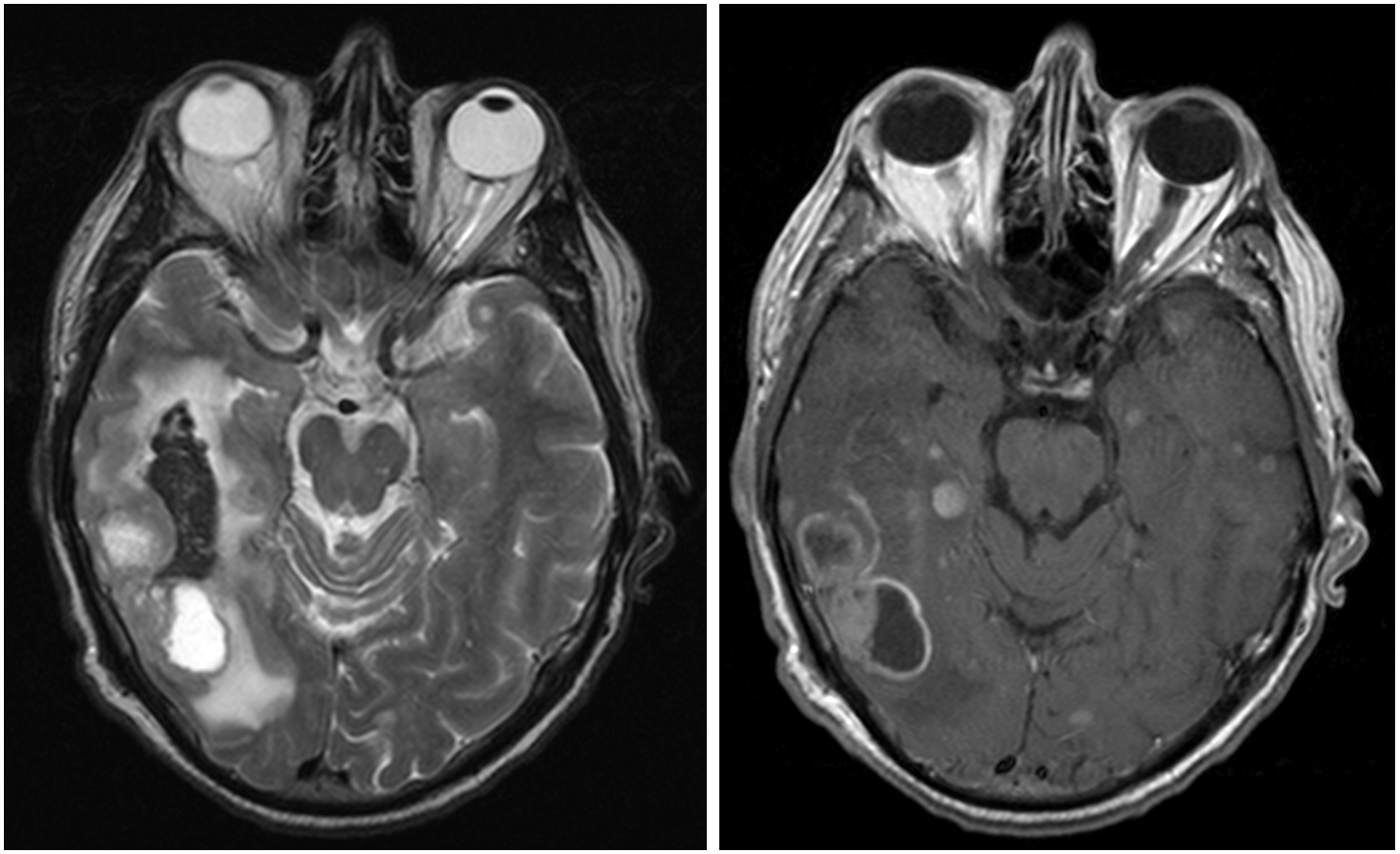
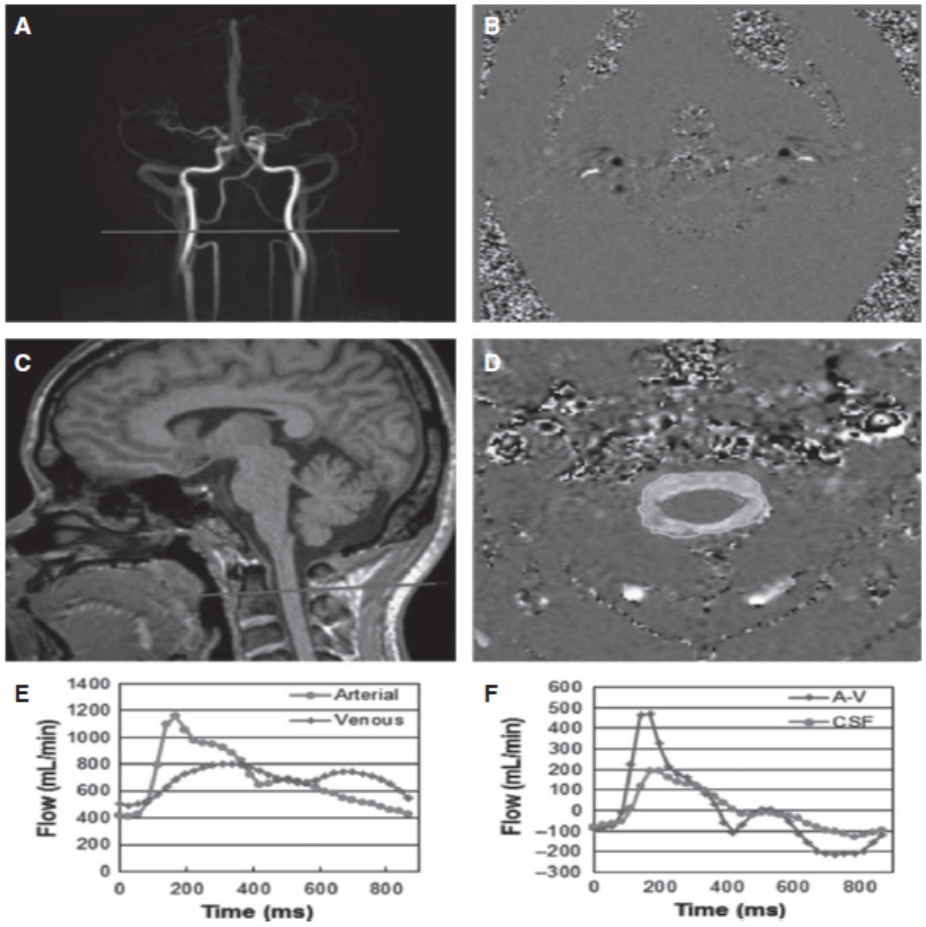
MRI



MRI could be more reliable limited availability and imaging time constraints preclude its widespread use as a real-time estimator of ICP

MR cerebrospinal fluid volume accounting



Alperin et al Radiolgy 200

MR cerebrospinal fluid volume accounting

- **Arteriovenous malformations (with assessment of blood and CSF dynamics as well)**
- **Patients with symptomatic hydrocephalus**
- **Severity of headaches in acute mountainsickness is correlated with the change in MR-ICP**

MEINEL Eur J Radiol 2014;83(8):1442–7.
GLICK RP,.Neurosurgery 2006;59(5):1052–60;
LAWLEY AnnNeurol 2014;75(6):890–8.

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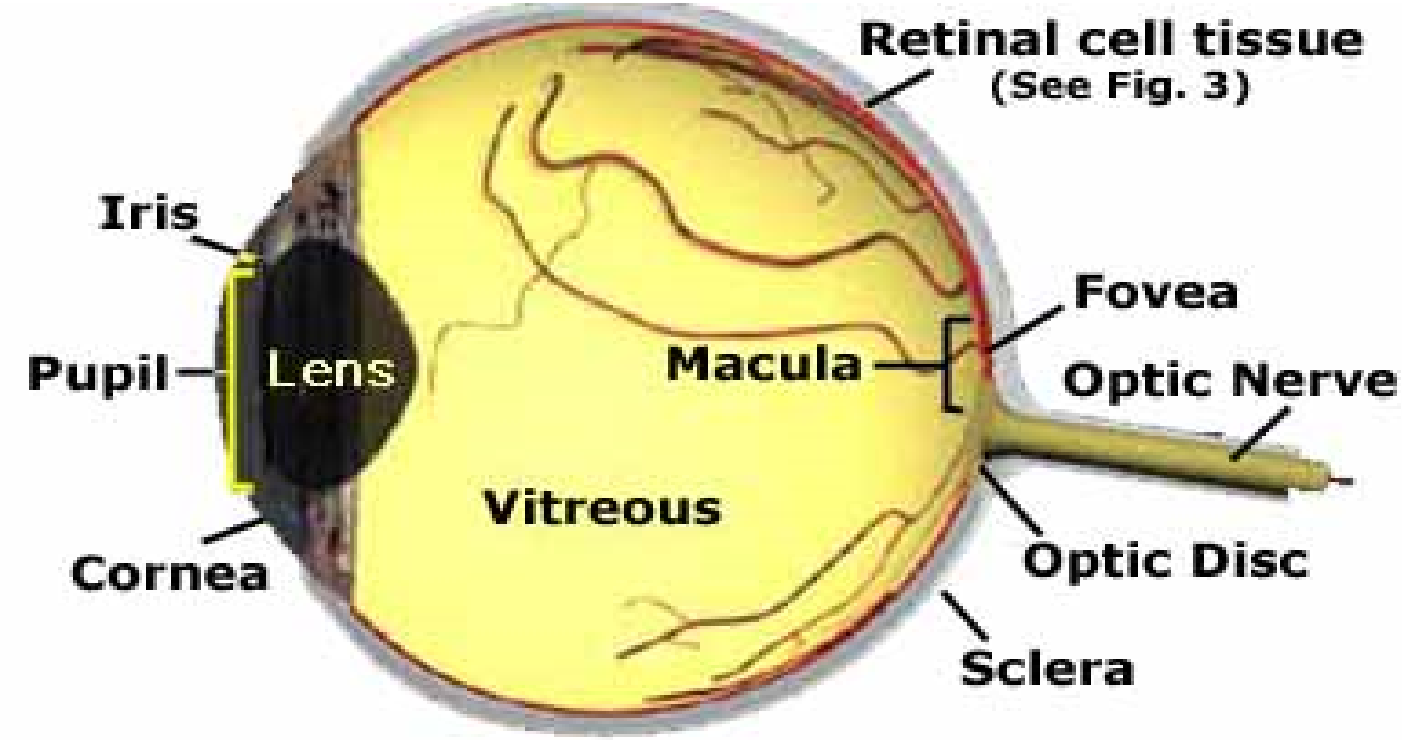
Optic nerve sheath diameter (ONSD)

The perspective of eyes

The optic nerve sheath is anatomically continuous with the dura mater, and has a trabeculated arachnoid space through which cerebrospinal fluid slowly percolates[4]

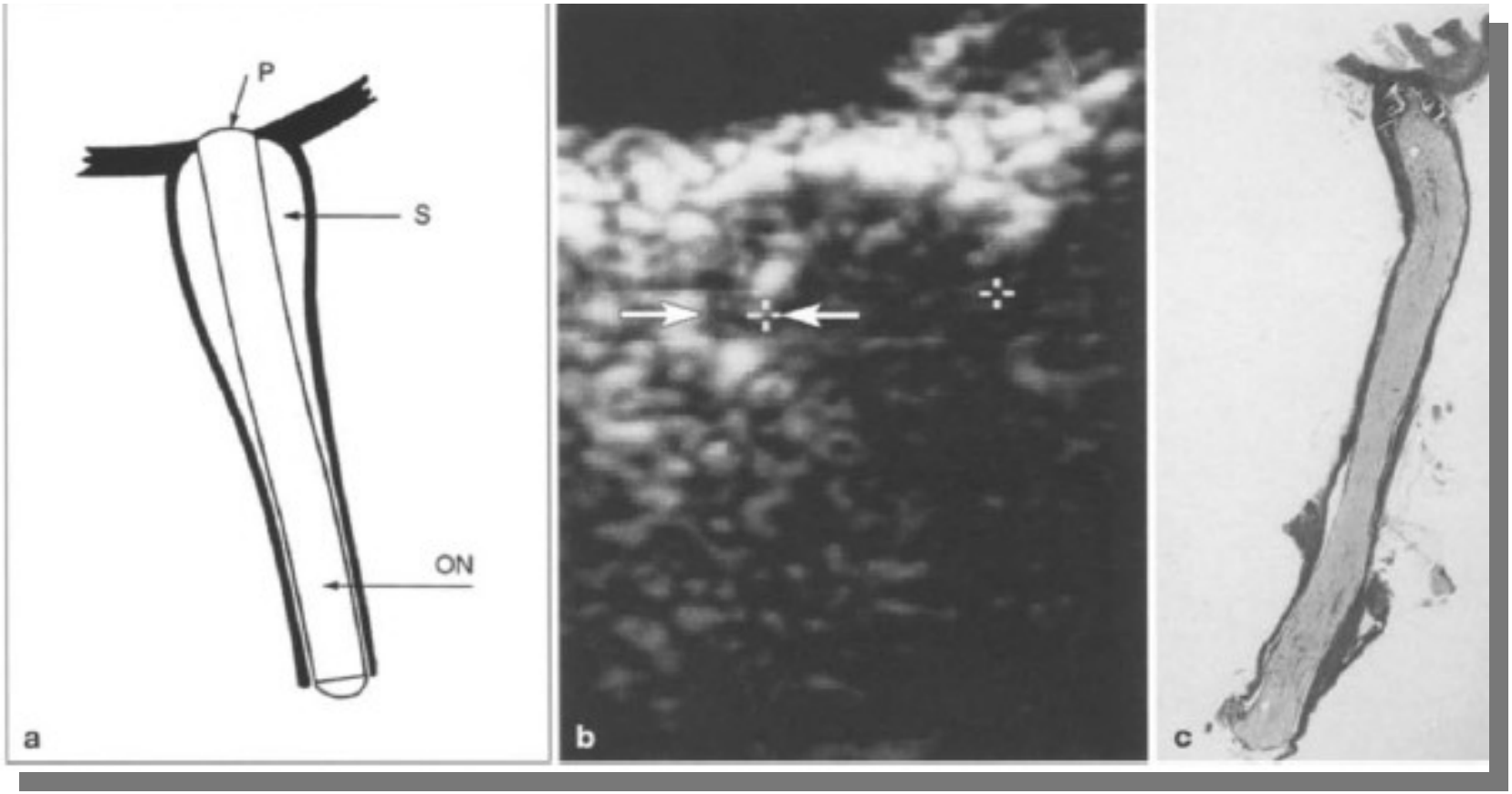


Measurement and relationship of subarachnoid pressure of the optic nerve to intracranial pressures in fresh cadavers
4 Liu D, Kahn MAm J Ophthalmol. 1993 Nov 15;116(5):548-56.

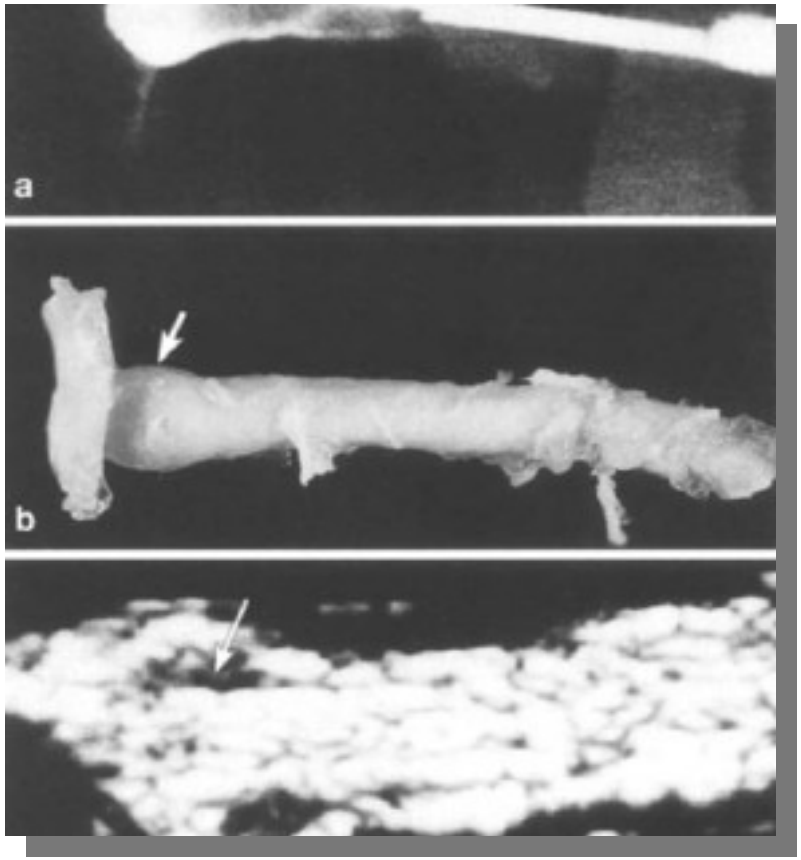
Misurazione non i

Fundamentals of transorbital sonographic evaluation of optic nerve sheath expansion under intracranial hypertension

I. Experimental study

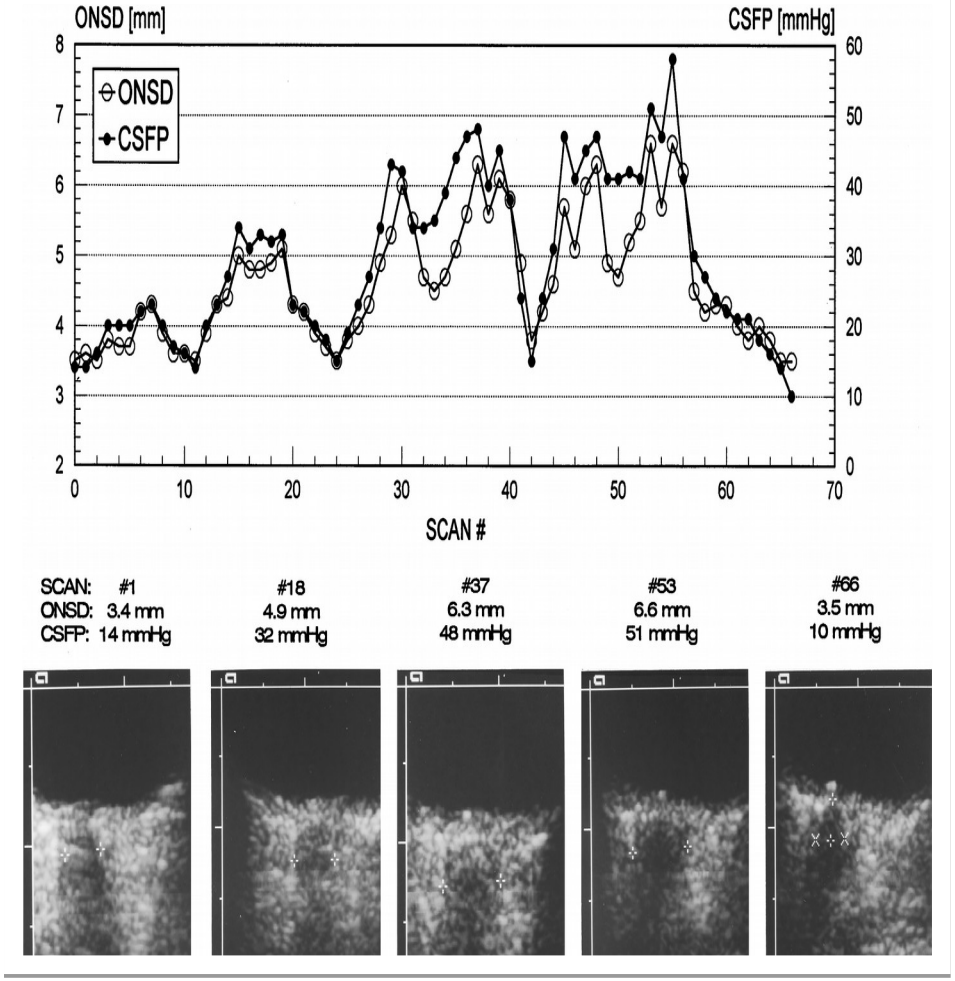


Demonstration of an enlarged perineural sheath after experimental filling



The optimal experimental scanning position was at a right angle to the optic nerve (longitudinal section). Under clinical conditions, however, only axial sections can be obtained using anterior probe positions with transbulbar sound directions. Using such axial projections the 3 mm position proved reliably reproducible. The reduced resolution of the optic nerve itself, allowing it to be distinguished from its surrounding sheath, proved to be somewhat disadvantageous from this projection angle.

Validation of the optic nerve sheath response to changing cerebrospinal fluid pressure

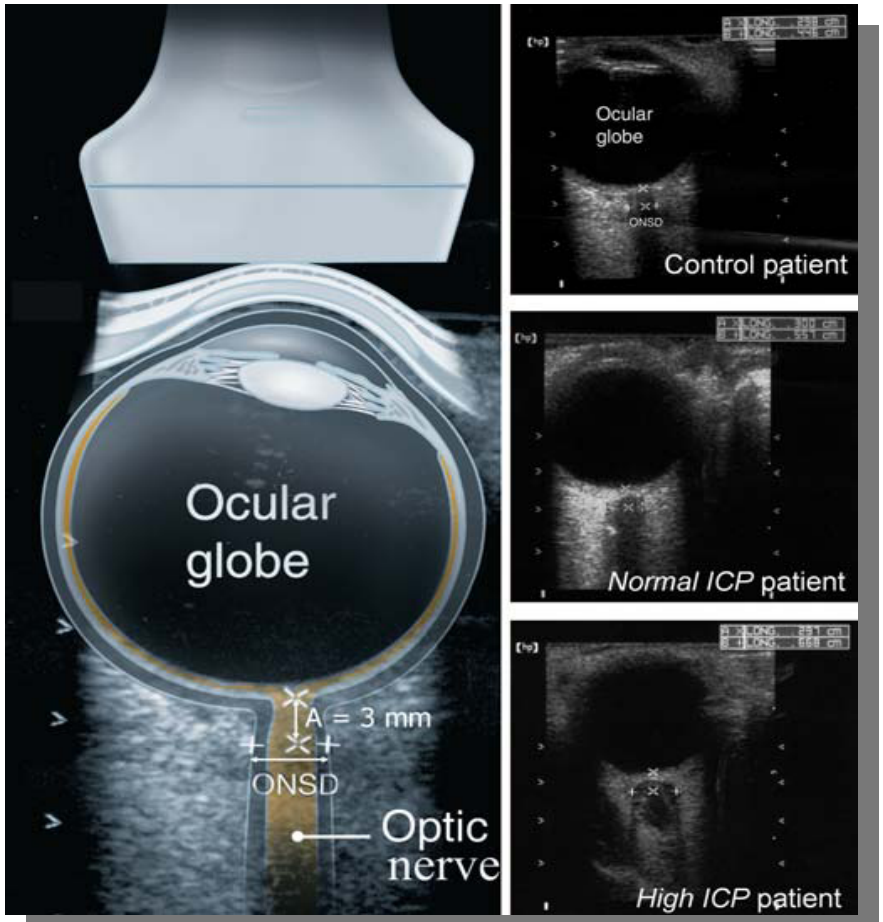


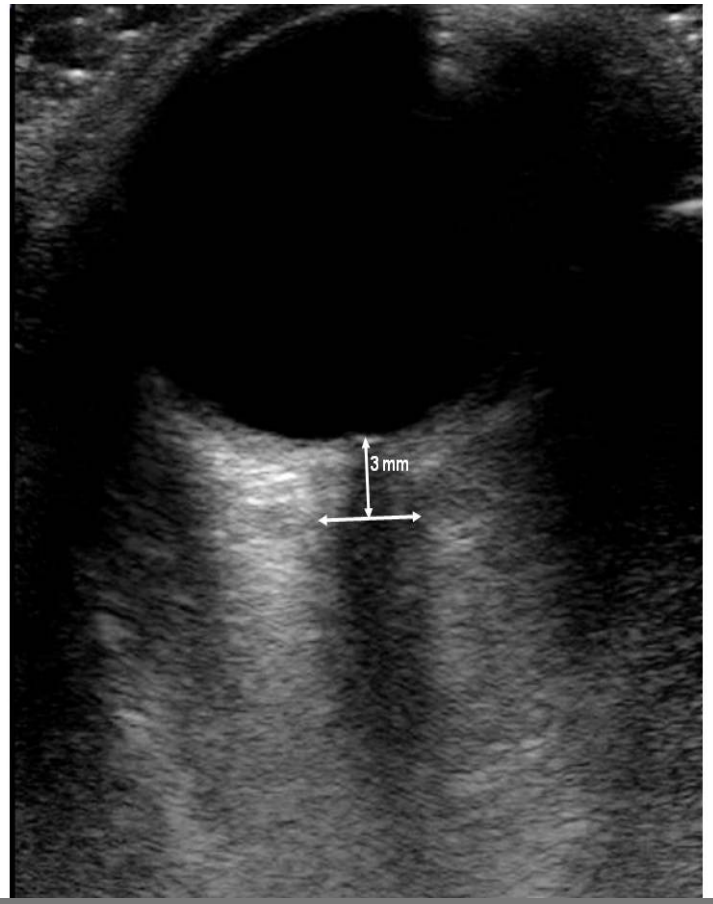
Ultrasound findings during intrathecal infusion tests

ONS diameter between baseline and peak pressure conditions was 1.8 mm on average (range 0.7–3.1 mm), corresponding to an average ONS diameter variation of 45% (range 15–89%)

Spontaneous return of the CSF pressure accompanied by a reduction of ONS diameter

Technique


Ocular
globe
A = 3 mm
ONSD
Optic
nerve
Ocular
globe
ONSD
Control patient
Normal ICP patient
High ICP patient

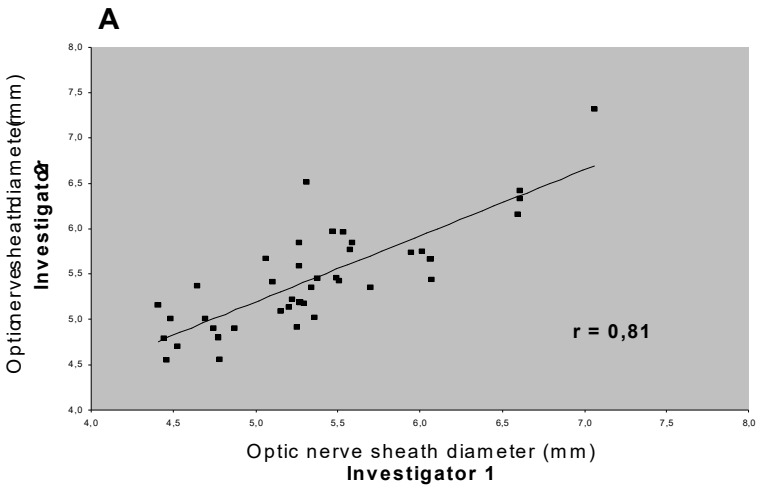

3 mm

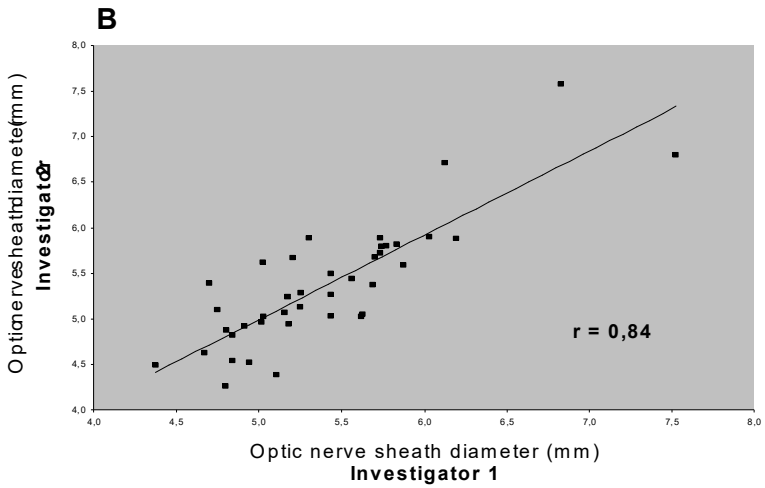
INTRAOBSERVER RELIABILITY_

- **Considering the results of investigator 1 this value was found to be 0,95 for the right bulbus and 0,97 for the left.**

- **With regard to investigator 2 Cronbach´s Alpha was 0,92 respectively 0,93.**

INTEROBSERVER RELIABILITY
PEARSON CORRELATION





Analysing the meassurements of both eyes separately,Pearson's correlation coefficient between investigator 1 and 2 was 0.81 on the right side and 0.84 on the left.

ON-US method to assess the ONSD with a high intra and interobserver reliability

Results

- **Depicting the optic nerve and its sheath was possible in all individuals.**
- **The ONSD was measured in 40 individuals aged 18 to 77 years (mean 37.1 ± 13.9 years).**
- **The mean ONSD was 5.4±0.6 mm with a range of 4.3–7.6 mm.**
- **Their mean body-mass index was 24.5 ± 3.8 kg/m2 (range 18.6 – 33.6 kg/m2)**

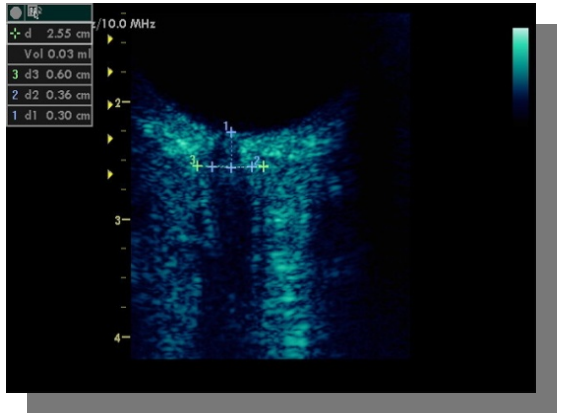
Intraobserver and interobsever reproducibility of ultrasound assessment of the optic nerve sheath diameter

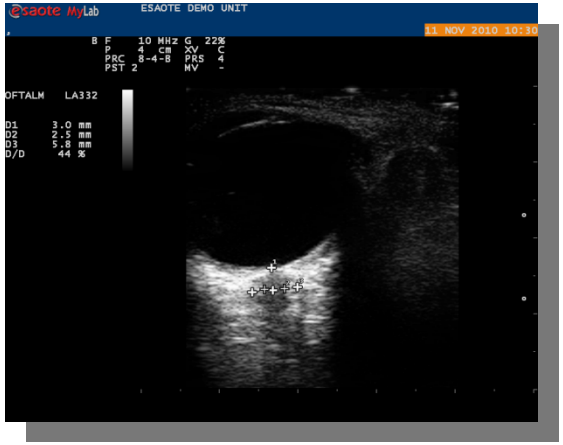
Piergiorgio Lochner [1], Jochen Bäuerle[1], Max Nedelmann[1]
[1] Neurologische Universitätsklinik, Justus-Liebig Universität Giessen, Germany Riga 2009

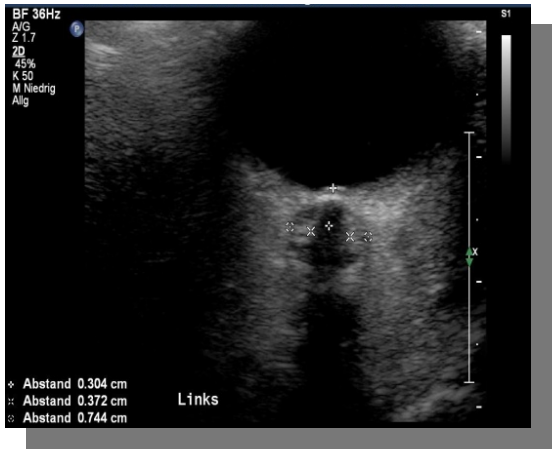
Table 1 Optic nerve sheath diameter (mm) in 40 individuals

	Right bulb Investigator	Investigator	Left bulb Investigator	Investigator	Both bulbs Both
Mean	5,5	5,4	5,4	5,4	5,4
Standard	0,6	0,6	0,6	0,7	0,6
95%	5,3 – 5,6	5,1 – 5,6	5,2 – 5,6	5,1 – 5,6	5,2 – 5,6
Median	5,4	5,3	5,3	5,3	5,3
3rd	4,5	4,4	4,5	4,3	4,6
97th	7,1	7,0	7,4	7,4	7,1

DIFFERENT PROBES?







Conditions where is a change of intracranial pressure (ICP) is suspected and ONSD-monitoring might be useful

Diseases	Author	Year	Journal
Post-dural puncture headache (PDPH)	Dubost C	2011	Br J Anaesth.
Altitude illness	Fagenholz PJ	2007	High Alt Med Biol
Traumatic head injury	Geeraerts T,	2008	Intensive Care Med.
Intracerebral hemorrhage	Moretti R Skoloudík D,	2009 2011	Br J Ophthalmol. 2011 Neurocrit Care.
Subarachnoid Hemorrhage Stroke	Geeraerts T,	2008	Intensive Care Med
Hydrocephalus	Newman WD	2002	Br J Ophthalmol
Posterior reversible encephalopathy Preeclampsia	Lochner P Dubost C	2013 2012	Neurol Sci Anesthesiology
Hepatic encefalopathy	Helmke K	2000	Transplantation
CNS infections	Jacobson EE	1999	J Clin Neurosci
Idiopatic intracranial hypertension	Bäuerle J	2011	J Neurol

Detection of increased ONSD compared to invasive and non-invasive methods

ONSD vs GOLD STANDARD	Type of measurement	Reference gold standard	Number of patients	Pathology	Cut off (mm)	Correlation Coefficient	Sensitivity (%)	Specifcity (%)
Sekhon et al. (120)	CT	Intraparenchymal	57	TBI	6	0.74	97	42
Geeraerts et al. (50)	MRI	Intraparenchymal	38	TBI	5.82	0.71	90	92
Watanabe et al. (121)	MRI	subdural	12	SDH or hygroma	NA	0.88	NA	NA
Caffery et al. (122)	US	LP	51	Miscellaneous	5	0.53	75	44
Wang et al. (123)	US	LP	279	Miscellaneous	4.1	$P < 0.001$	95	92
Nabeta et al. (124)	US	LP	57	Cryptococcal Meningitis	5	0.44	85	59
Aminiet al. (125)	US	LP	50	Miscellaneous	5.5	0.88	100	100
Rajajee et al. (126)	US	Intrap and EVD	65	Miscellaneous	4.8	0.76	96	94
Strumwasser et al. (42)	US	Intrap and EVD	10	TBI	6	0.45(uni), 0.21(bilat les)	36	38
Moretti et al. (127)	US	Intrap e EVD	53	ICH and SAH	5.2	0.69	94	76
Moretti et al. (128)	US	Intrap o EVD	63	ICH and SAH	5.2	0.7	93	74
Geeraerts et al. (129)	US	Intraparenchymal	37	Miscellaneous	5.9	0.71	87	94
Kimberly et al. (130)	US	EVD	15	TBI and ICH	5	0.59	88	93
Soldatos et al. (131)	US	Intraparenchymal	32	Brain injury	5.7	0.68	74	100
Geeraerts et al. (132)	US	Intraparenchymal	31	TBI	5.86	0.68	95	79

Robba et al.

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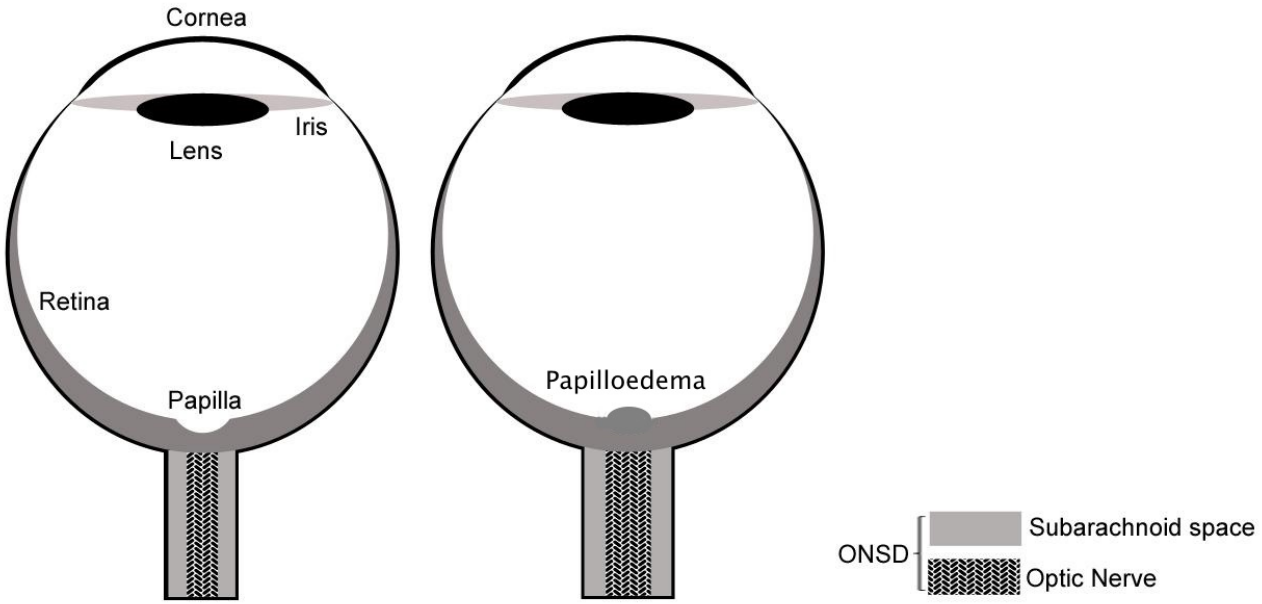
Optic disc elevation (i.e., papilledema, ODE)

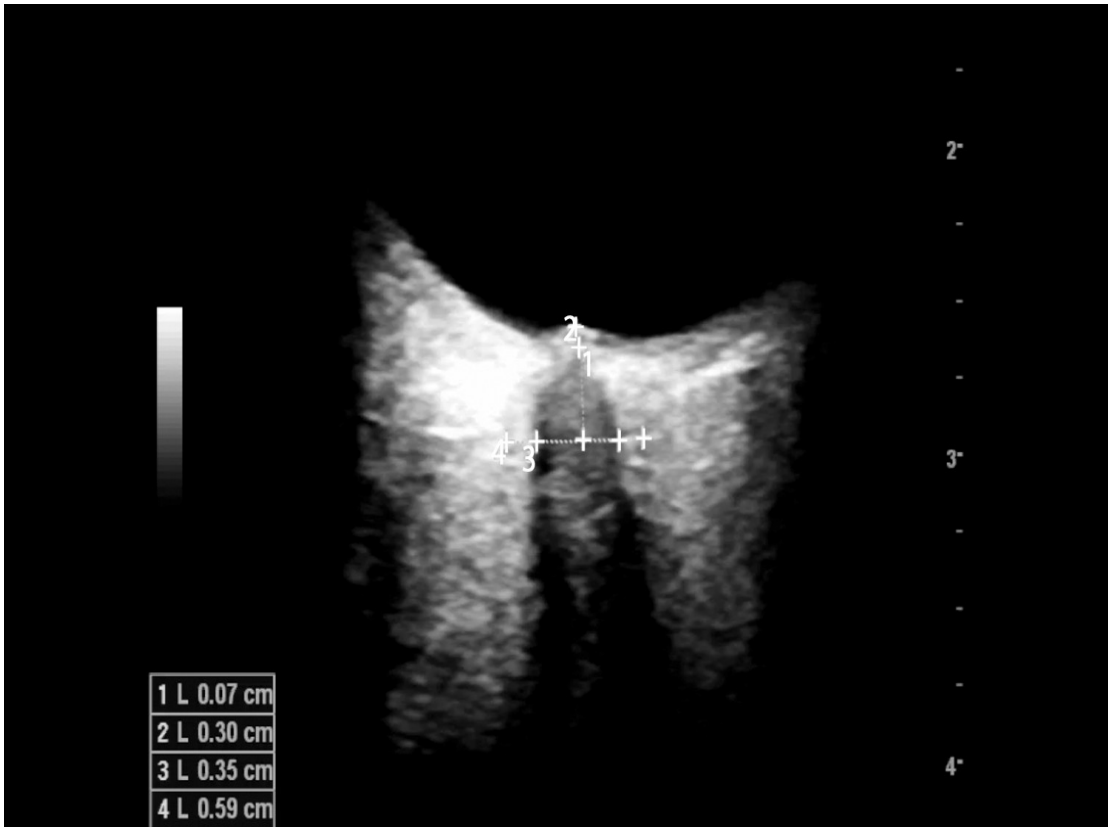


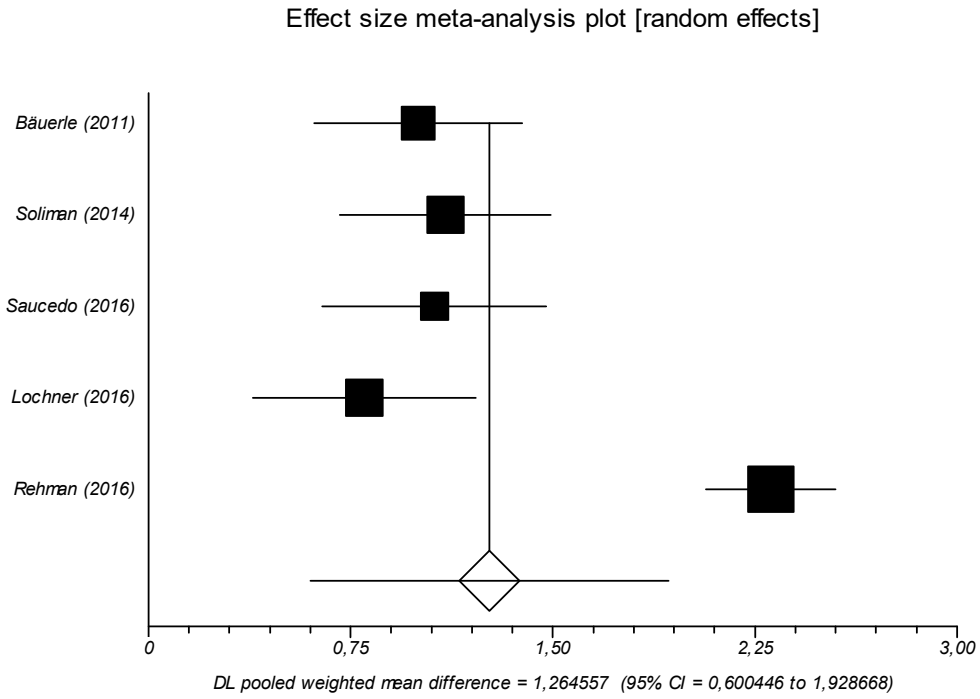
fundoscopy.

of the swelling can be graded by Frisén scale which includes 5 categories and it is built on oph-

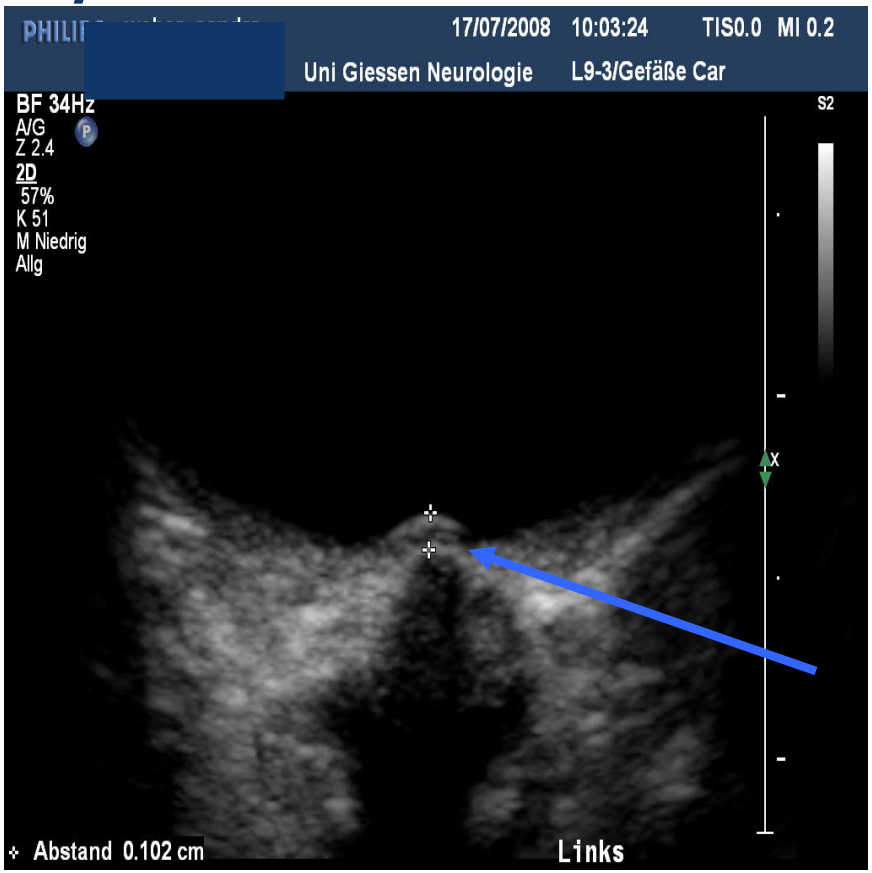
time (59), and therefore, this technique is not suitable for emergency conditions or when acute ICP increases are suspected.

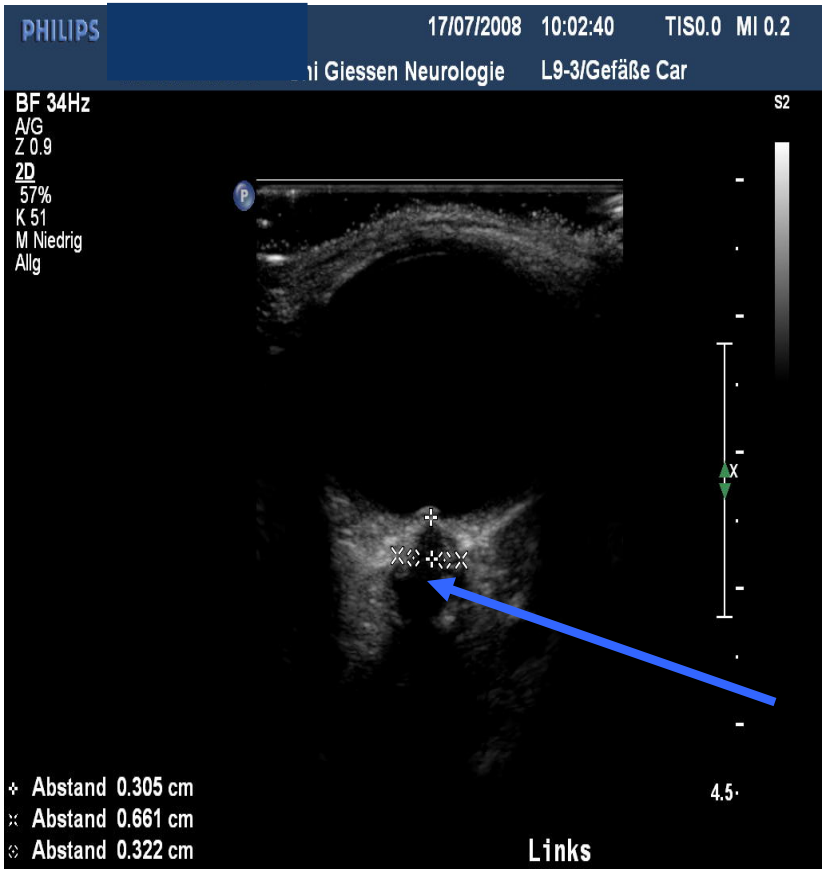
SELHORST JB, GUDEMAN SK, BUTTERWORTH J, HARBISON JW, MILLER JD, BECKER DP. Papilledema after acute head injury. Neurosurgery 1985;16(3):357–63.


2
3
4
1 L 0.07 cm
2 L 0.30 cm
3 L 0.35 cm
4 L 0.59 cm

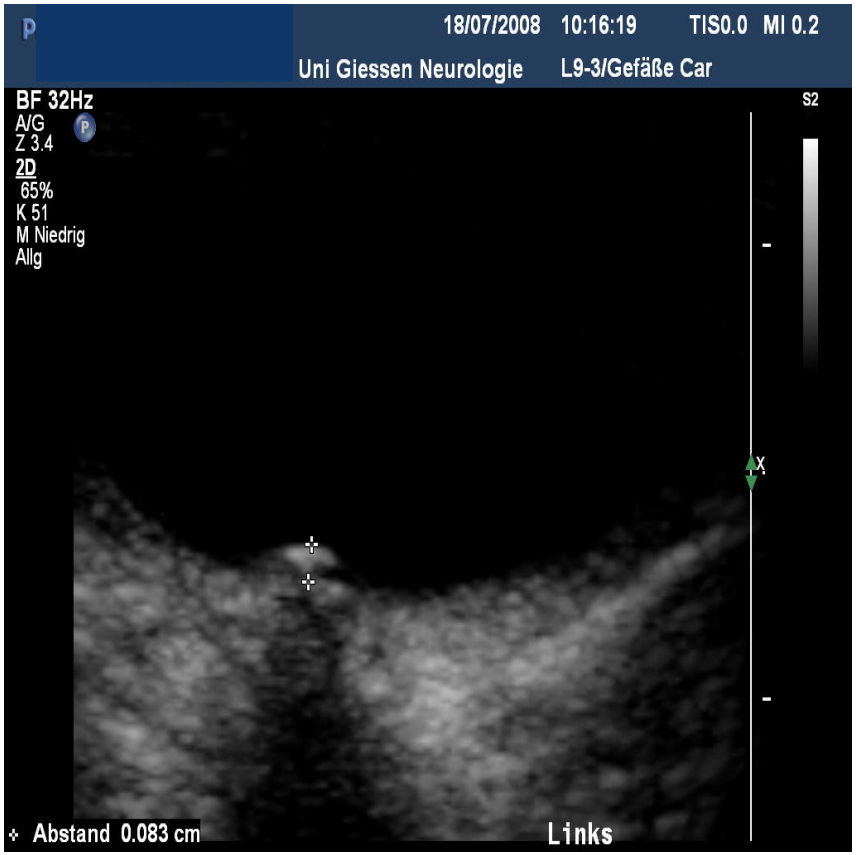

Effect size meta-analysis plot [random effects]
Bäuerle (2011)
Soliman (2014)
Saucedo (2016)
Lochner (2016)
Rehman (2016)
0
0,75
1,50
2,25
3,00
DL pooled weighted mean difference = 1,264557 (95% CI = 0,600446 to 1,928668)

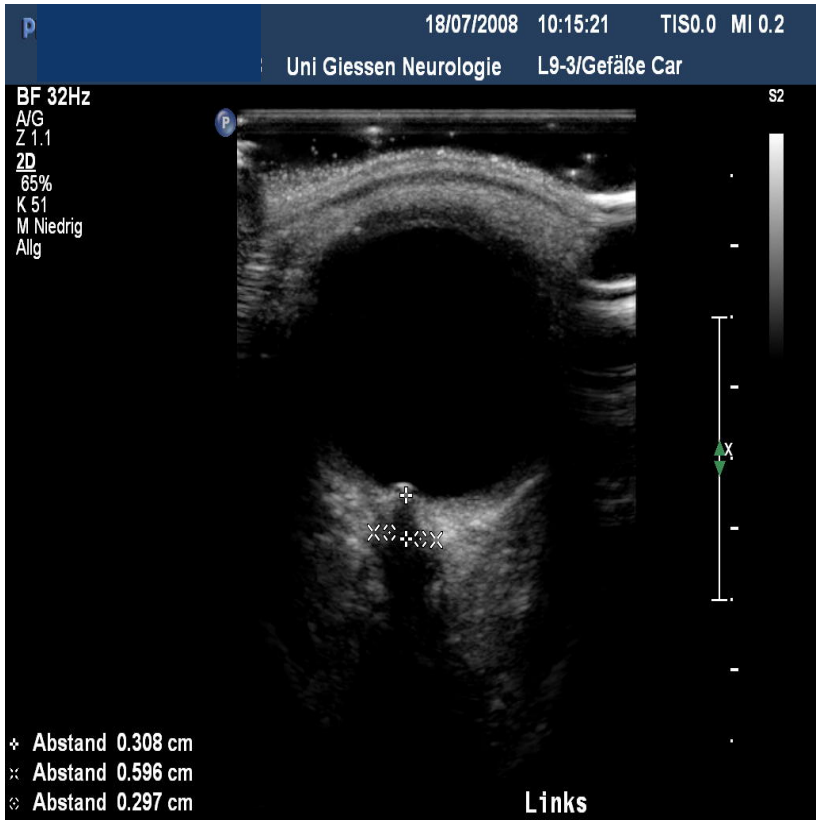
PAPILLA E NERVO OTTICO SX 17/07





PAPILLA E NERVO OTTICO SX 18/07





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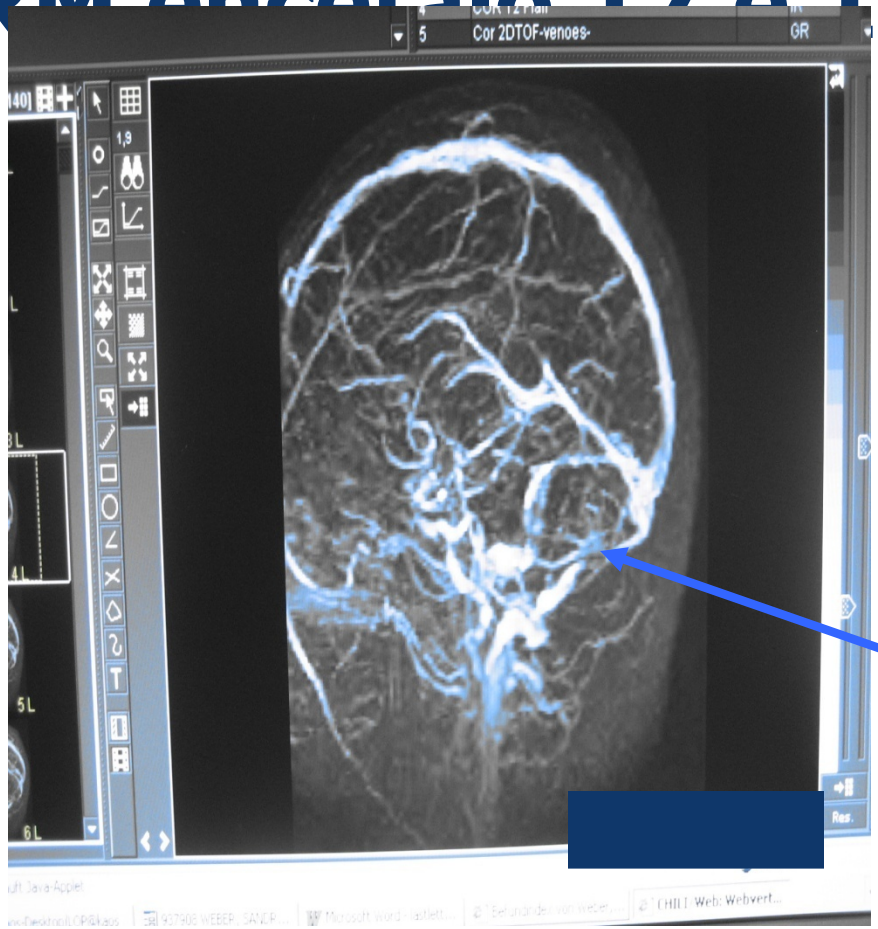

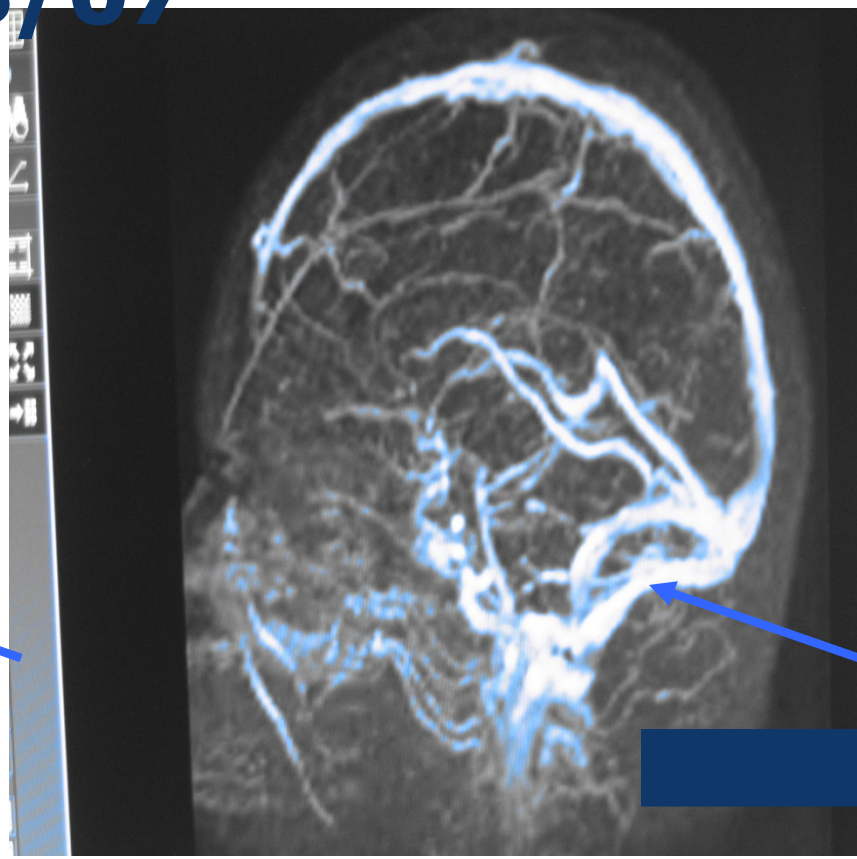

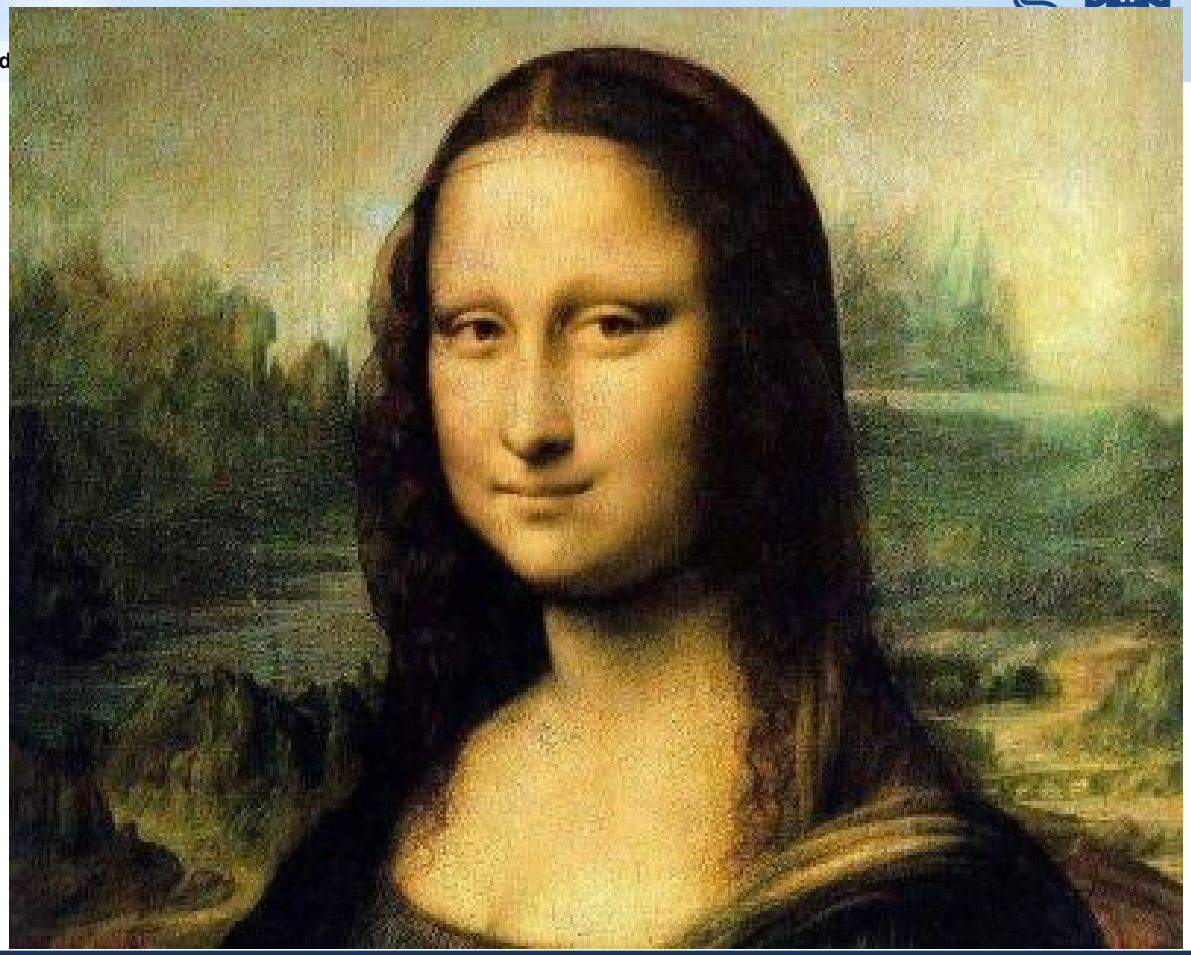

Nobil natura è quella
Che a sollevar si ardisce
Gli occhi mortali incontra
Al comun fato, e che con franca lingua[...]
Confessa il mal che ci fu dato in sorte.

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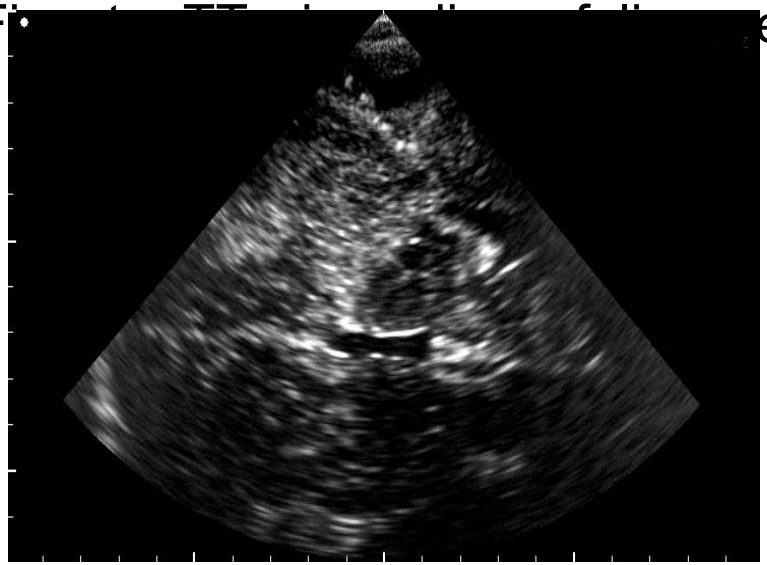
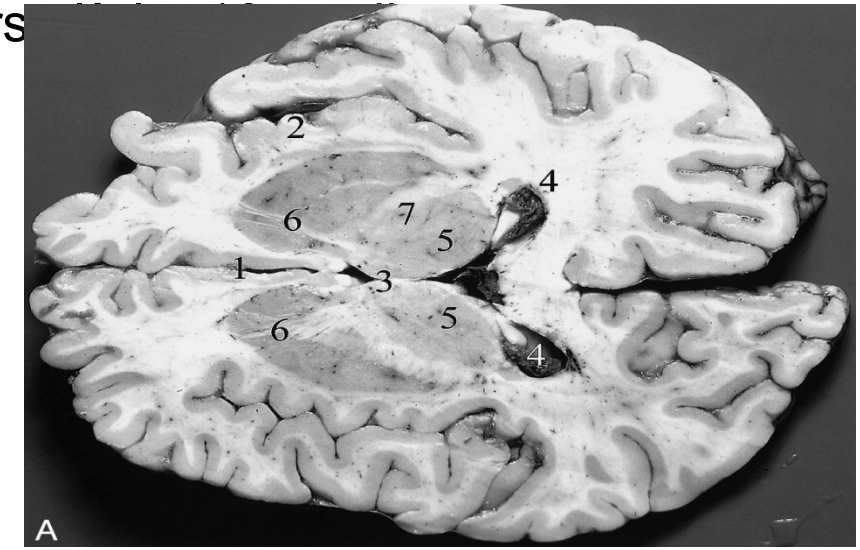
transcranial color duplex and Midline shift

Fi ers

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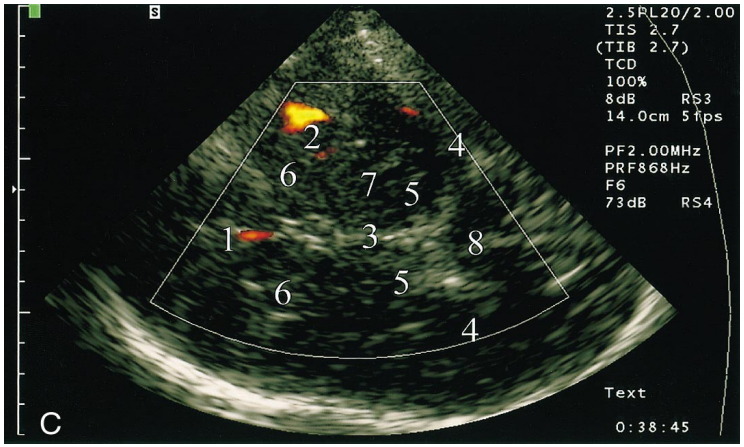
S
2.5RL20/2.00
TIS 2.7
(TIB 2.7)
TCD
100%
8dB RS3
14.0cm 5fps
PF2.00MHz
PRF868Hz
F6
73dB RS4
2
4
6
7
5
1
3
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6
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4
Text
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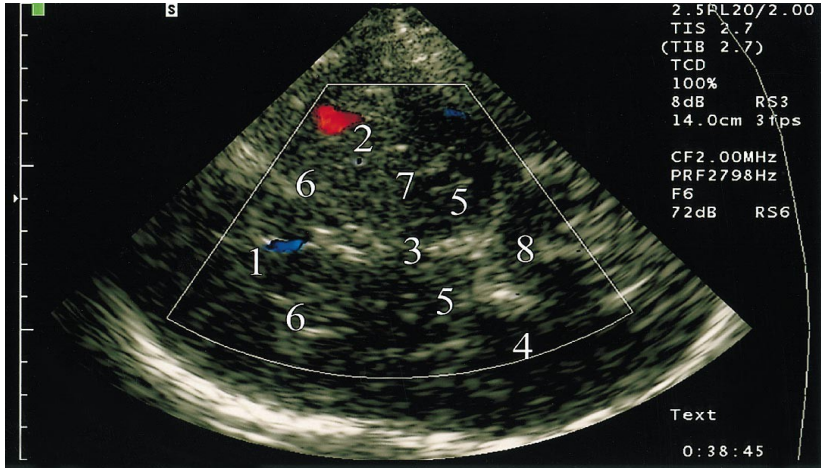
C


S
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TIS 2.7
(TIB 2.7)
TCD
100%
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14.0cm 3fps
CF2.00MHz
PRF2798Hz
F6
72dB RS6
2
6
7
5
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Text
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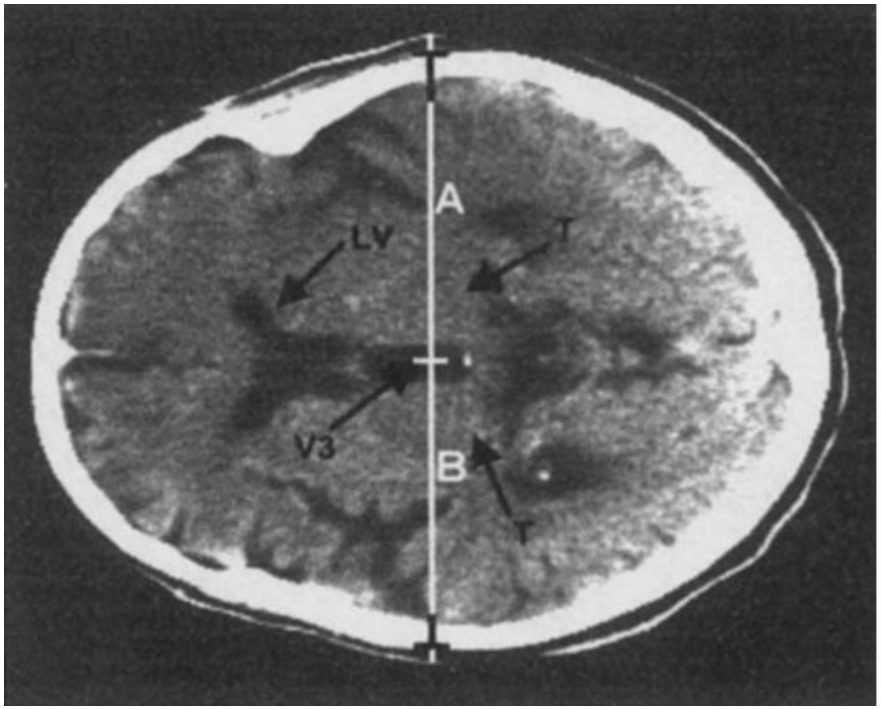
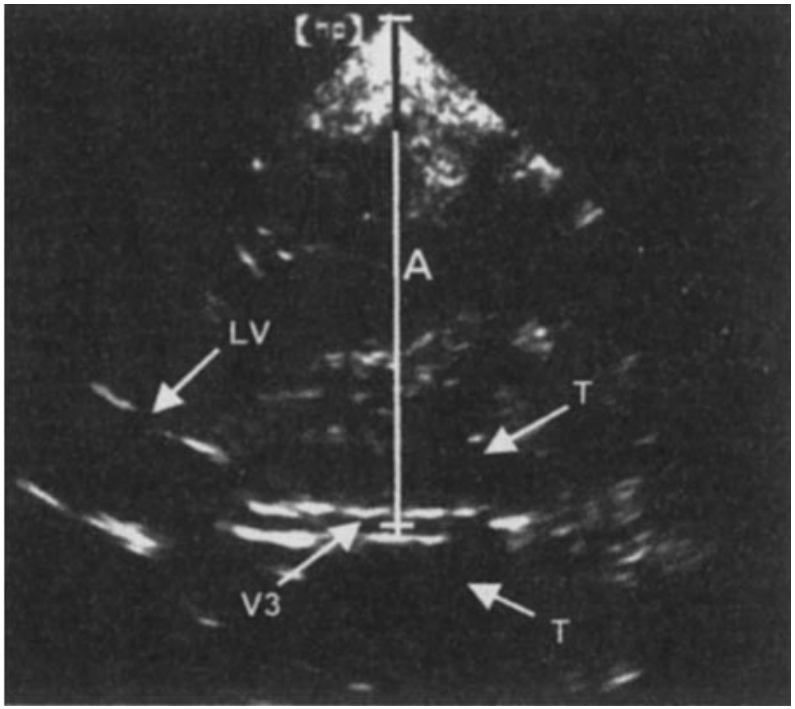
A-B/2





Seidel G. J Neuroimaging 1995

T. Gerriets Sonographic monitoring of midline shift in hemispheric infarctions Neurology 1999

Sixteen patients with acute middle cerebral artery (MCA) occlusion
Five patients died from cerebral herniation (group 1), 10 survived (group 2), and 1 patient (Patient 16) survived after decompressive surgery.

TS was performed on days 1 to 4
(10 +/- 3)
32 +/- 4,
57 +/- 5,
82 +/- 5 hours after onset of symptoms

Neurology. 1999 Jan 1;52(1):45-9. Piergiorgio Lochner 47

T. Gerriets Sonographic monitoring of midline shift in hemispheric infarctions Neurology 1999

All patients with an MLS < 4 mm at 32 hours survived, whereas patients with an MLS > 4 mm died as a result of cerebral herniation, with the exception of the one patient who underwent decompressive hemicraniectomy.

The value of MLS in determining the indication of decompressive craniectomy merits further study.

Sonographic monitoring of midline shift in space-occupying stroke: an early outcome predictor.

42 with acute, severe hemispheric stroke

Cranial computed tomography (CCT) and extracranial duplex sonography were performed on admission.

TCCS was carried out 8+/-3, 16+/-3, 24+/-3, 32+/-3, and 40+/-3 hours after stroke onset.

Lesion size was determined from follow-up CCT.

Gerriets, Stroke. 2001 Feb;32(2):442-7

Sonographic monitoring of midline shift in space-occupying stroke: an early outcome predictor.

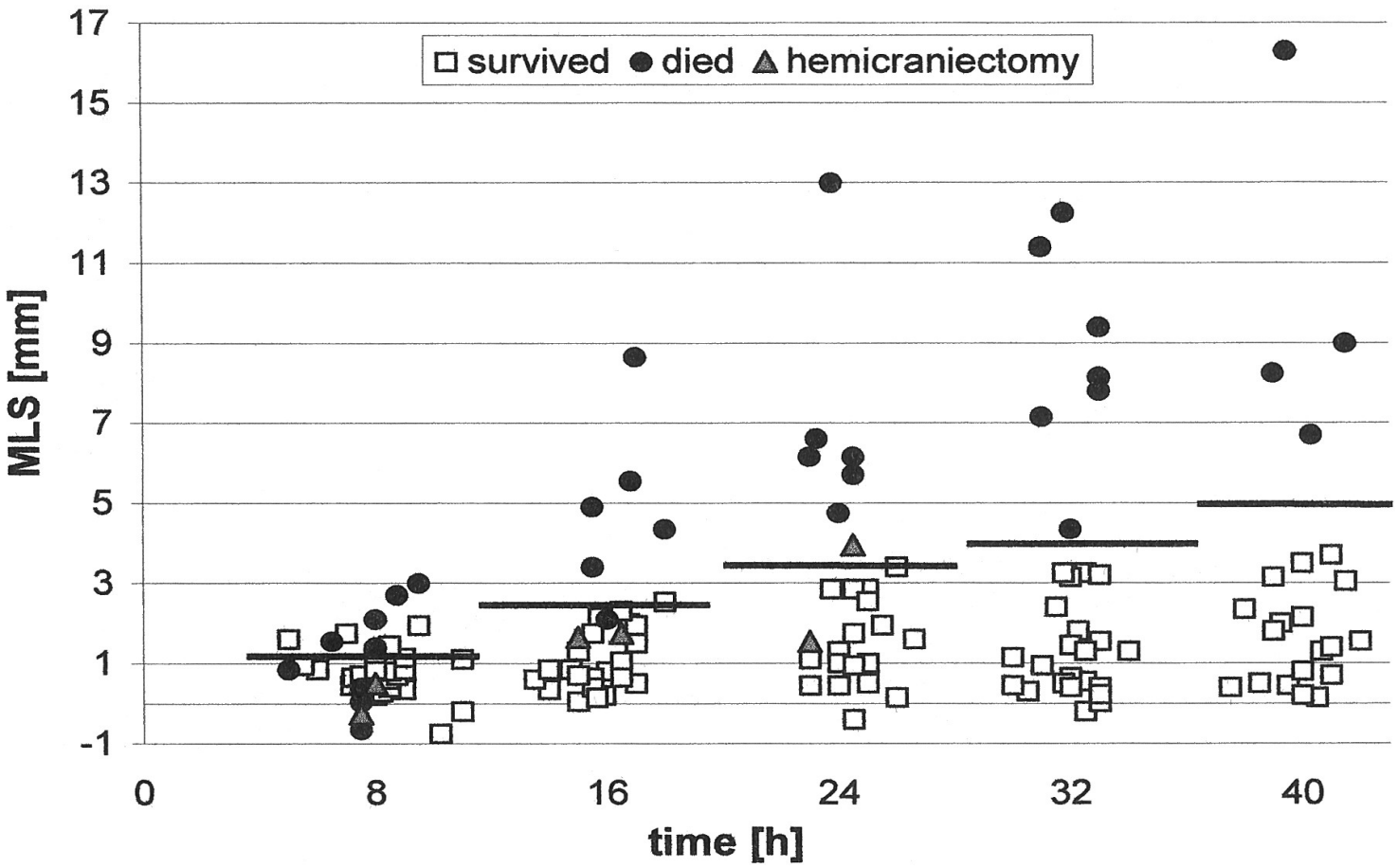
Twelve patients died as the result of cerebral herniation (**group 1);**

28 survived (group 2).

MLS was significantly higher in group 1 as early as 16 hours after onset of stroke. Specificity and positive predictive values for death caused by cerebral herniation of MLS >/=2.5, 3.5, 4.0, and 5.0 mm after 16, 24, 32, and 40 hours were 1.0.

TCCS helps to estimate outcome as early as 16 hours after stroke onset and thus facilitates identification of patients who are unlikely to survive without decompressive craniectomy.

T. Gerriets An Early Outcome Predictor 2001 Stroke



Mean MLS was 1.18 mm (SD 1.15) on CCT and 1.25 mm (SD 1.30) on TCCS images.

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Non invasive measurment of ICP

indirectly transmitted ICP

fundoscopy

tympanic membrane displacement (TMD)

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Cerebral blood flow charateristics and alterations

Reliability of the blood flow velocity pulsatility index

BACKGROUND: It has been postulated that the **Gosling pulsatility index (PI) assessed with transcranial Doppler (TCD) has a diagnostic value for noninvasive estimation of intracranial pressure (ICP) and cerebral perfusion pressure (CPP**).

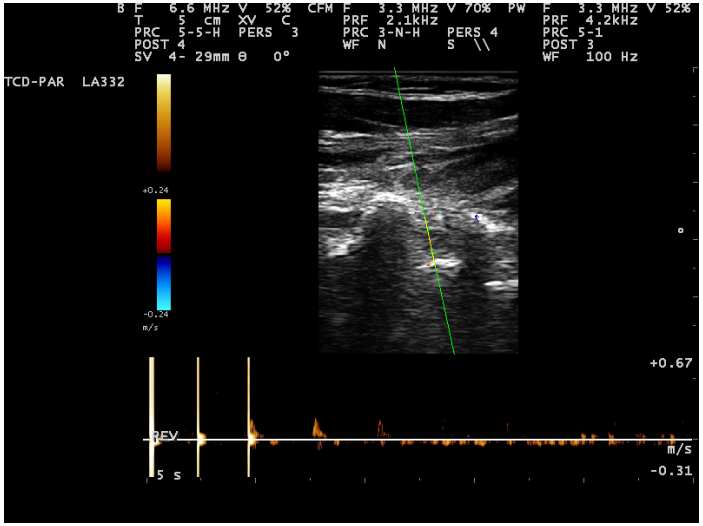
RESULTS: **The correlation between PI and ICP was 0.31 (P<.001) and for PI and CPP -0.41 (P<.001).**

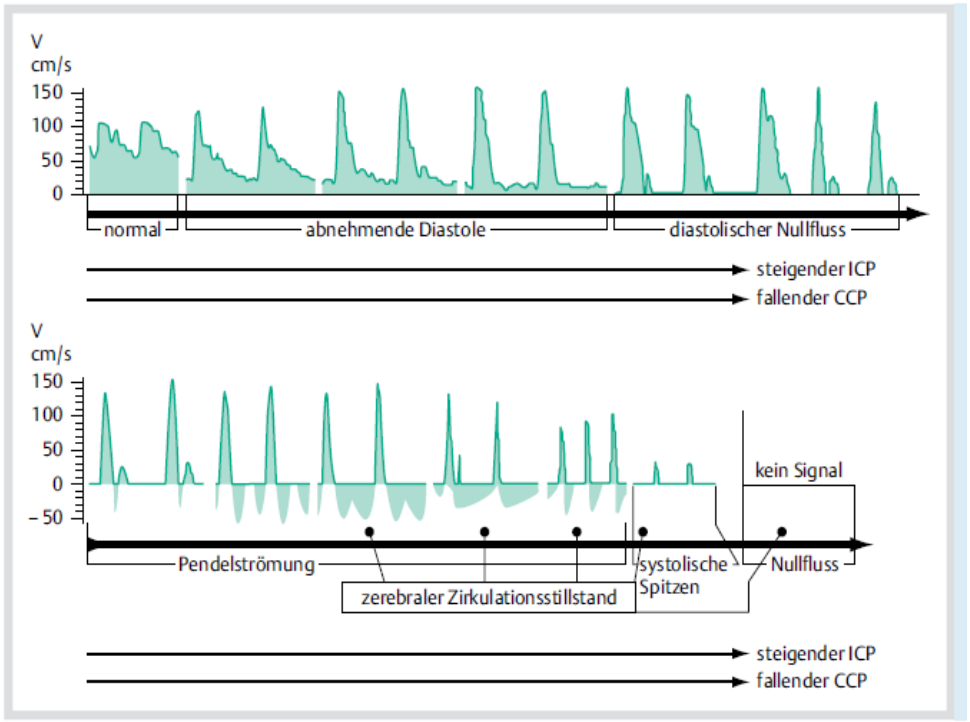
CONCLUSION: Overall, the value of TCD-PI to assess ICP and CPP noninvasively is very limited. However, extreme values of PI can still potentially be used in support of a decision for invasive ICP monitoring.

Zweifel C Neurosurgery. 2012 Oct;71(4):853-61.

UKS Saarland University Medical Center

Dynamic





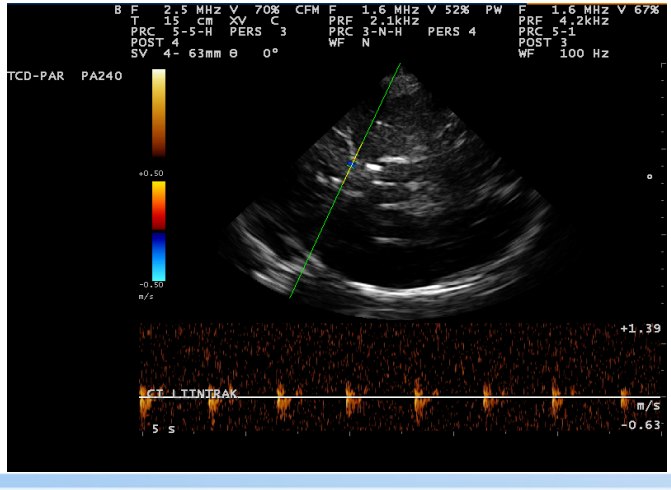


Abb. 1 Zeitliche Dynamik der intrakraniellen Drucksteigerung. Doppler-Frequenzspektrum abgeleitet aus der A. cerebri media im zeitlichen Verlauf. Die diastolische Strömungskomponente verschwindet, wenn der intrakranielle Druck den diastolischen Blutdruck übersteigt. Biphasische Strömungssignale signalisieren den zerebralen Zirkulationsstillstand, wenn kein Netto-Vorwärts-Fluss mehr vorliegt [31].

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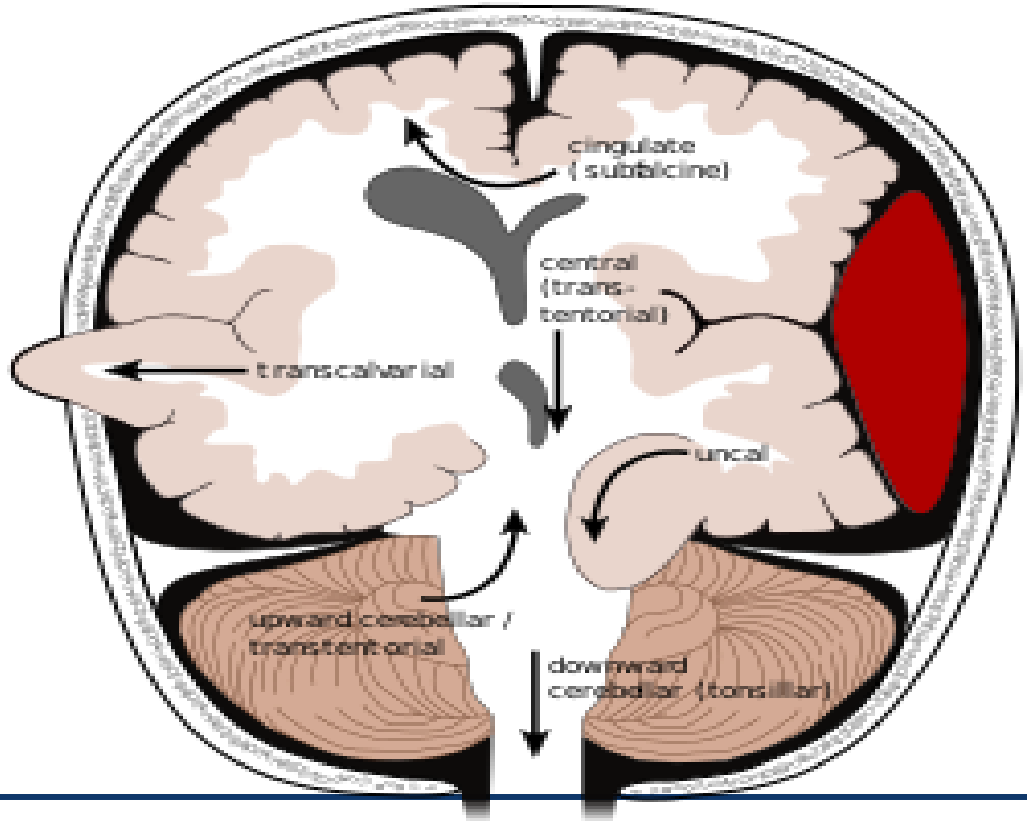
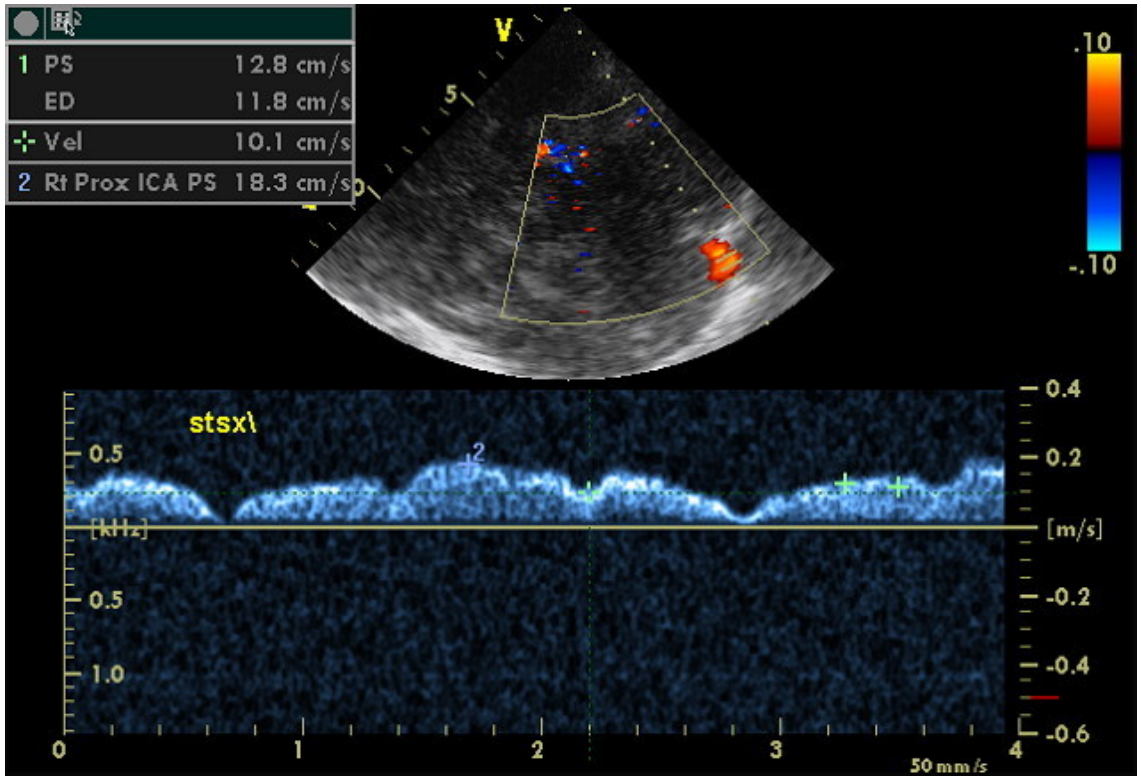
Venous TCD



_Types of brain herniation[3] 1) Uncal 2) Central 3) Cingulate 4) Transcalvarial 5) Upward 6) Tonsillar supratentorial and infratentorial

PRF <



SENO TRASVERSO

The impact of raised intracranial pressure on cerebral venous hemodynamics: a prospective venous transcranial

A linear relationship between mean ICP and maximal venous BFV in the basal vein of Rosenthal (r = 0.645; P = 0.002) and in the straight sinus was found (r = 0.928; P = 0.0003) (77).

SCHOSER BG, J Neurosurg 1999
Stolz et al. Stroke 2002

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monitoring of metabolic
alterations (near-infrared spectroscopy
(NIRS)),

NIRS

Can NIRS Monitoring Help Guide Management?

19 studies, mostly small observational studies describe how NIRS may be used physiology or guide management in neurocritical care:

Cerebral autoregulation [
CPP and MAP assessment
vasospasm
Head positioning
hematoma assessment surgical decision making

The results are mixed, NIRS is to be used, it is best integrated with other monitors to answer research questions but at the moment not to guide management.

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Neurophysiological registrations of functional activity

Electroencephalography, (EEG)

visual-evoked potential (VEP)

otoacoustic emissions

time of flight (TOF) method

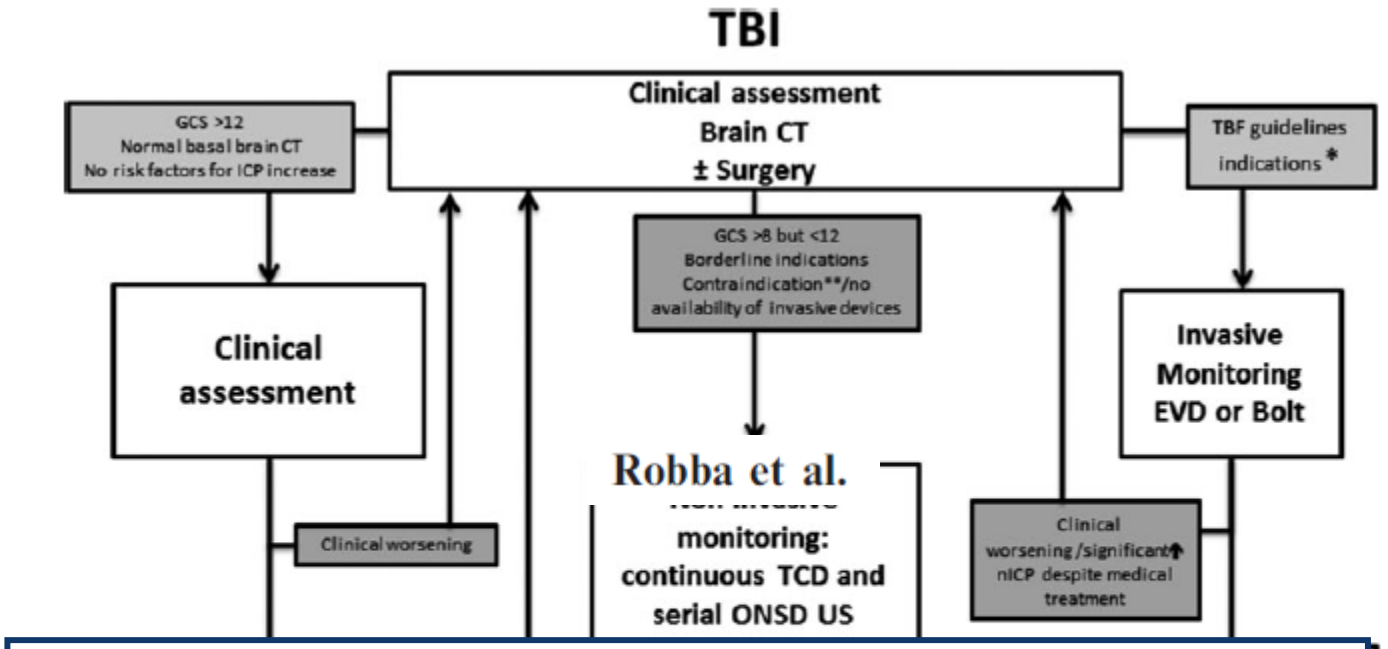
CONCLUSIONI

TRAUMATIC BRAIN INJURY

CLINICAL ASSESSMENT-BRAIN CT +- SURGERY

GCS > 12 (normal CT, no risk factors for ICP increase)	CLINICAL ASSESSMENT
GCS > 8<12 (borderline indications, controindications, no availability of devices	CONTINOUS TCD and SERIAL ONSD US
GCS < 8	Tbf GUIDELINES

Robba et al. Acta neurologica scandinavica 2016



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thanks