Traumatic Brain Injury

-ICP and Multimodal monitoring-

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Traumatic Brain injury

- A major cause of **death** and **disability**
- Traumatic brain injury (TBI) is a **nondegenerative**, **noncongenital** insult to the brain from an external mechanical force, possibly leading to permanent or temporary impairment of cognitive, physical, and psychosocial functions, with an associated diminished or altered state of consciousness
- 외상성 뇌 손상 (TBI)은 **외부의 기계적 힘**으로부터 뇌에 대한 비퇴행성, 비선천성 손상으로 인지, 신체적, 심리 사회적 기능의 영구적 또는 일시적 손상을 초래할 수 있으며, 의식의 저하나 변화가 동반된다.

150 Years of Treating Severe Traumatic Brain Injury: A Systematic Review of Progress in Mortality

JOURNAL OF NEUROTRAUMA 27:1343–1353 (July 2010)

Sherman C. Stein,[1] Patrick Georgoff,[1] Sudha Meghan,[1] Kasim Mizra,[1] and Seema S. Sonnad[2]

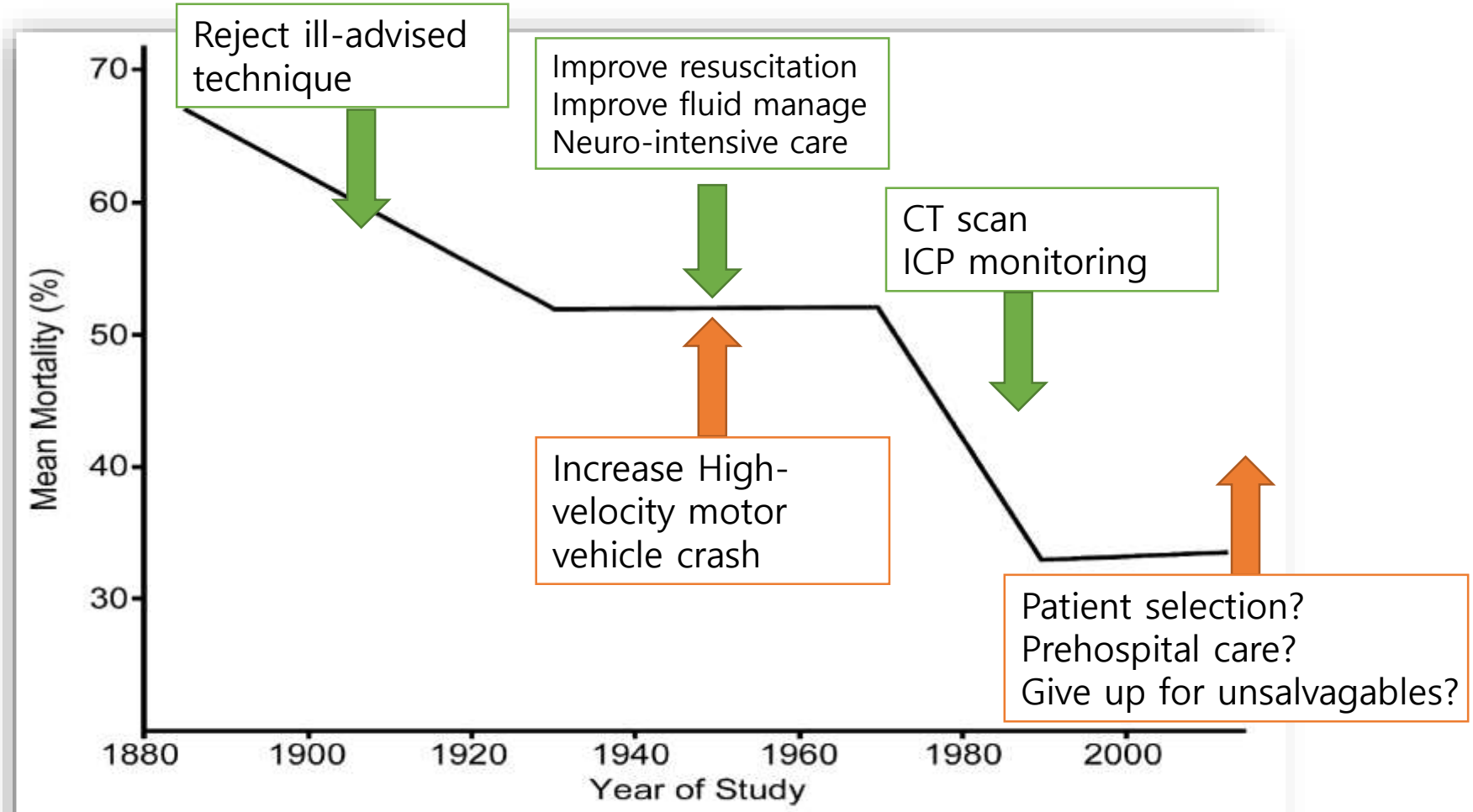
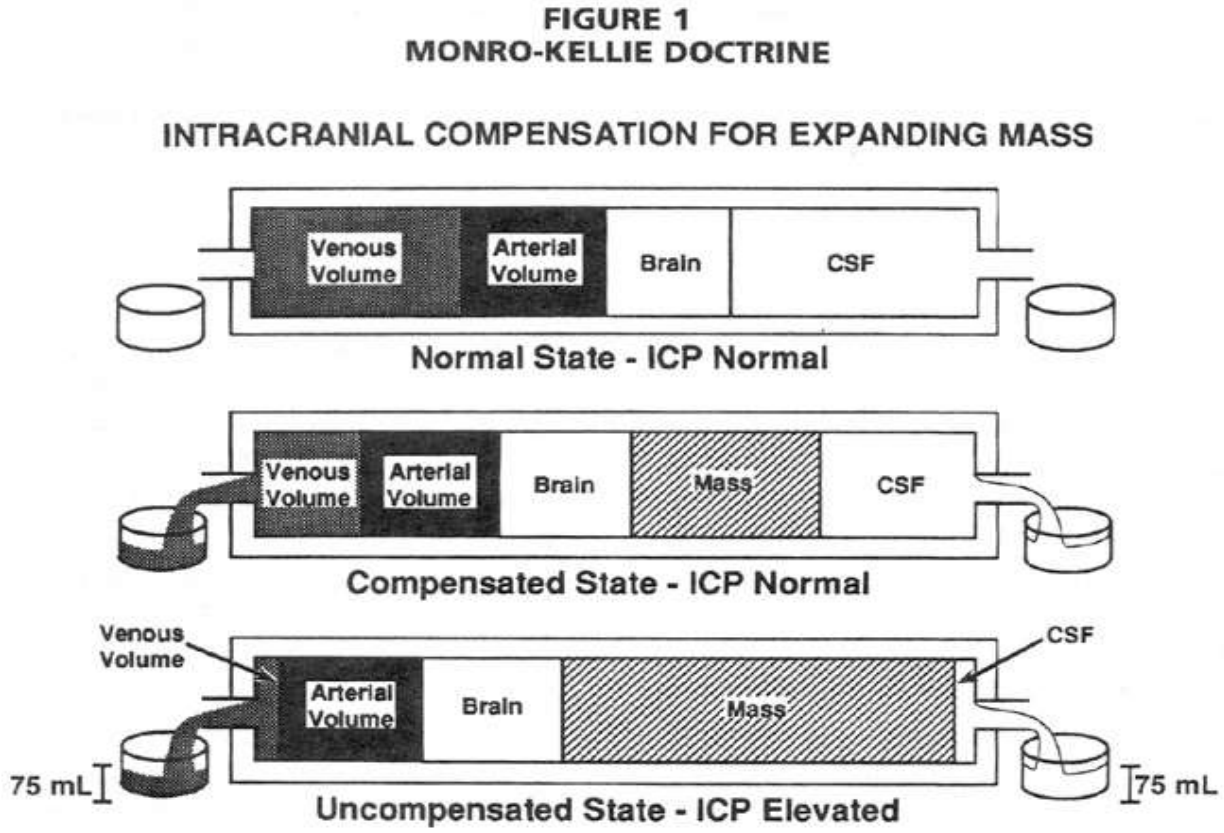
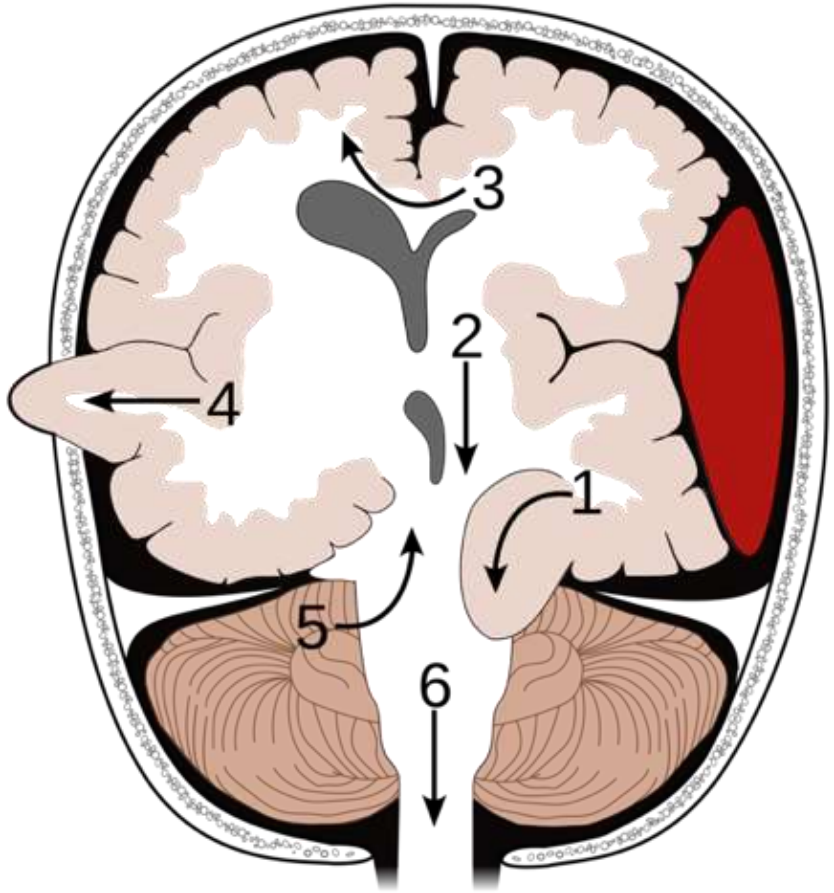


FIG. 3. Composite graph of mortality rates from 1885 to 2006.

MONRO KELLIE DOCTRINE & ICP





Decision making for Surgical treatment

- After initial resuscitation,
- Neurologic examination
- CT scan

SURGICAL INDICATION

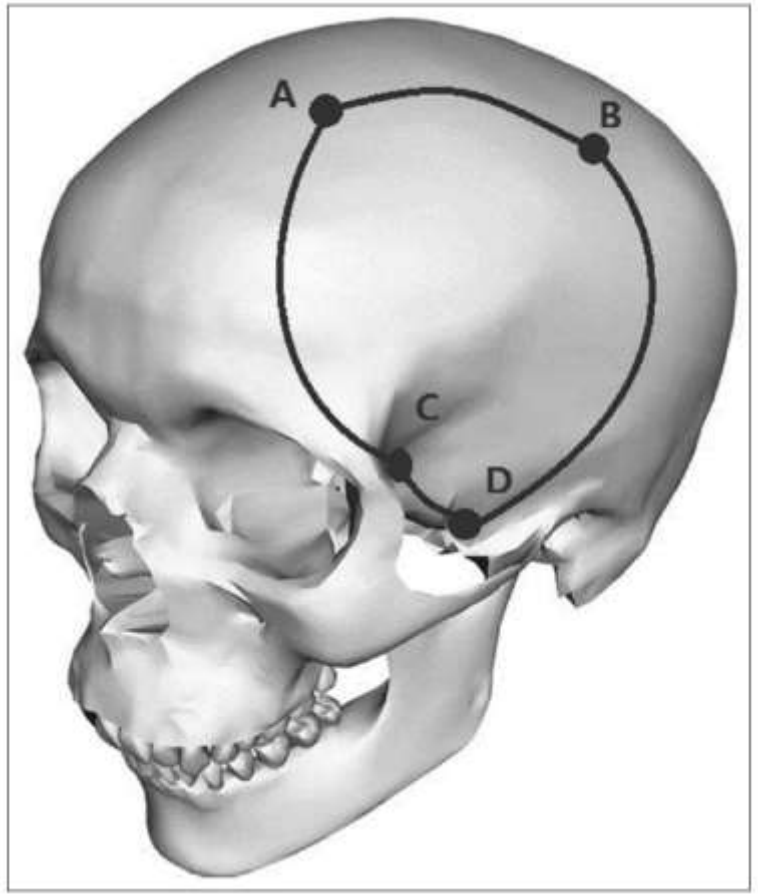
	Should be evacuated (surgery)	Observation (Serial CT scan)	Consideration
Acute EDH	EDH > 30 cm^3	EDH < 30 cm^3	Anisocoric coma (GCS <9)
Acute SDH	10mm thickness MLS 5mm	Should ICP in GCS < 9	GCS decreased 2 more btw injury and admission Anisocoria Dilated and fixed pupil ICP > 20mmHg
Traumatic ICH	GCS 6~8 with frontal contusion > 20 cm^3, MLF > 5 mm and cisternal compression Any lesion > 50 cm^3	No evidence of neurologic compromise Controlled ICD	
Posterior fossa	Mass effect on CT Neurologic deterioration		

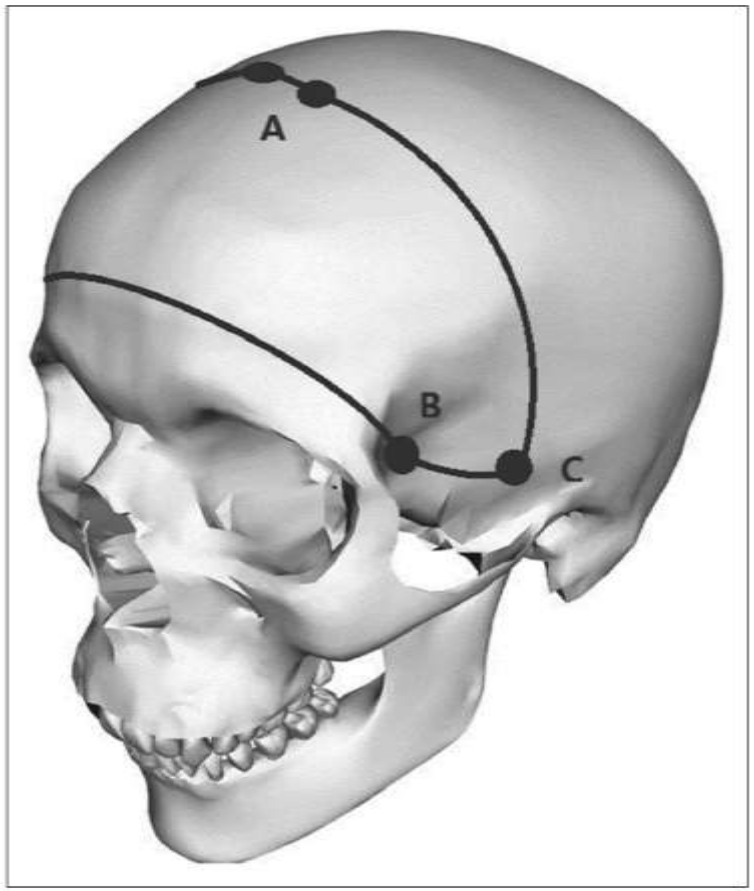
Secondary Decompression in TBI

Guidelines for the Management of Severe Traumatic Brain Injury: 2020 Update of the Decompressive Craniectomy Recommendations

- Secondary DC performed for **late refractory ICP** elevation is recommended to improve mortality and favorable outcomes.
- Secondary DC performed for early refractory ICP elevation is not recommended to improve mortality and favorable outcomes.
- A **large frontotemporoparietal** DC (not less than 12 × 15 cm or 15 cm in diameter) is recommended over a small frontotemporoparietal DC for reduced mortality and improved neurological outcomes in patients with severe TBI.
- Secondary DC, performed as a treatment for either early or late refractory ICP elevation, is suggested to **reduce ICP and duration of intensive care**, though the relationship between these effects and favorable outcome is uncertain

MEDTHODS OF DECOMPRESSIVE CRANIECTOMY





Ji Won Moon and Dong Keun Hyun. Decompressive Craniectomy in Traumatic Brain Injury: A Review Article. Korean J Neurotrauma. 2017 Apr;13(1):1-8

EARLY vs LATE DC in TBI

Table 2. Primary and secondary end-point outcomes according to the timing of decompressive craniectomy.

Characteristics	Total	Early DC	Late DC	p
Mortality-30 days	21 (9.8)	17 (10.8)	4 (8.7)	0.39
GCS at discharge				
Median	15	15	15	
Range (IQR)	3–15	3–15	3–15	
<8	32 (11.2)	28 (17.7)	4 (8.7)	0.21
≥9	172 (84.3)	130 (82.2)	42 (91.3)	
Length of hospital stay (days), median (range)	23 (2–44)	21 (2–40)	28 (2–44)	0.20
EDH alone	7 (2–15)	6 (2–14)	8 (2–15)	0.24
EDH ± DAI/contusion	21 (5–34)	20 (5–32)	23 (5–34)	0.21
SDH alone	10 (3–17)	10 (3–14)	9 (3–17)	0.19
SDH ± DAI/contusions	23 (5–39)	21 (5–35)	24 (7–39)	0.20
Parenchymal hemorrhage	27 (10–41)	25 (10–38)	28 (15–41)	0.14
DAI/contusions	27 (11–44)	27 (15–41)	30 (11–44)	0.15
GOSE-60 days				
Median	7	7	6	
Range (IQR)	1–8	1–8	1–8	
Poor outcome (1–4)	54 (26.4)	41 (25.9)	13 (28.3)	0.75
Good outcome (5–8)	150 (73.5)	117 (74.1)	33 (71.7)	

DC: Decompressive Craniectomy; GCS: Glasgow Coma Scale; GOSE: Glasgow Outcome Scale Extended; IQR: Interquartile range.
p-value: Pearson Chi-square test.

Nida Fatima et al. Early versus late decompressive craniectomy in traumatic brain injury: A retrospective comparative case study. Trauma 2021, Vol. 23(2) 127–132

EARLY vs LATE DC in TBI

Table 3. Parameters predicting outcome (GOSE-60 days) in decompressive craniectomy according to uni- and multi-regression analysis adjusted for time since surgery.

Variables	Univariate OR (95% CI; p-value)	Multi regression adjusted for time, age, sex		
		OR	p-value	95% CI
Age (<35 /≥35 years)	1.4 (0.66–3.17; 0.35)	–	–	–
Sex (male/female)	0.87 (0.14–5.37; 0.88)	–	–	–
GCS at admission (<9/≥9)	0.07 (0.32–0.18; < 0.05)	0.07	<0.05*	0.03–0.16
Mechanism of injury	0.99	–	–	–
Type of DC (HC/BF)	0.99	–	–	–
Indication for DC (EDH alone/others)	3.8 (1.3–11.1; 0.01)	1.75	0.02*	1.09–3.25
Location of mass lesion	13.2 (0.6–261; 0.09)	–	–	–
Type of trauma	1.4 (0.62–3.40; 0.38)			

Note: indicates that the value could not be calculated due to insignificant p-value in univariate analysis. *Indicates significant values.
BF: Bi frontal decompressive craniectomy; DC: decompressive craniectomy; EDH: extradural hematoma; GOSE: Glasgow Outcome Scale Extended; HC: hemicraniectomy.

Nida Fatima et al. Early versus late decompressive craniectomy in traumatic brain injury: A retrospective comparative case study. Trauma 2021, Vol. 23(2) 127–132

EARLY DECOMPRESSION FOR SEVERE TBI

- Within 4 hours
- 127 cases

TABLE 3. Postoperative clinical outcomes according to various predisposing factors

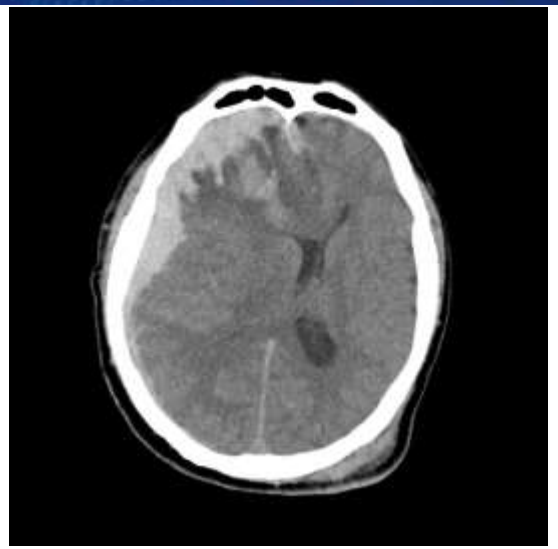
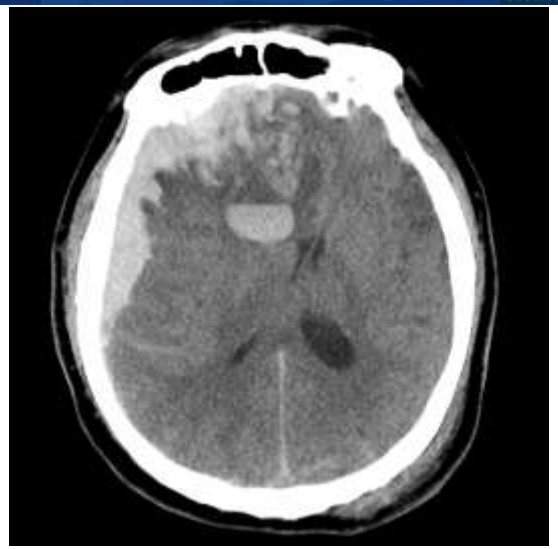
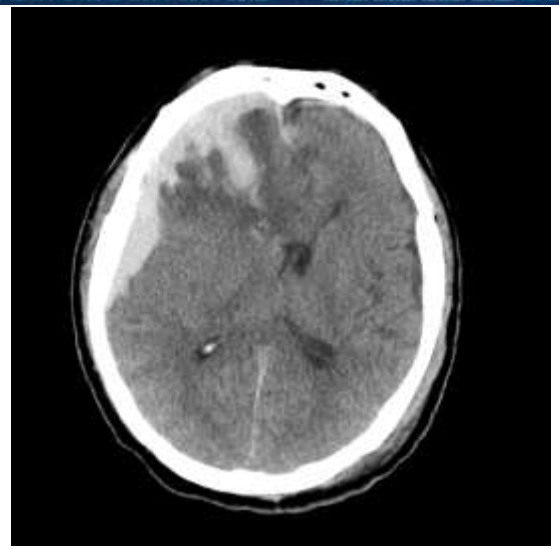
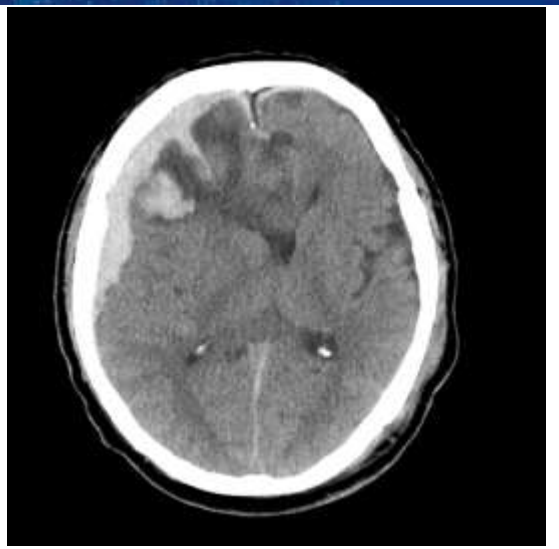
Parameters	No. of patients	Expire (%)	Unfavorable outcome (%)	Favorable outcome (%)	p value
Age					0.001
<29	21	8 (38.2)	12 (57.1)	1 (4.7)	
30–49	43	27 (62.8)	12 (27.9)	4 (9.3)	
>50	63	52 (82.5)	10 (15.9)	1 (1.6)	
Sex					0.687
Male	97	65 (67.0)	27 (27.8)	5 (5.2)	
Female	30	22 (73.3)	7 (23.3)	1 (3.4)	
Injury mechanisms					0.544
Motor vehicle	27	19 (70.4)	8 (29.6)	0 (0)	
Driver TA	14	9 (64.3)	3 (21.4)	2 (14.3)	
Pedestrian TA	28	21 (75)	6 (21.4)	1 (3.6)	
Fall down	20	15 (75)	3 (15)	2 (10)	
Slip down	23	15 (65.3)	7 (30.4)	1 (4.3)	
Rolling down	13	8 (61.5)	5 (38.5)	0 (0)	
Assault	2	0 (0)	2 (100)	0 (0)	
GCS					<0.001
3	27	27 (100)	0 (0)	0 (0)	
4–5	45	37 (82.2)	8 (17.8)	0 (0)	
6–8	55	23 (41.8)	26 (47.3)	6 (10.9)	
Marshall classification					0.42
2	15	9 (60)	5 (33.3)	1 (6.7)	
3	27	24 (88.9)	2 (7.4)	1 (3.7)	
4	85	54 (63.5)	27 (31.8)	4 (4.7)	
Midline shift					0.912
<10 mm	72	52 (72.3)	15 (20.8)	5 (6.9)	
10–20 mm	45	28 (62.2)	16 (35.6)	1 (2.2)	
>20 mm	10	7 (70)	3 (30)	0 (0)	
Time to op					0.43
<4 hrs	60	39 (65.0)	19 (31.7)	2 (3.3)	
>4 hrs	67	48 (71.6)	15 (22.4)	4 (6.0)	

GCS: Glasgow coma scale, TA: traffic accident

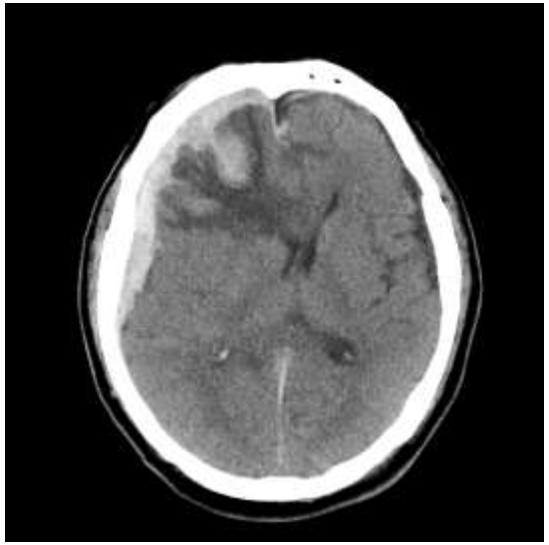
Jun-Hee Park et al. Outcomes of Ultra-Early Decompressive Craniectomy after Severe Traumatic Brain Injury-Treatment Outcomes. Korean J Neurotrauma 2014;10(2):112-118 after Severe TBI

CASE

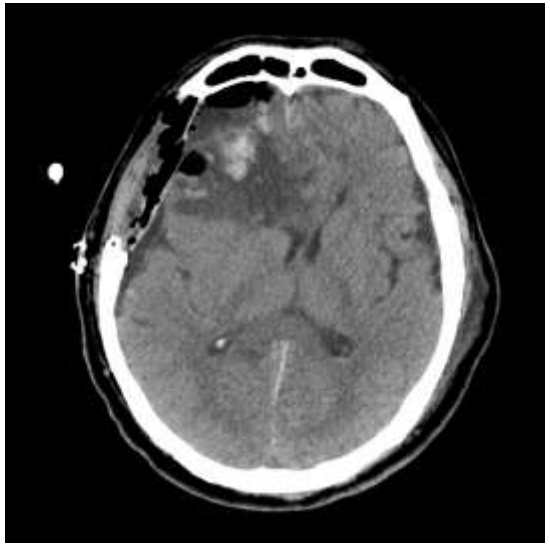
Barbiturate Coma
Hypothermia

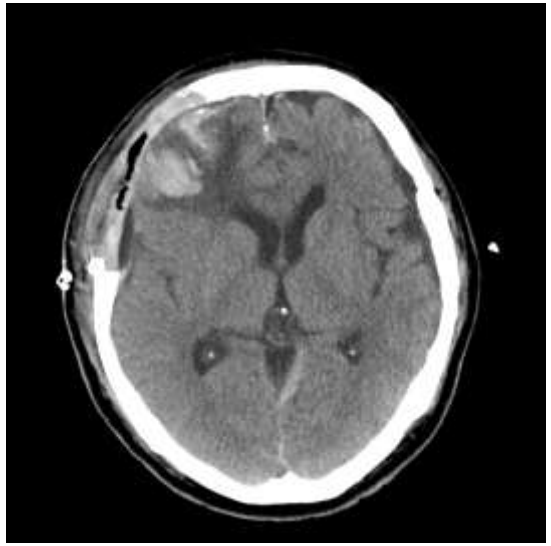
F/U CT (HOD2)



F/U CT (HOD6)

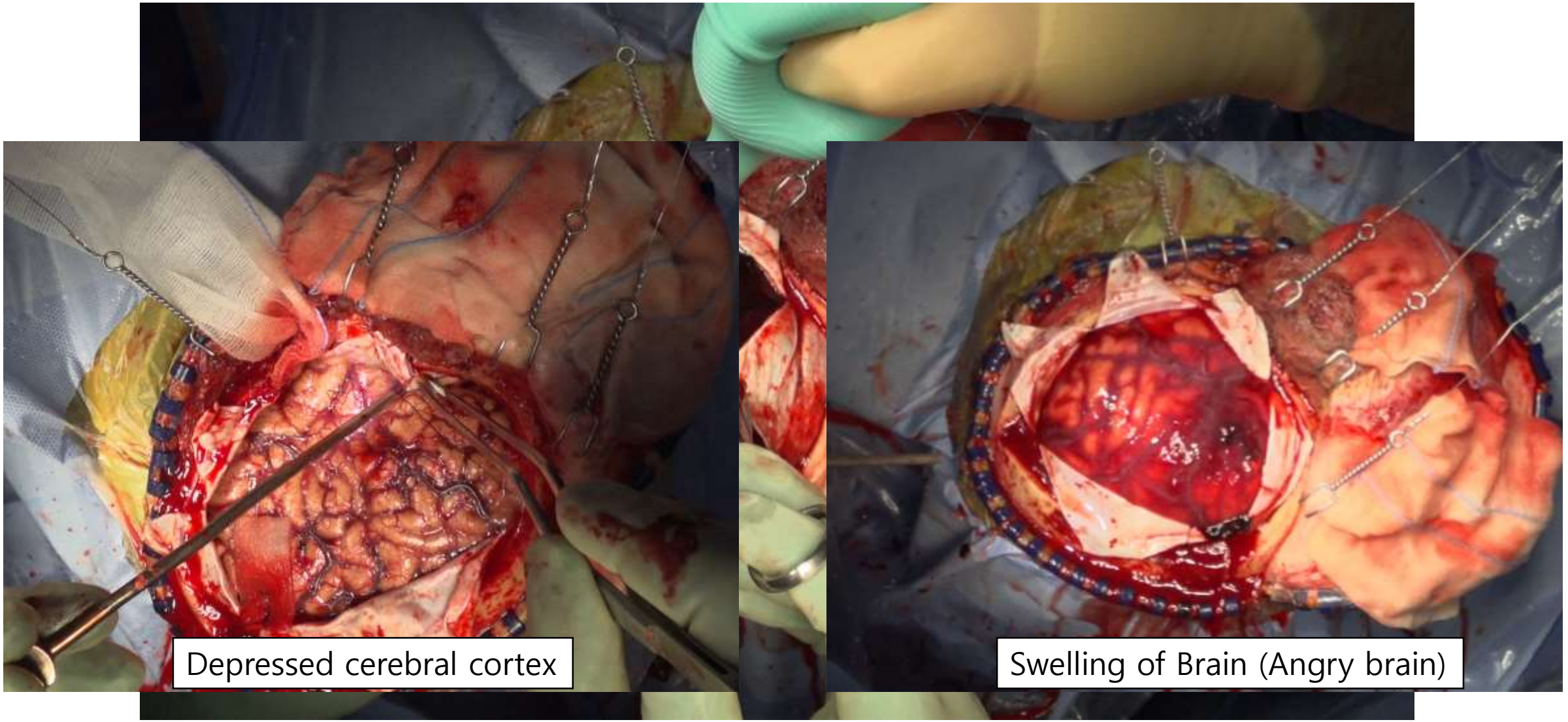


Postop CT (HOD6)



F/U CT (HOD9)

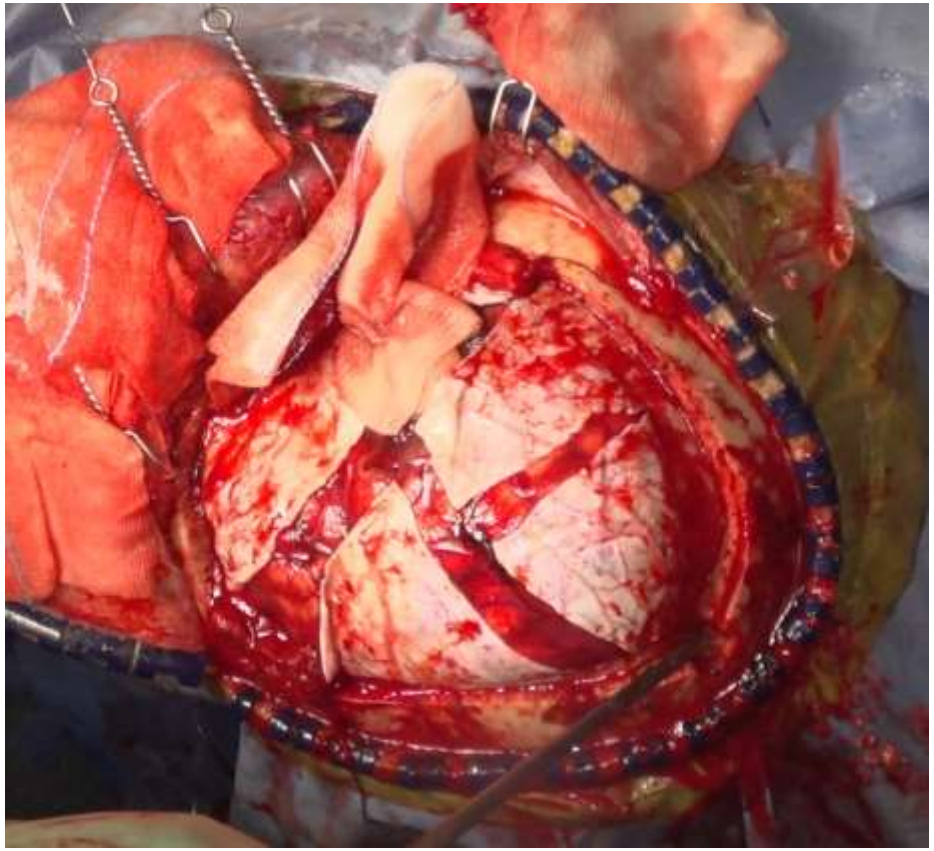
INTRAOPERATIVE SCENE

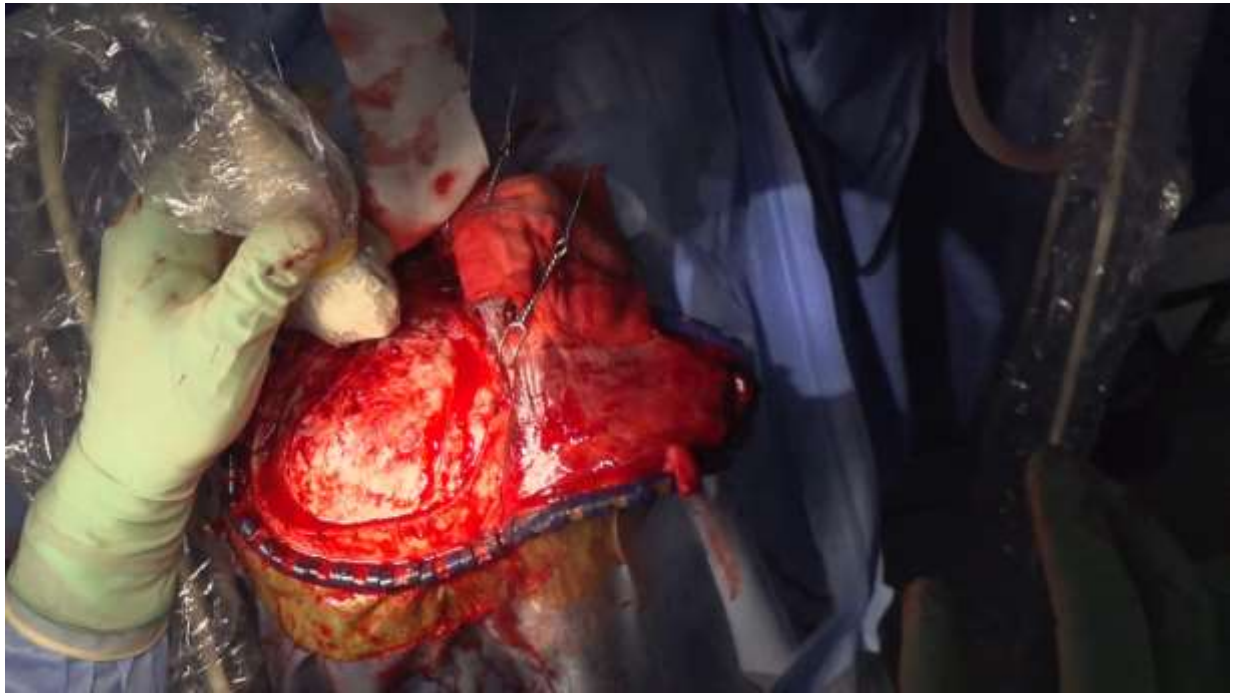


Depressed cerebral cortex

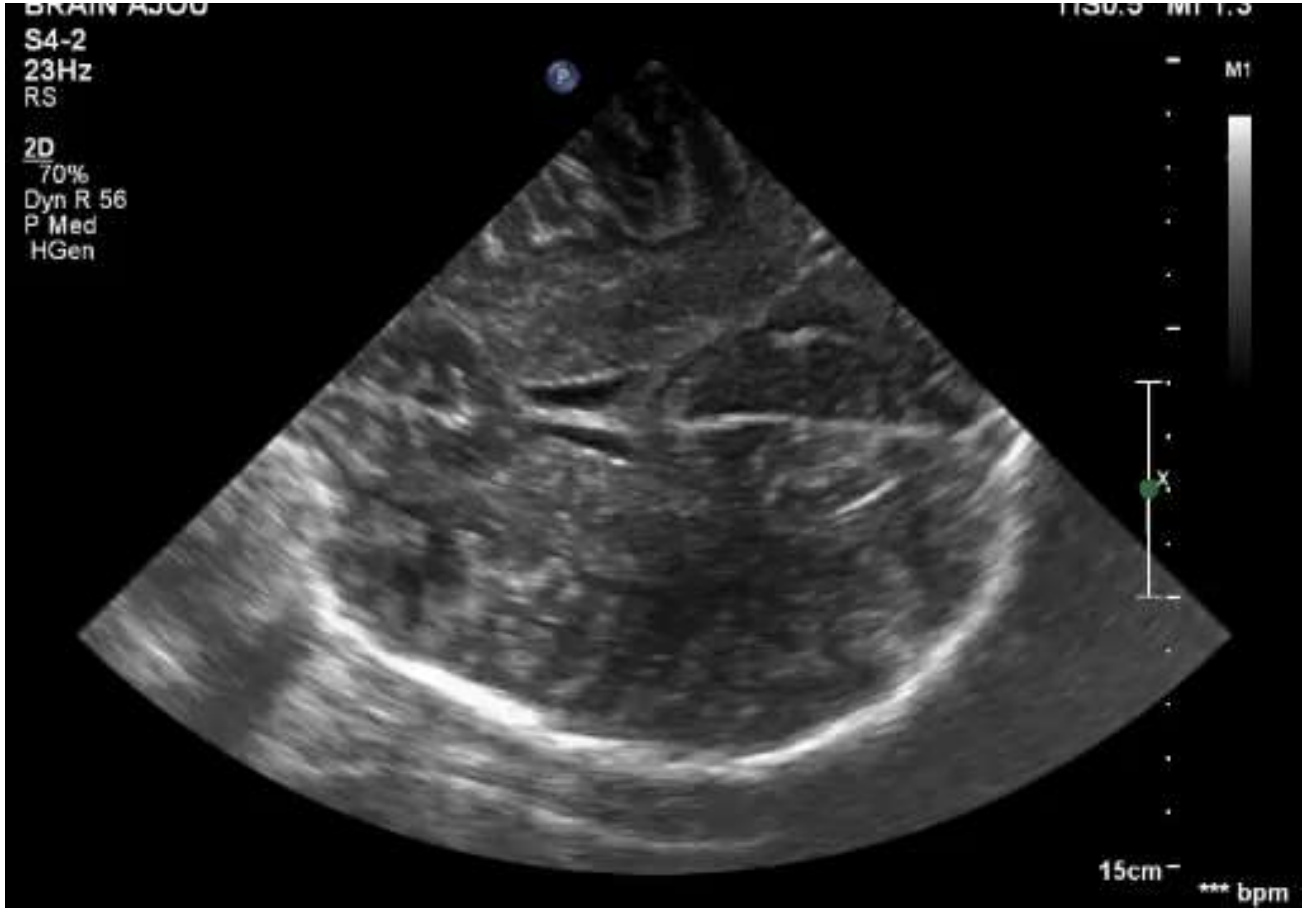
Swelling of Brain (Angry brain)

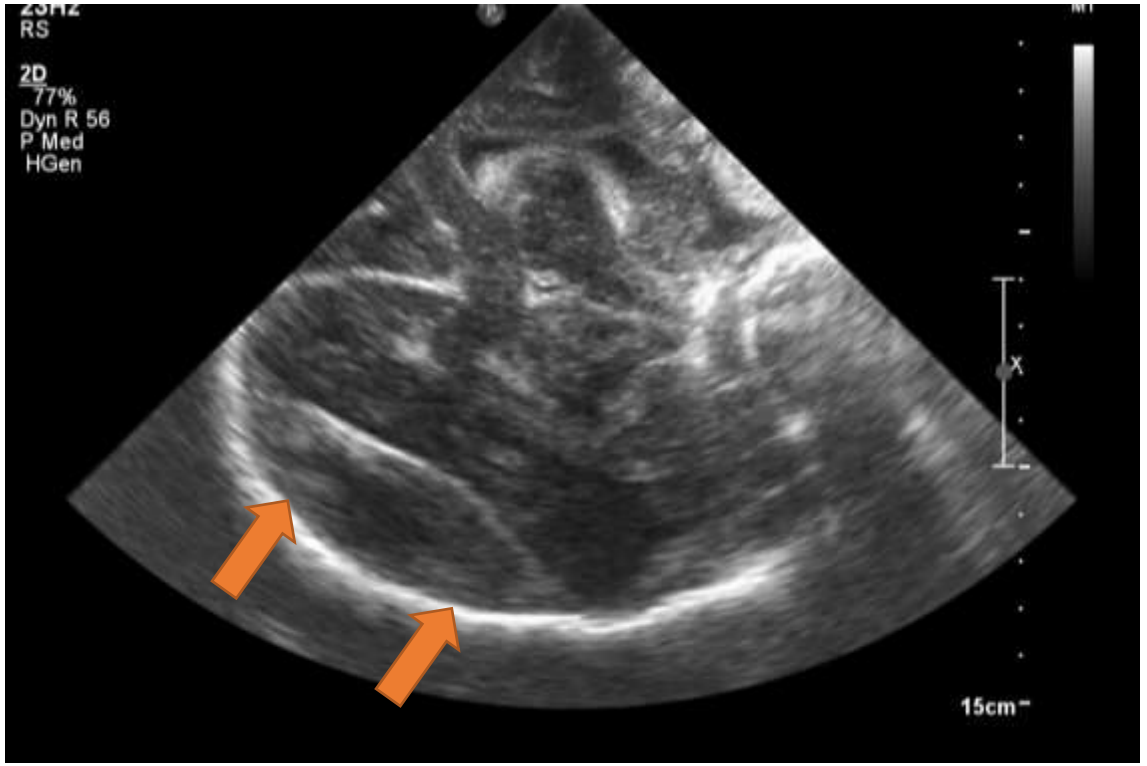
INTRAOPERATIVE ULTRASOUND SCAN





INTRAOPERATIVE ULTRASOUND SCAN





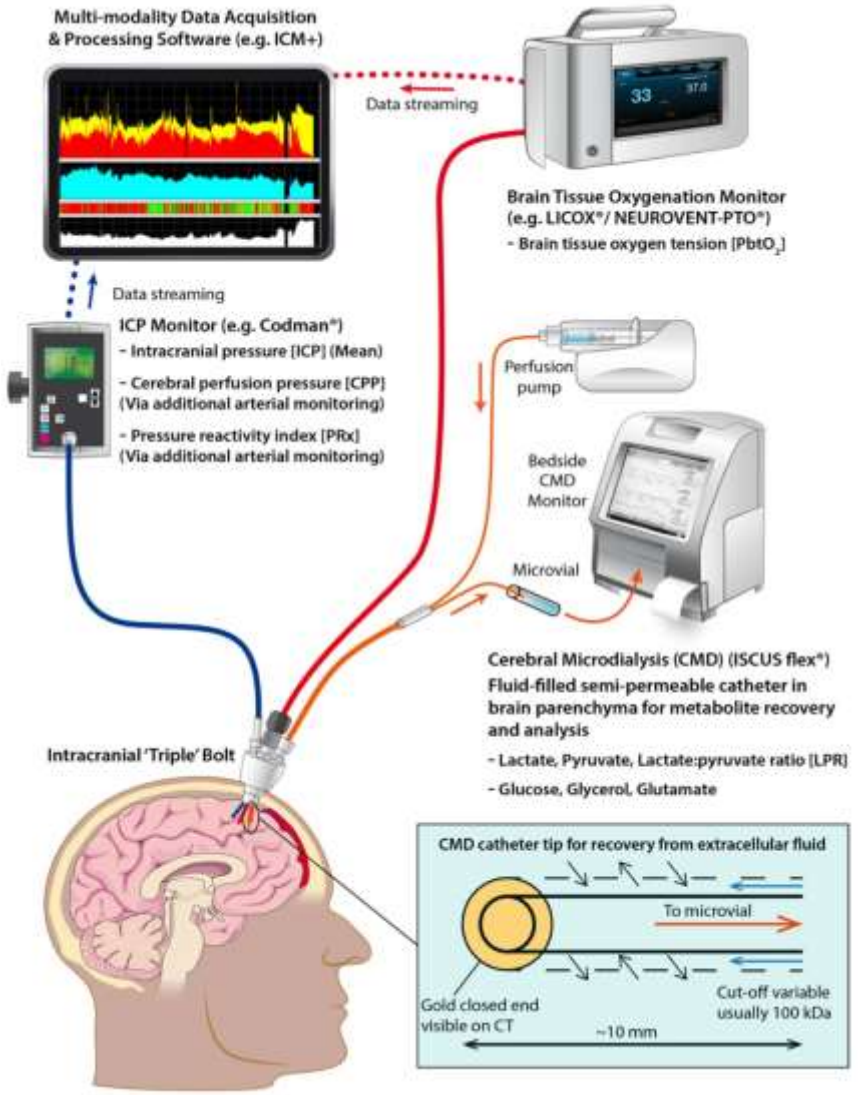
MONITORING

MONITORING

- ICP monitoring
  - Management of severe TBI patients using information from ICP monitoring is recommended to reduce in-hospital and 2-week post-injury mortality. (Level II B)
- CPP monitoring
  - Management of severe TBI patients using guidelines-based recommendations for CPP monitoring is recommended to decrease 2-week mortality (Level II B)
- ADVANCED monitoring
  - **Jugular bulb monitoring** of arteriovenous oxygen content difference (AVDO2), as a source of information for management decisions, may be considered to reduce mortality and improve outcomes at 3 and 6 months post-injury. (Level III)

MULTIMODAL MONITORING

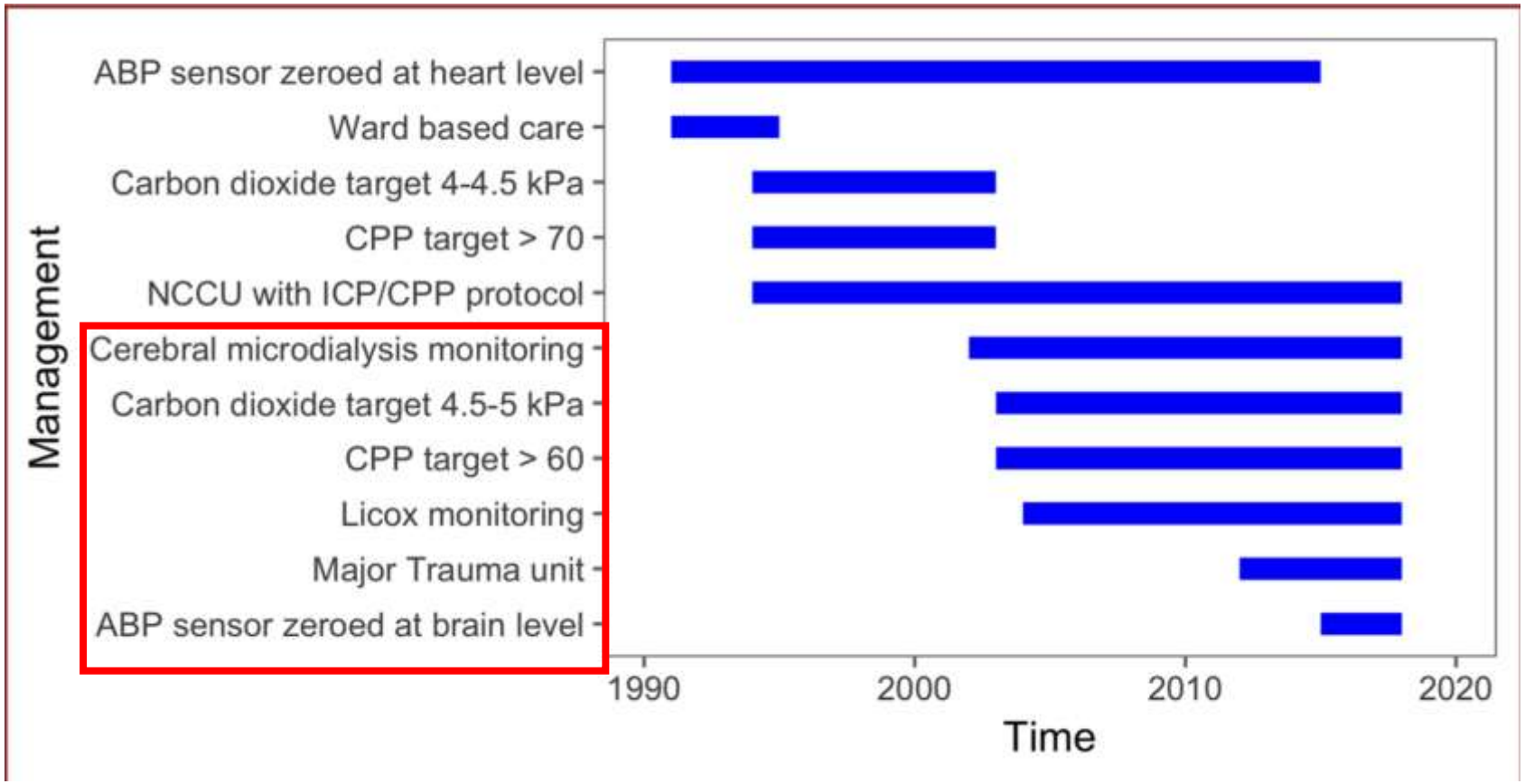
- ICP
- BRAIN TISSUE OXIGENATION
- NIRS
- VENOUS JUGULAR OXYGENATION
- MICRODIALYSIS
- TEMPERATURE
- PUPILOMETRY
- ULTRASOUND (ONSD, TCD)

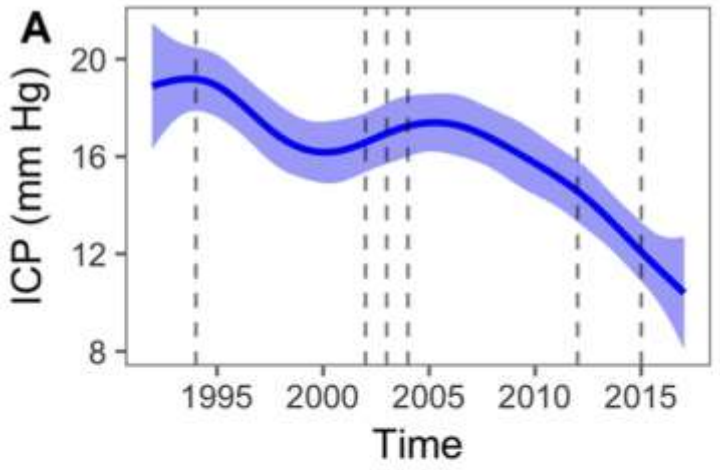


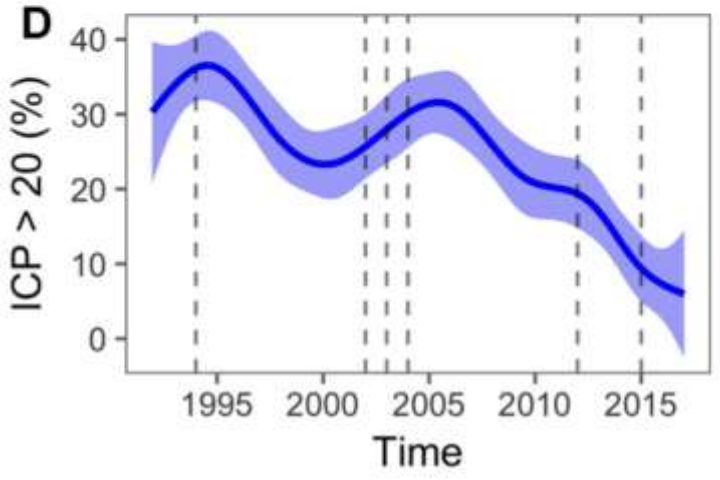
CNS Spotlight

Twenty-Five Years of Intracranial Pressure Monitoring After Severe Traumatic Brain Injury: A Retrospective, Single-Center Analysis

Joseph Donnelly, MBChB
Marek Czosnyka, PhD
Hadie Adams, MD
Danilo Cardim, PhD





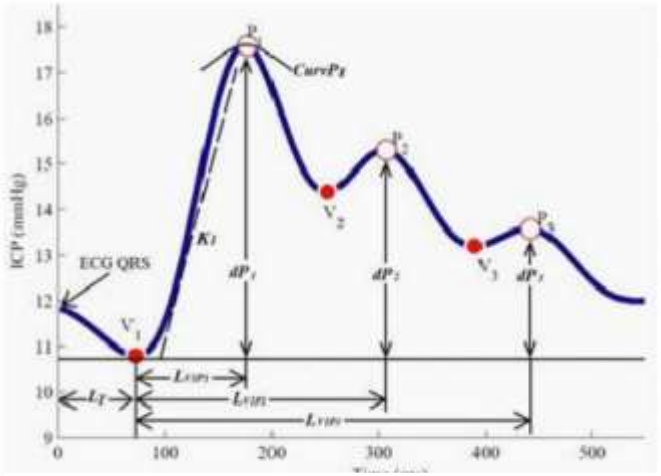


ICP MONITORING

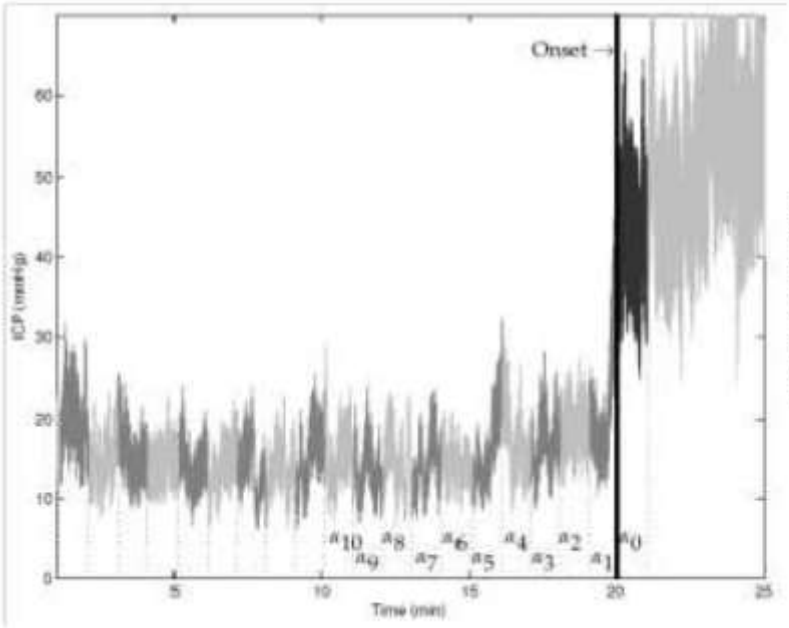
- MOST WIDELY USED
- MOST RELIABLE
- EASY TO APPLY
- CLASSIC MONITORING

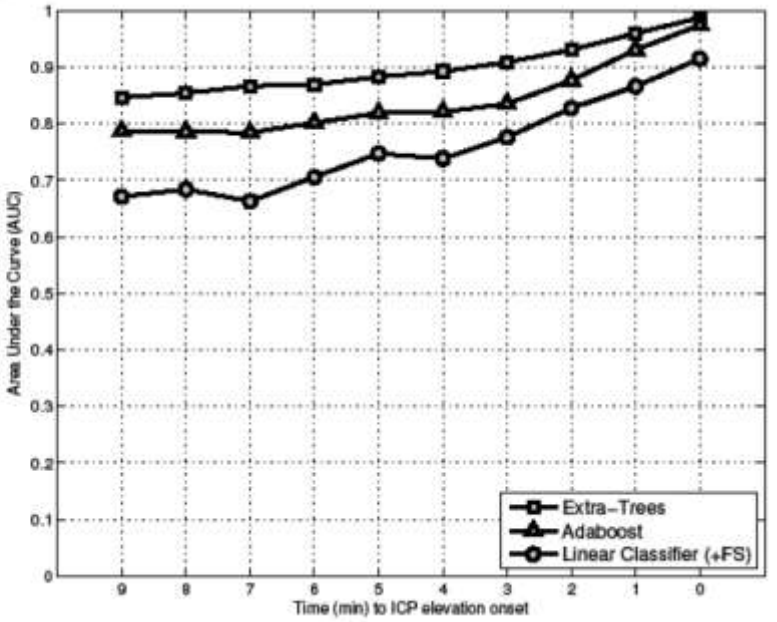
- INVASIVE
- INFECTION
- ZERO DRIFT
- SIDE (LOCATION)

ICP WAVE MORPHOLOGIC ANALYSIS



28 Basic metrics extracted from individual landmarks or over all characteristics	
dV1, dV2, dV3, dP1, dP2, dP3	Amplitude of landmark relative to the minimum point prior to initial rise
L_{V1P1}, L_{V1P2}, L_{V1P3}, L_{V2P2}, L_{V3P3}	Time delay among landmarks
$Curv_{v1}$, $Curv_{v2}$, $Curv_{v3}$, $Curv_{p1}$, $Curv_{p2}$, $Curv_{p3}$	Absolute curvature of each landmark
K1, K2, K3, RC1, RC2, RC3	K1, K2, K3 are slope of each rising edge and RC1, RC2, RC3 are time-constants of each descending edge
mICP, diasICP	Mean ICP and diastolic ICP
L_T	Time delay of V_1 to ECG QRS peak
mCurv	Mean absolute curvature of the pulse
WaveAmp	Maximum among dP1–dP3
100 extended metrics calculated as ratios among metrics within each group	
$dP_{p1p2,...}$	Ratio among landmark amplitudes
$L_{V1P1}/L_{T,...}$	Ratio among time delays
$Curv_{v1}/Curv_{v2,...}$	Ratio among curvatures
$K_1/RC_{1,...}$	Ratio among slopes/RCs





Scalzo et al. Real-Time Analysis of Intracranial Pressure Waveform Morphology. Advanced Topics in Neurological Disorders 2012.

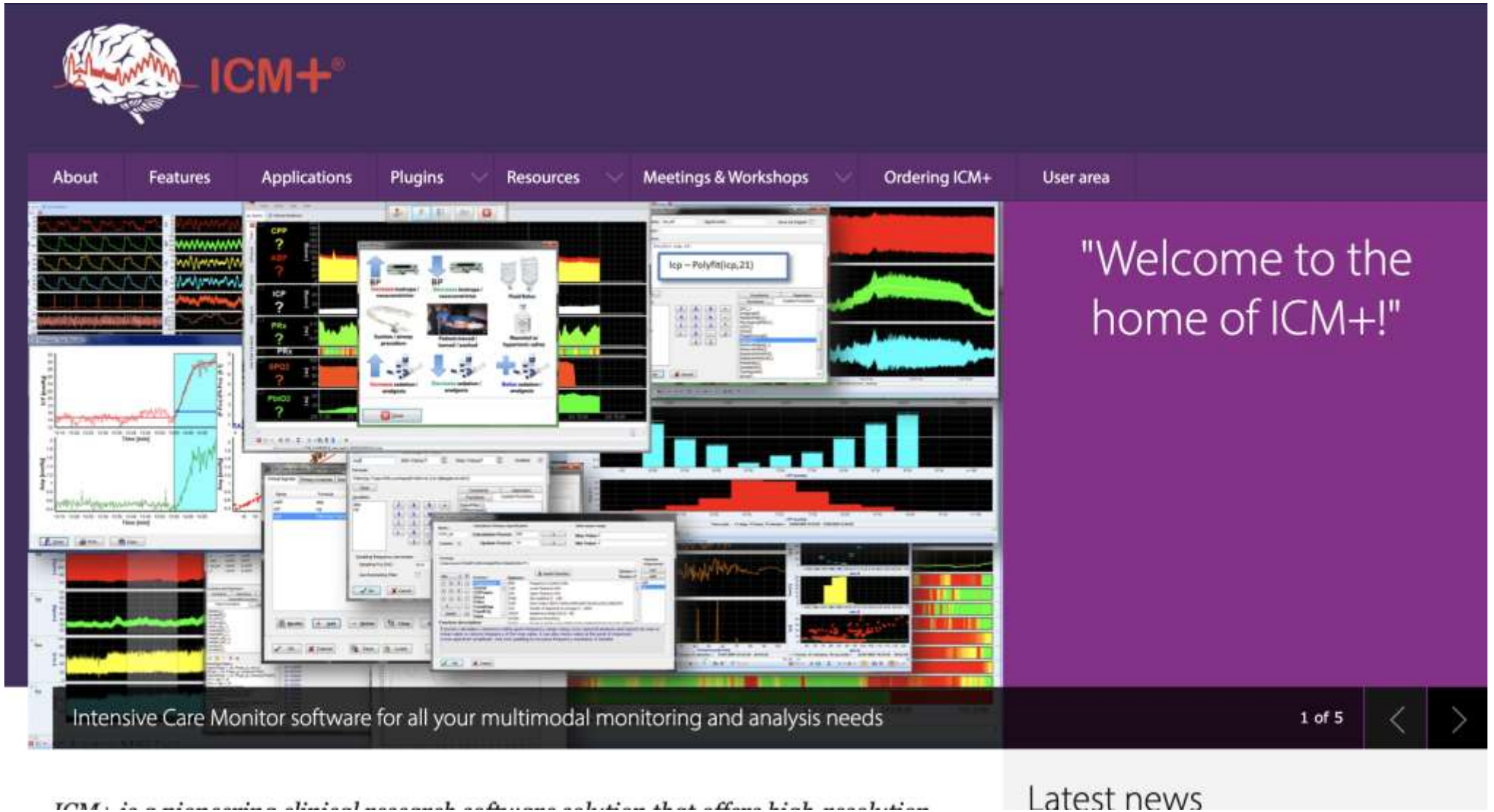

KIM YONG *
TICU B-6
Adult
TICU B-2
8 : 13
86
86
-0.01
0
0.77
100
(12)
18
(20)
69
133/ 70
(89)
7
127/ 84(95)
18
29
0
NIHON KOHDEN


CO2 Check Sensor
Adult
8 : 15
75
76
0.03
0
1.75
100
(6)
17
(19)
68
147/ 55(87)
156/ 76
(126)
NIHON KOHDEN

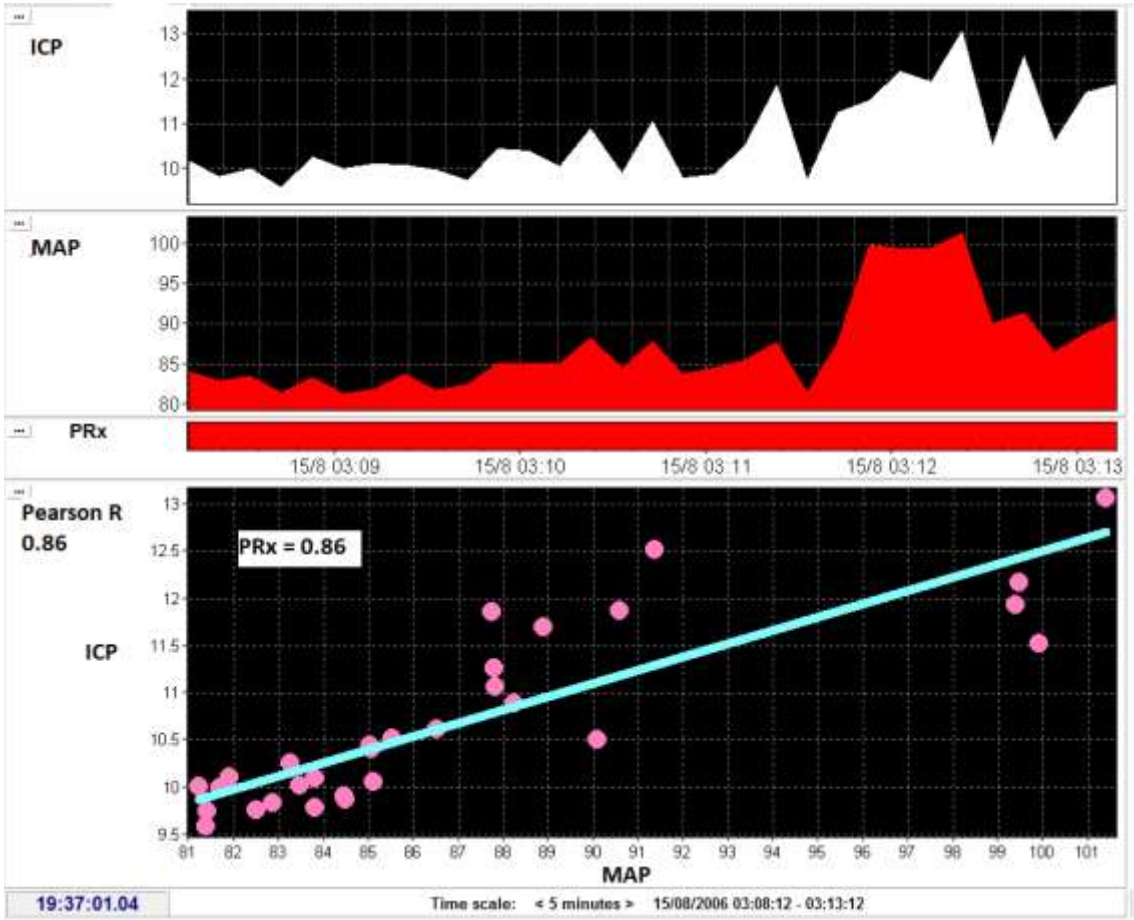
CEREBRAL PERFUSION PRESSURE

- CPP = MAP - ICP
- AUTOREGULATION
- CPP Targeted management
- Optimal CPP

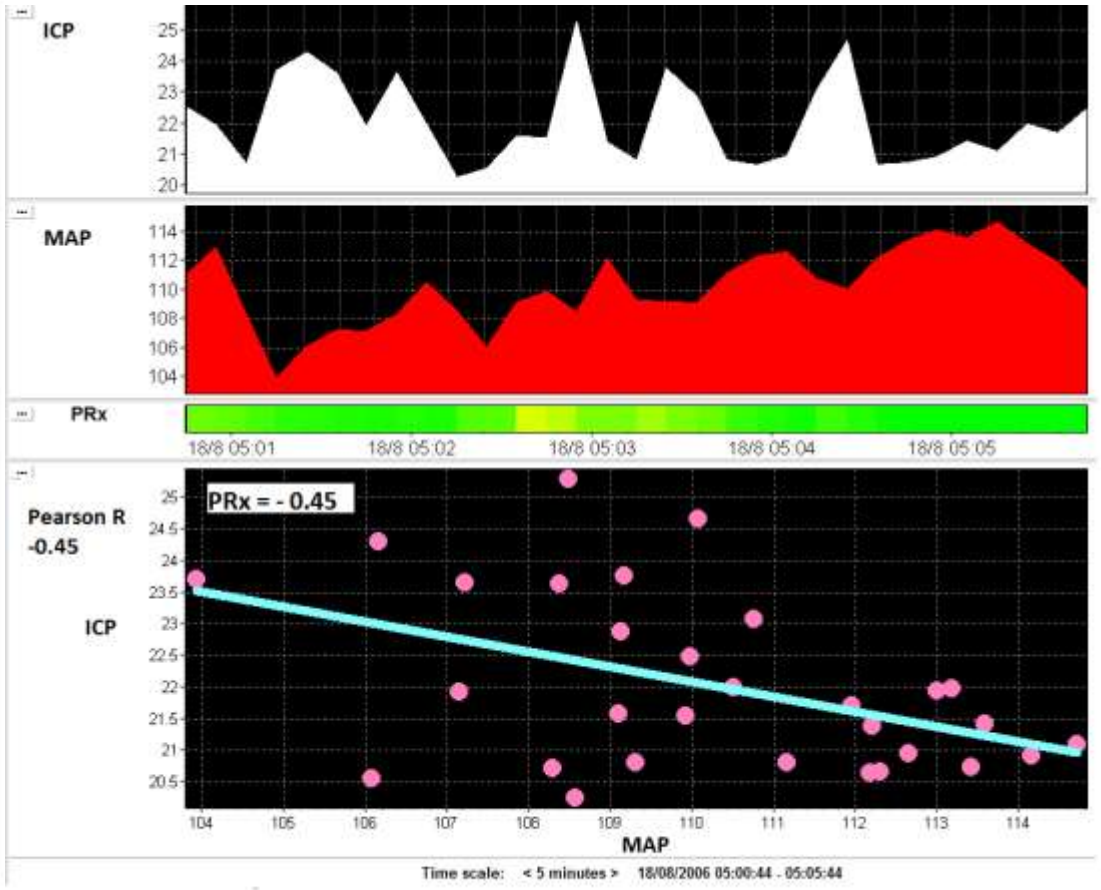
CEREBRAL PERFUSION PRESSURE



CEREBRAL PERFUSION PRESSURE
- pressure reactivitiy (PRx)

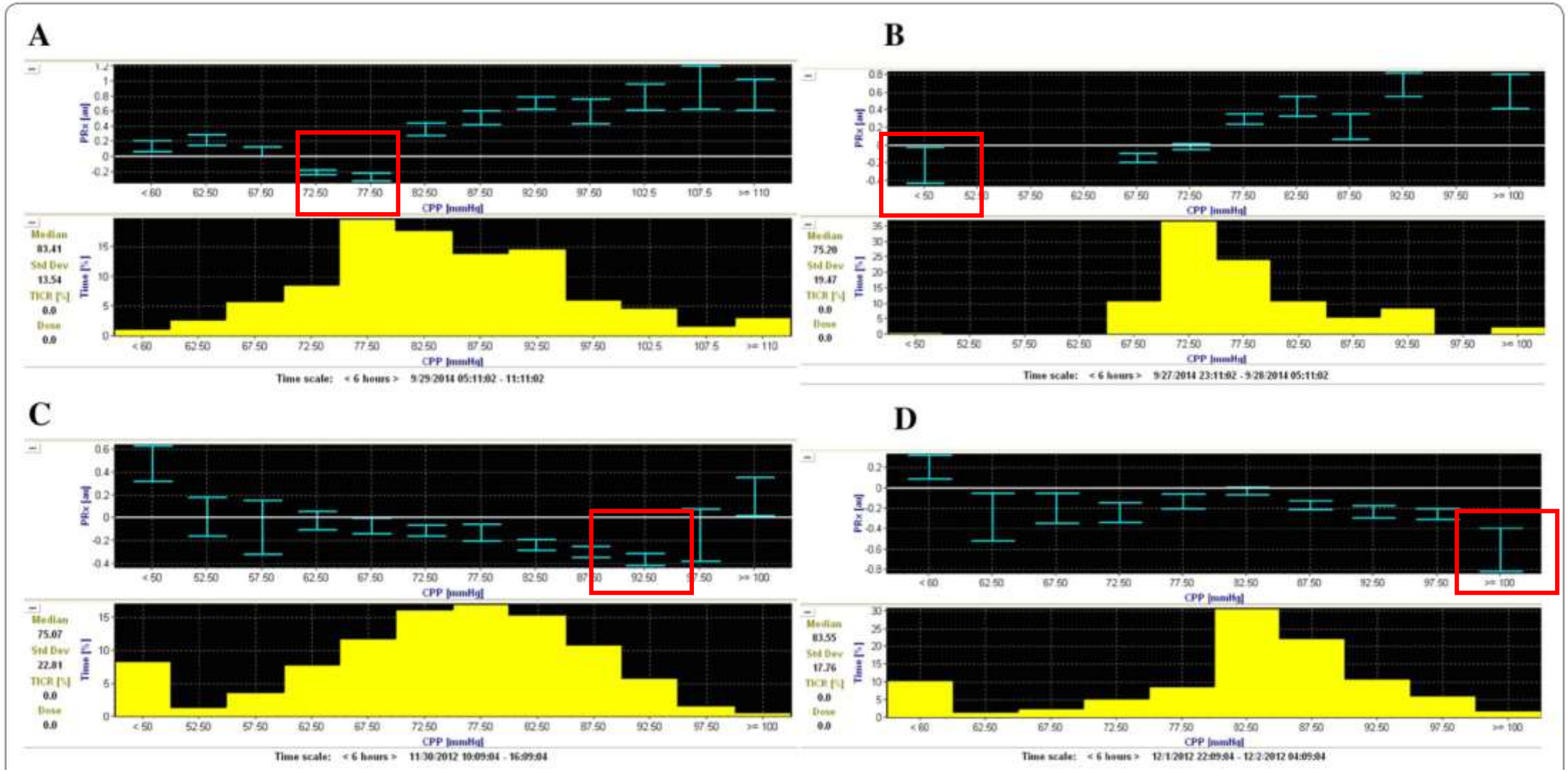


Poor pressure reactivity index after traumatic brain injury



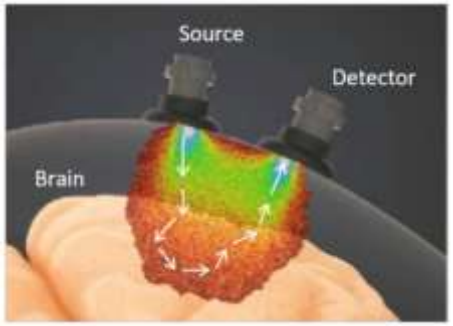
Good pressure reactivity after traumatic brain injury

CEREBRAL PERFUSION PRESSURE
Optimal CPP



Kramer et al. Continuous Assessment of “Optimal” Cerebral Perfusion Pressure in Traumatic Brain Injury: A Cohort Stud y of Feasibility, Reliability, and Relation to Outcome. Neurocrit Care (2019) 30:51–61

NEAR INFRARED SPECTROSCOPY



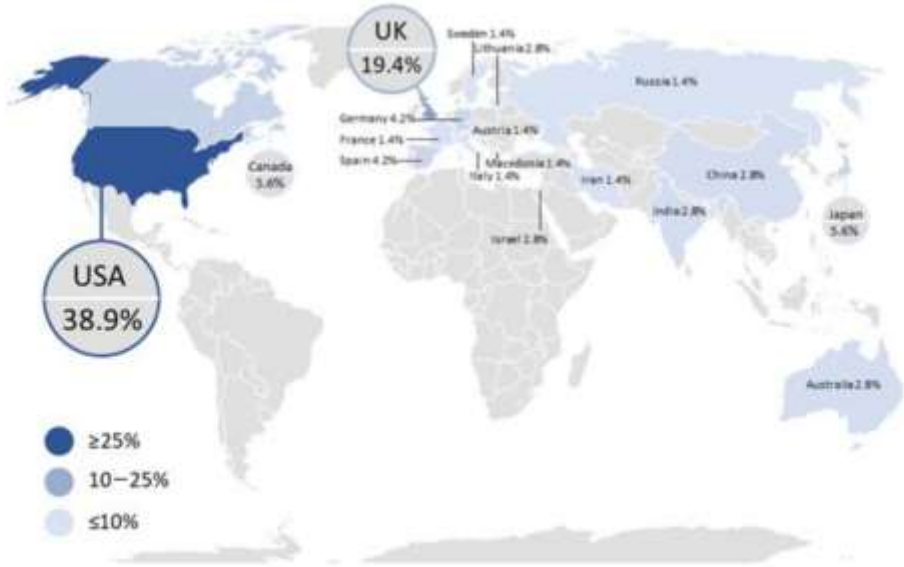
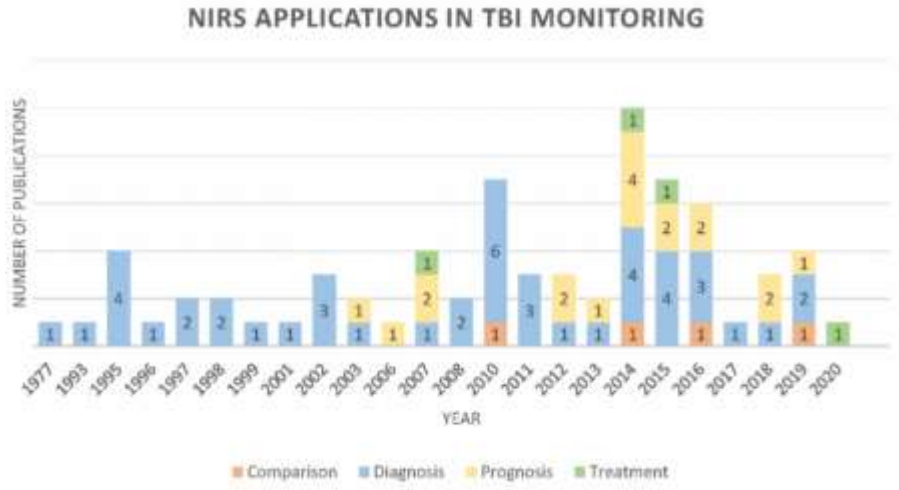


Figure 2. Global distribution of scientific articles that discussed the use of near-infrared spectroscopy (NIRS) technology in traumatic brain injury (TBI) monitoring until July 2020. The number of publications per country is indicated by the intensity of the color, with darker colors representing a higher number of articles than lighter colors.



Roldán et al. Near-Infrared Spectroscopy (NIRS) in Traumatic Brain Injury (TBI). Sensors2021, 21, 1586.

NEAR INFRARED SPECTROSCOPY

Mortality prediction

Correlation with
Other monitoring

(Zweifel et al., 2010) [93]	40 (31:9)	NIRO 200, Hamamatsu Photonics U.K. Ltd., Hertfordshire, UK. (SRS; S-D NR)	THx	PRx	THx showed a significant correlation with the validated volume reactivity index PRx.
(Shafer et al., 2010) [94]	22 (10:12)	INVOS 5100, Medtronic, MN, USA. (CW; S-D NR)	rSO_2	XeCT	The relationship between either the left or right NIRS values and Xe/CT scan was not significant.
(Diedler et al., 2011) [95]	37 (NR)	NIRO 200, Hamamatsu Photonics U.K. Ltd., Hertfordshire, UK. (SRS; S-D NR)	THx	PRx	The agreement between PRx and THx is a function of the power of slow oscillations in the input signals.
(Taussky et al., 2012) [96]	8 (2:6)	Bifrontal NIRS optodes, Casmed, Branford, CT, USA. (CW; S-D 4.5 cm)	rSO_2	CBF	CT perfusion CBF has a significant linear correlation with NIRS derived rSO_2.
(Kim et al., 2014) [97]	10 (7:3)	Inhouse, DCS and NIRS system, Noncommercial. (SRS; S-D 2.5 cm)	CBF, ΔHbO_2, ΔHb and ΔTHb in 10 TBI patients	CBF, ΔHbO_2, ΔHb and THb in 10 healthy controls	HbO2, Hb, and THb concentration increased significantly in the brain-injured cohort with head-of-bed lowering. Accordingly, DCS/NIRS hybrid device is well-suited to provide non- invasive, continuous hemodynamic monitoring.
(Highton et al., 2015) [98]	27 (13:14)	NIRO 100, Hamamatsu Photonics U.K. Ltd., Hertfordshire, UK. (SRS; S-D 4 cm)	THx, TOx	PRx, Mx	Significant agreement among PRx and THx, and between Mx and TOx. However, the strength of the interrelationship between ICP or TCD and NIRS signals, THI or rSo2, limits the degree of agreement between these reactivity indices.
(Bindra et al., 2015) [99]	19 (12:7)	ForeSight, Casmed, Connecticut, USA. (CW; S-D NR)	nTOx	iTOx	nTOx from Finometer photoplethysmography and NIRS gives a similar measurement of cerebrovascular autoregulation to iTOx.

NEAR INFRARED SPECTROSCOPY

대뇌피질산소포화도감시용 Sensor 급여기준

1. 전신마취시 사용하는 대뇌피질 산소포화도 감시용 Sensor는 뇌 허혈 손상 가능성이 높은 다음의 수술에 요양급여를 인정함.

- 다 음 -

가. 심폐우회로를 이용한 심장수술
나. 심폐우회로를 이용한 대동맥수술
다. 복잡심기형수술 및 관상동맥우회수술
라. 경동맥수술(중재적 시술 포함)

2. 상기 1항의 급여 대상 이외 의학적 필요성이 인정되는 아래의 적응증에 한하여 사용한 치료재료비용은 「요양급여비용의 100분의 100미만의 범위에서 본인부담률을 달리 적용하는 항목 및 부담률의 결정 등에 관한 기준」에 따라 본인부담률을 80%로 적용함.

가. 상기 1에서 정하고 있는 급여범위 이외의 심장수술
나. 뇌수술 또는 뇌혈관의 중재적 시술
다. 간이식 수술
라. 만 70세 이상의 노인환자에서 3시간 이상의 개복술을 시행하는 경우

(고시 제2016-147호, '16.9.1. 시행)

- Non-invasive. Easy to apply
- Not represent whole brain oxygenation
- Cost, Continuous monitoring

BRAIN TISSUE OXYGENATION

- Measures the amount of Oxygen reaching the brain tissue
  - Partial pressure of brain Tissue Oxygenation($P_{bt}O_2$)
  - Normal $P_{bt}O_2$: 25~35mmHg

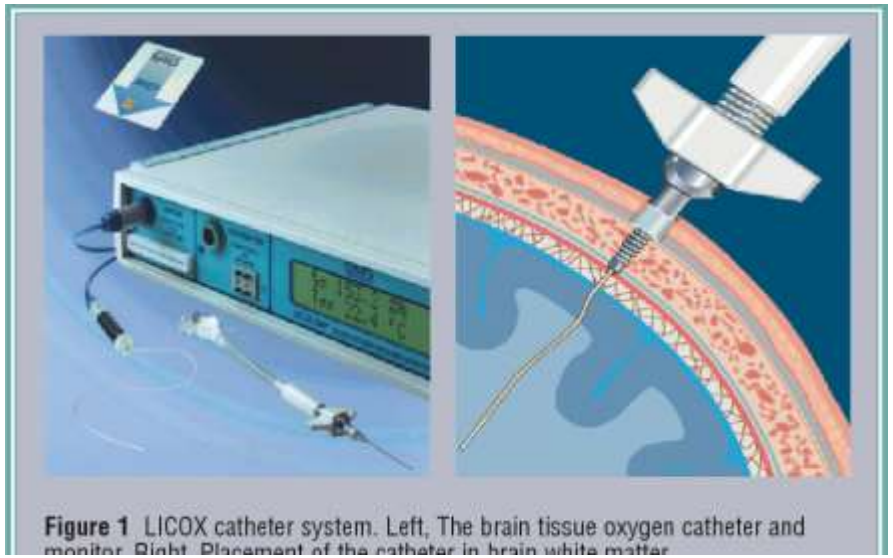
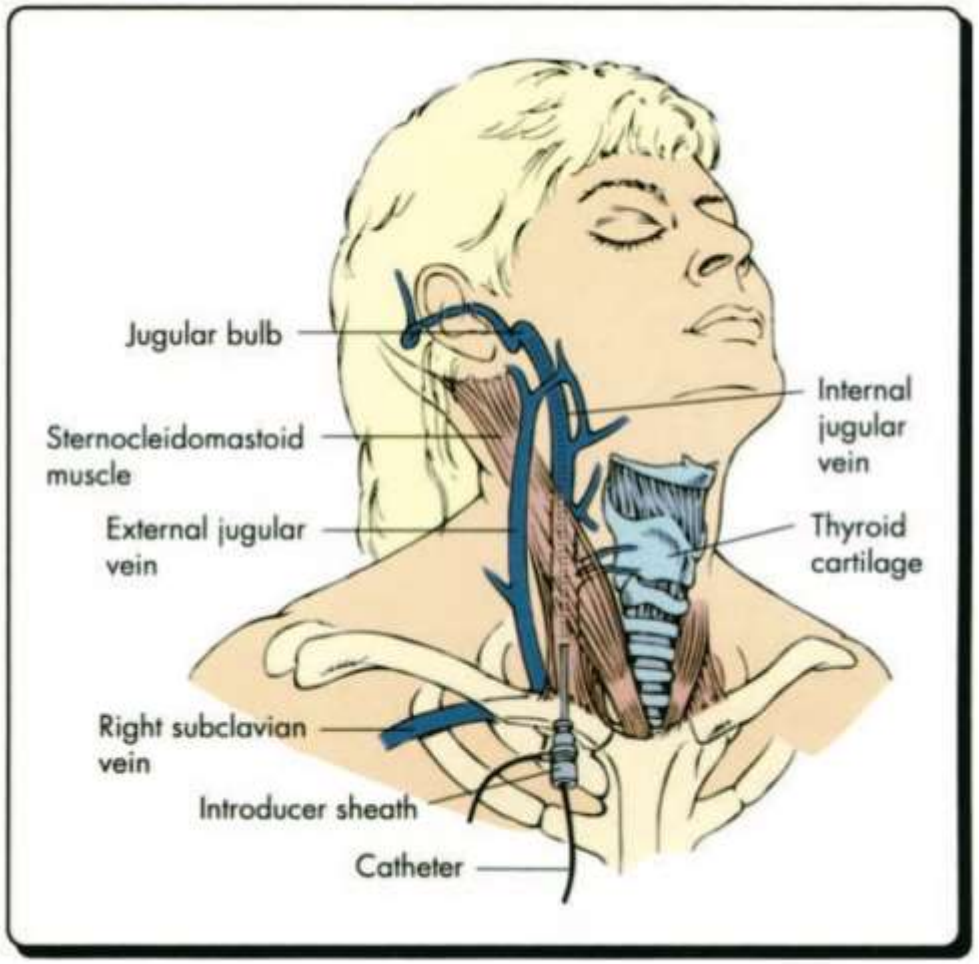
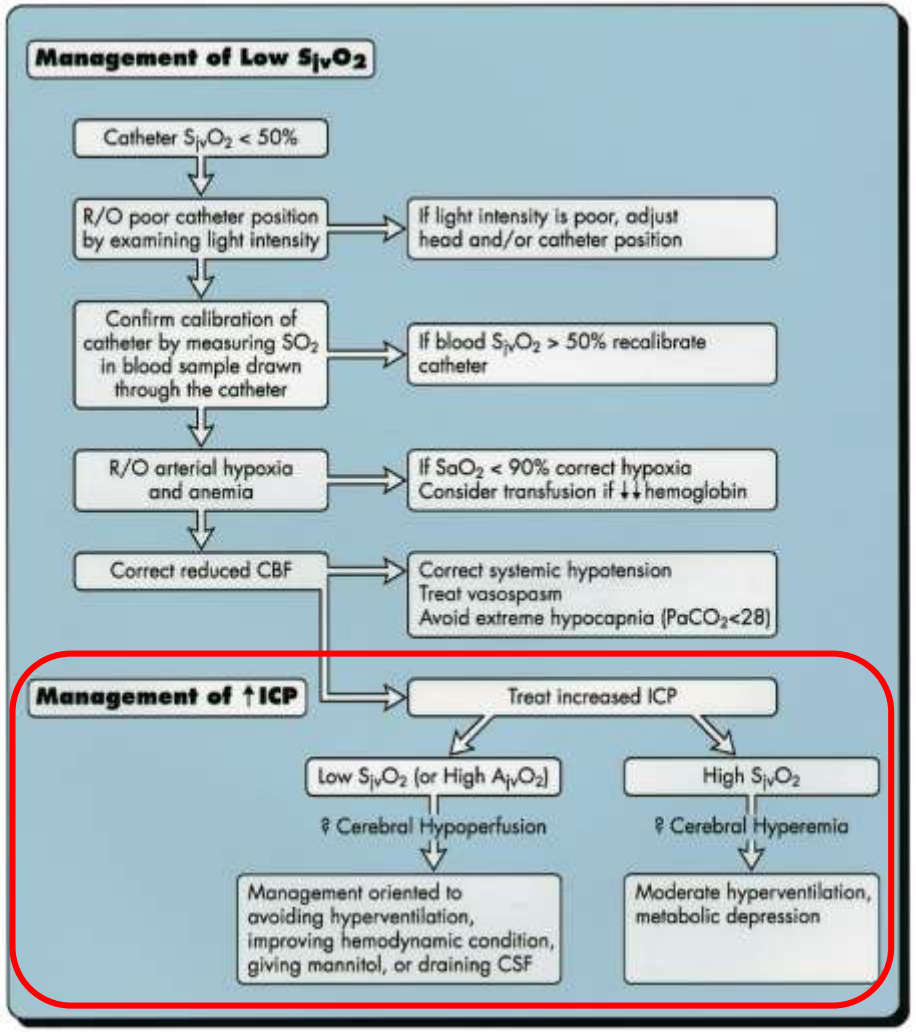


Figure 1 LICOX catheter system. Left, The brain tissue oxygen catheter and monitor. Right, Placement of the catheter in brain white matter.

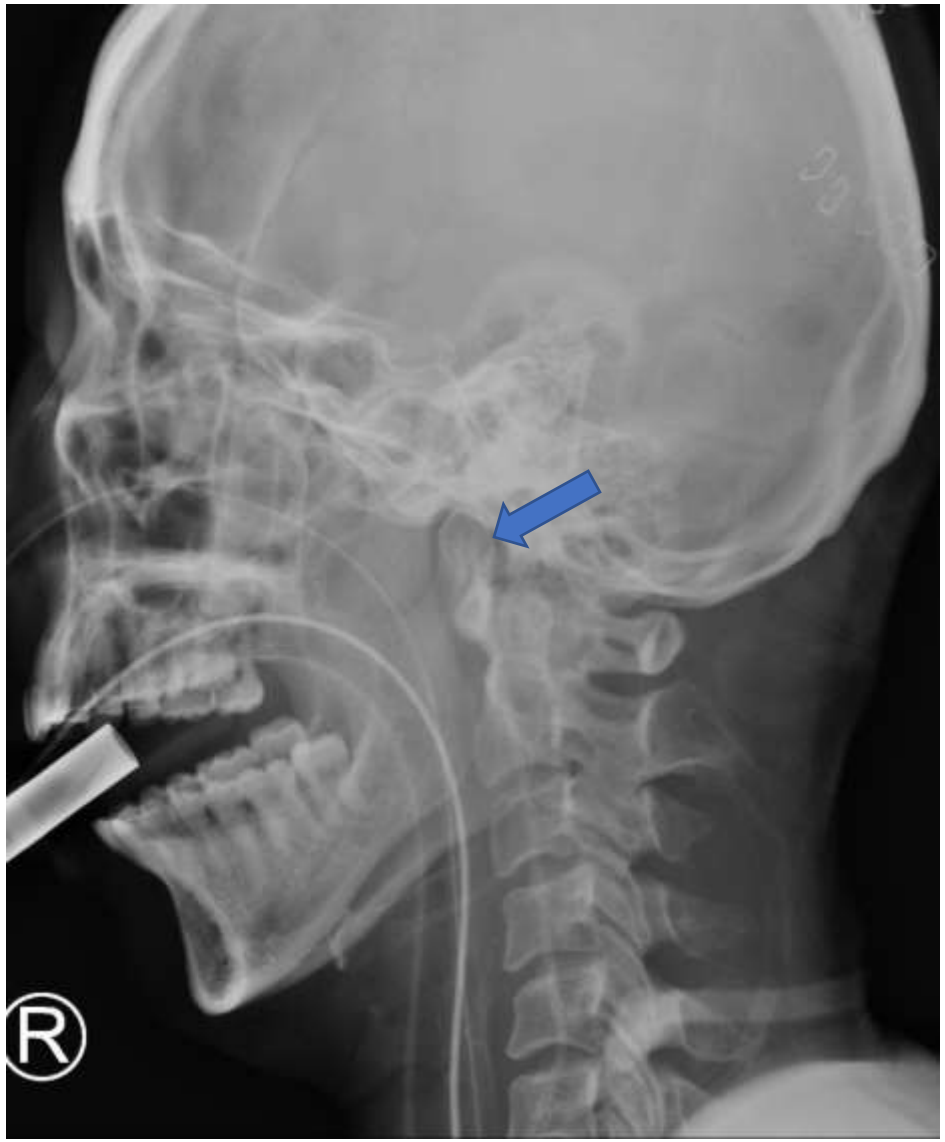
- Continuous, real time measurement

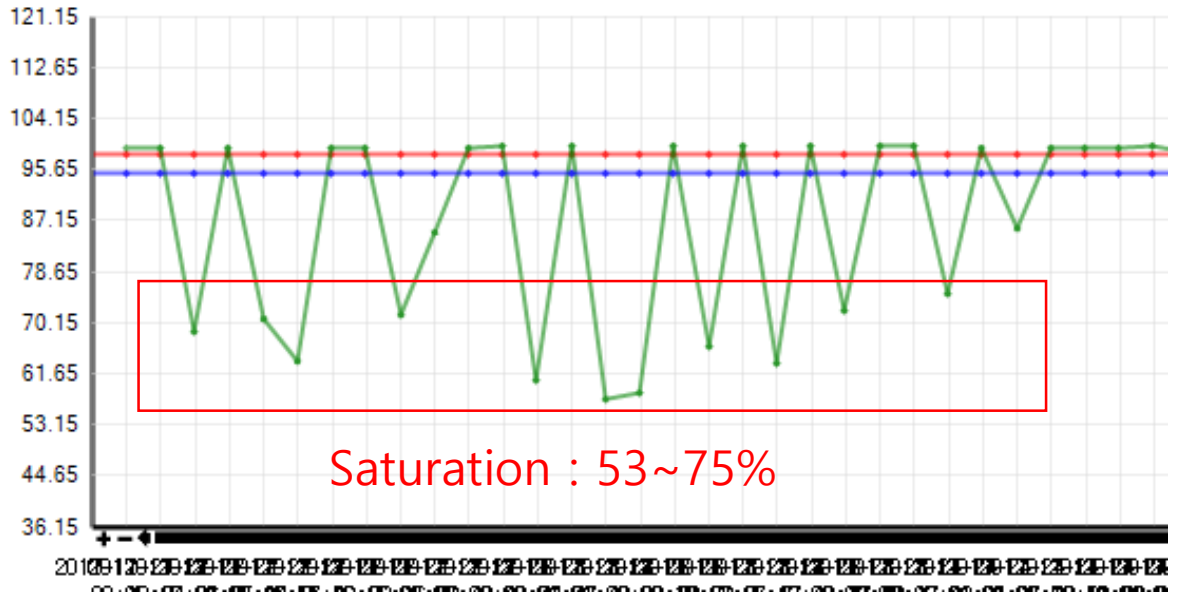
JUGULAR VENOUS OXYGENATION



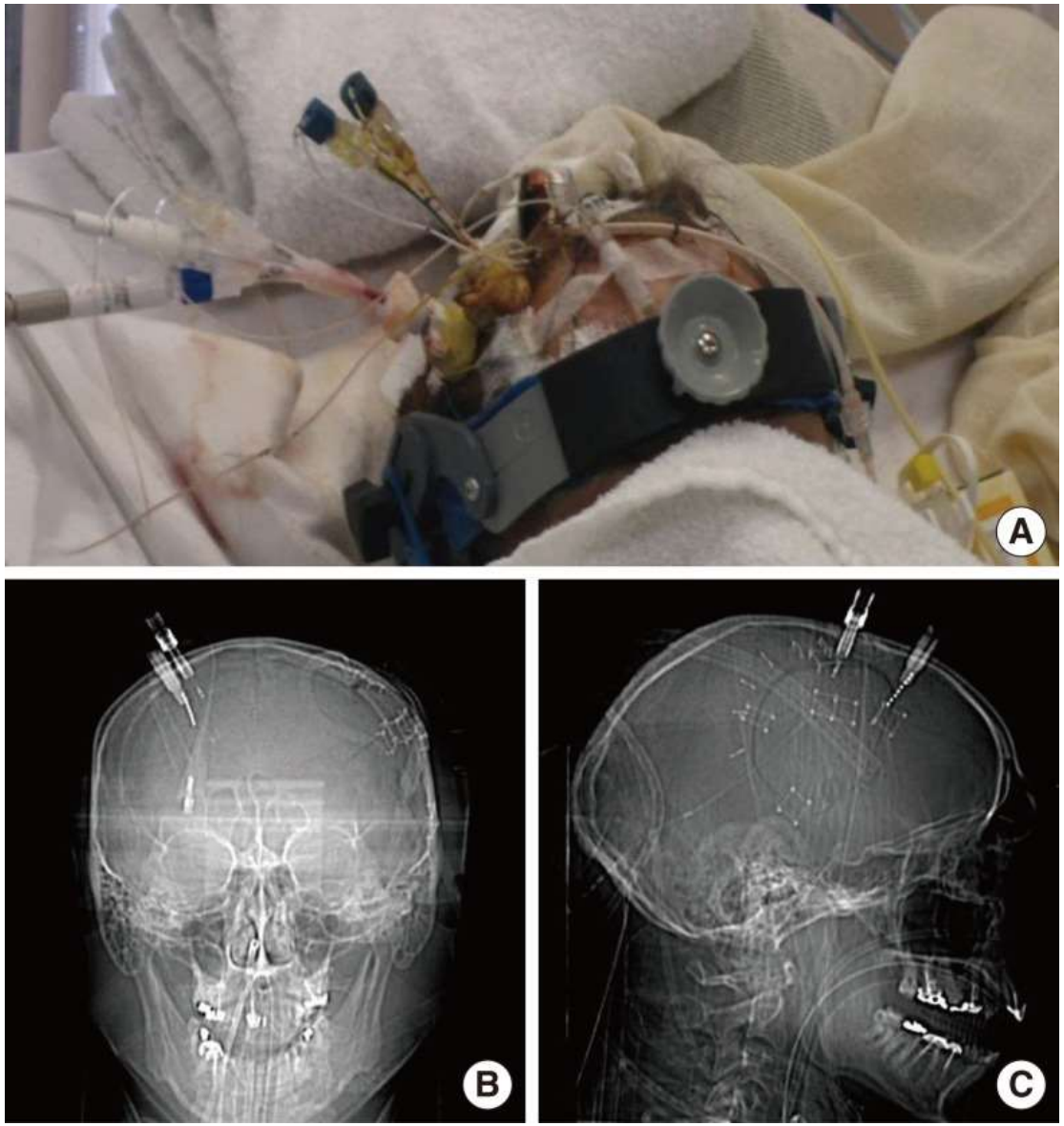


JUGULAR VENOUS OXYGENATION





INVASIVE CATHETERS in MULTIMODAL MONITORING…



SMART CATHETER FOR MULTIPMODAL MONITORING

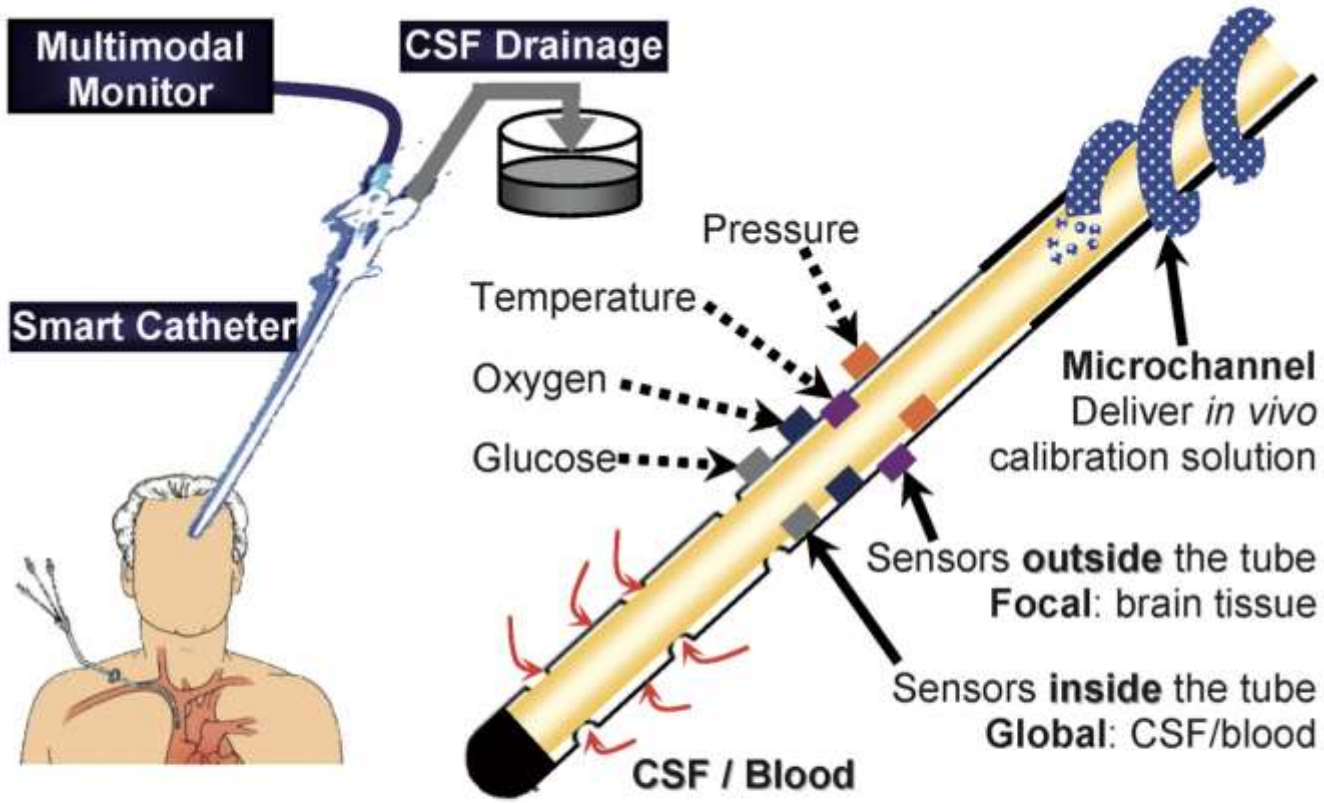
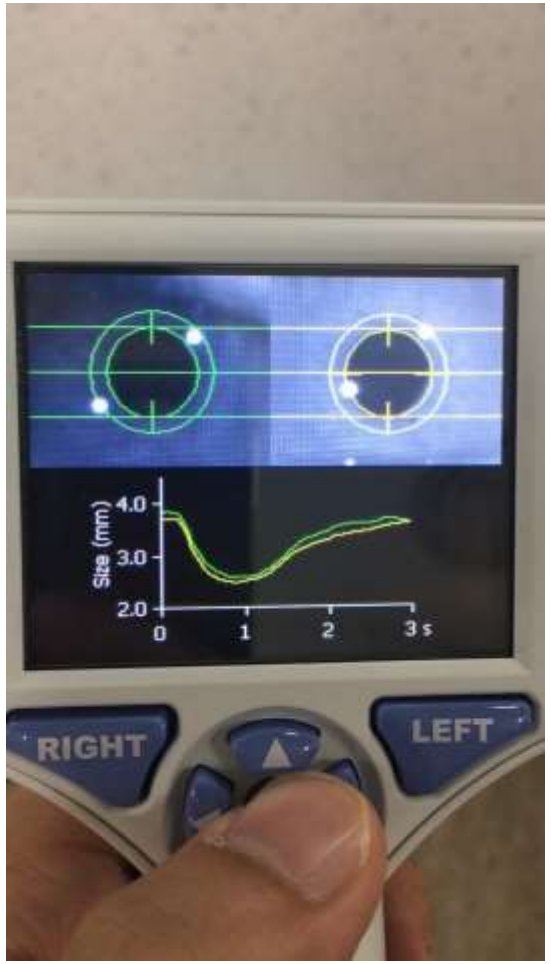


Fig. 1 Conceptual drawing of a novel 'lab-on-a-tube' for multimodal neuromonitoring of patients with traumatic brain injury. The lab-on-a-tube can measure pressure, oxygen, temperature and glucose information as well as drain CSF simultaneously.

PUPILLOMETRY

- Automated pupillometry
- Npi (Neurological Pupil index)



PUPILLOMETRY

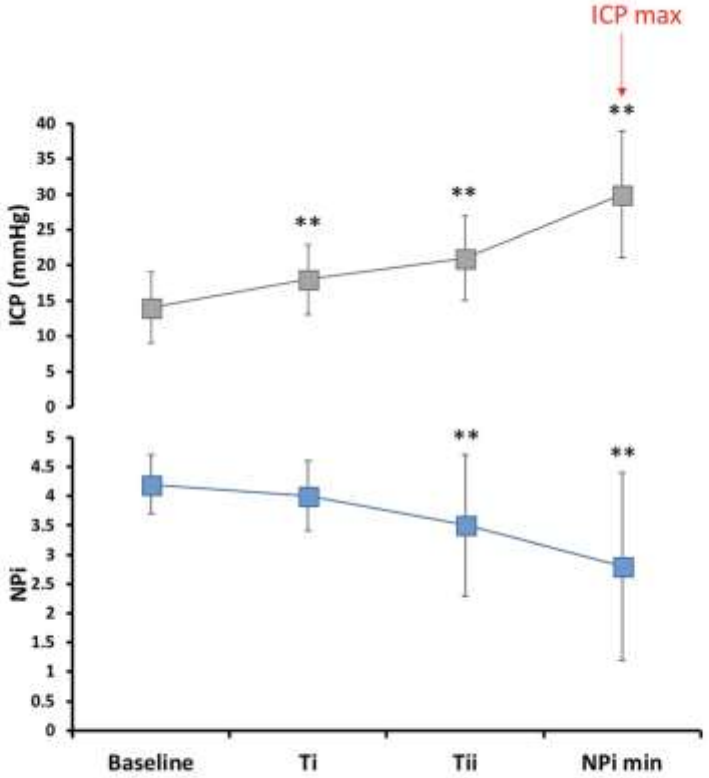


Fig. 2 Trends over time of the Neurological Pupil index (NPi) during episodes of sustained elevated intracranial pressure (ICP). Line graphs illustrating trends over time of the NPi (blue line) during 43 episodes of elevated ICP (gray line). Data are mean ± standard deviation of a total of 172 paired ICP-NPi measurements; $^{**}p < 0.001$ for pairwise comparisons of baseline ICP and NPi values (6 h previous to ICP max [red arrow]) with T_i (≈ − 4 h), T_{ii} (≈ − 2 h), ICP max, and NPi min, respectively (time 0)

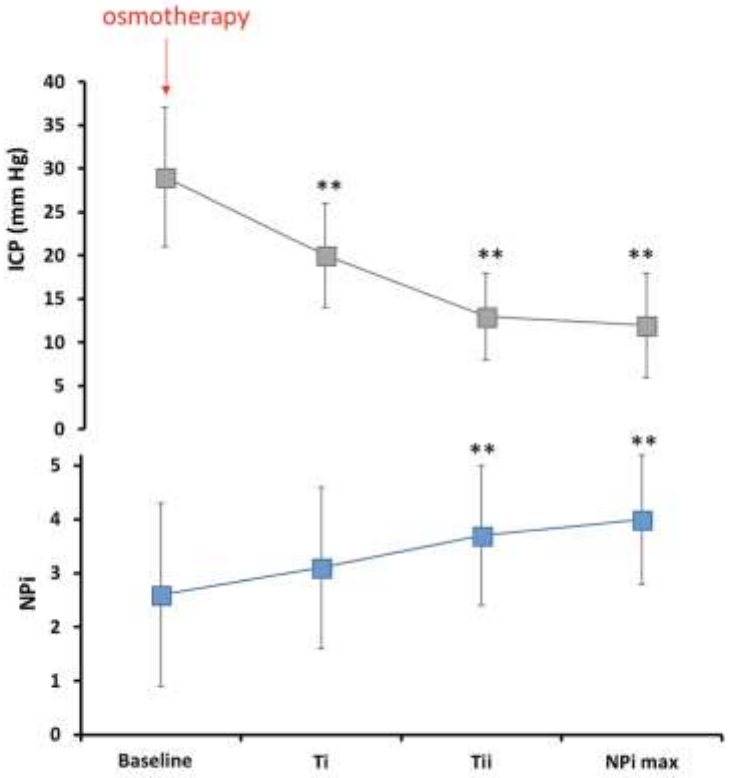
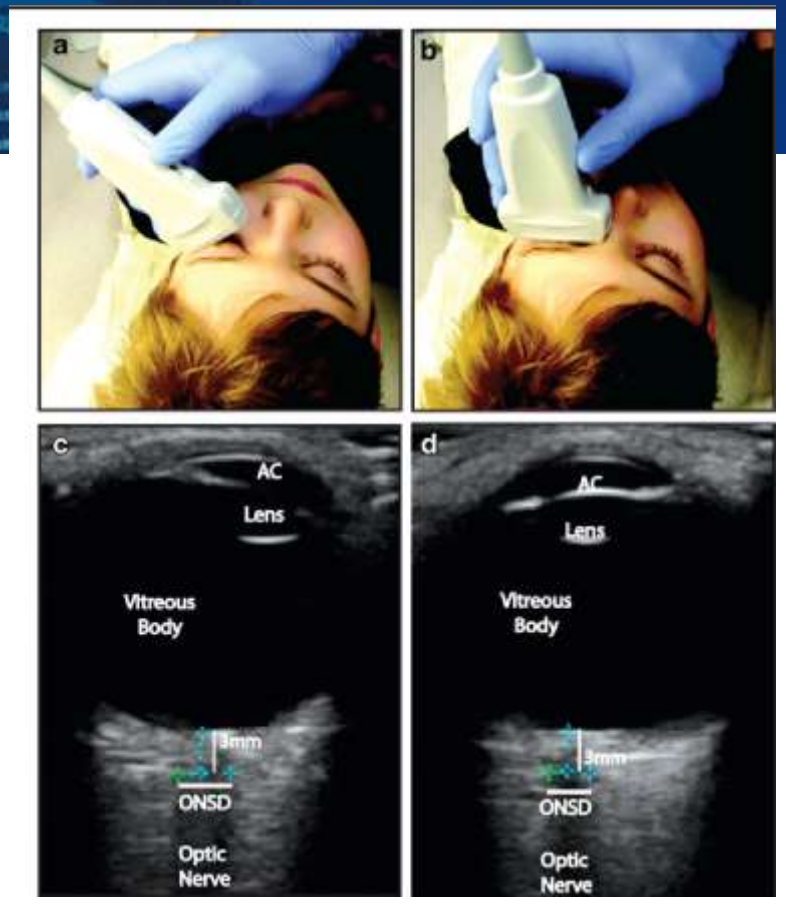


Fig. 3 Trends over time of the Neurological Pupil index (NPi) during elevated intracranial pressure (ICP) treated with osmotherapy (mannitol or hypertonic saline bolus). Line graphs illustrating trends over time of the NPi (blue line) during 15 episodes of elevated ICP (gray line). Data are mean ± standard deviation of a total of 50 paired ICP-NPi measurements; $^{**}p < 0.001$ for pairwise comparisons of baseline ICP and NPi values (start of osmotherapy [red arrow]) with T_i (≈ − 4 h), T_{ii} (≈ − 2 h), ICP min, and NPi max, respectively (time 0)

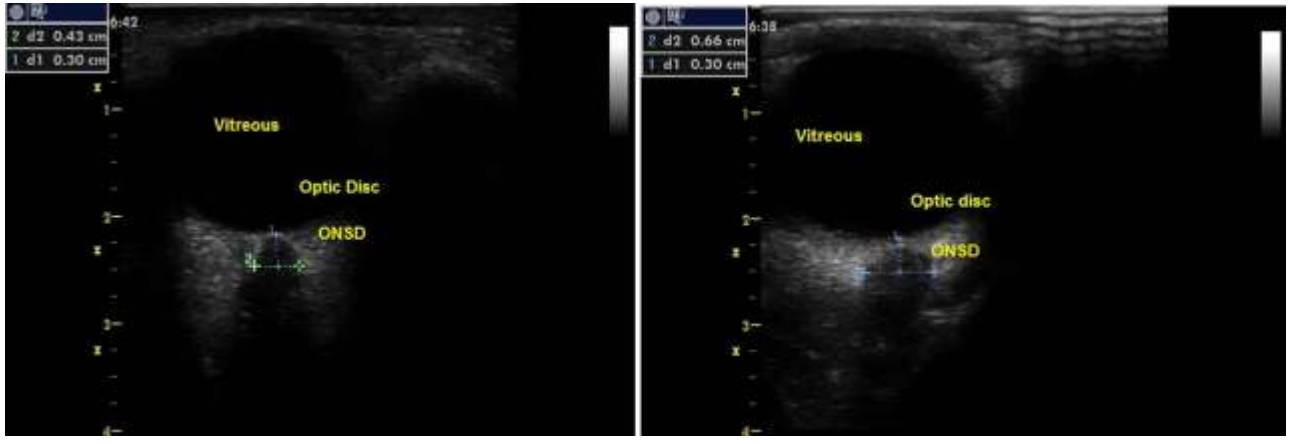
Jahns et al. Quantitative pupillometry for the monitoring of intracranial hypertension in patients with severe traumatic brain injury. Critical Care (2019) 23:155

ULTRASOUND – ONSD

- OPTIC NERVE SHEATH DIAMETER
- NON INVASIVE
- Correlation with ICP
- Emergency Department



- Orbital injury
- Reference value



NON SURGICAL TREATMENT

ICP and $P_{bt}O_2$

	ICP < 22 mmHg	ICP > 22 mmHg
$P_{bt}O_2$ > 20 mmHg	Type A	Type B
$P_{bt}O_2$ < 20 mmHg	Type C	Type D

	Tier1	Tier2	Tier3
A	TIER zero management ICU, Head elevation, Prevent fever, Analgegia/Sedations(not ICP/$P_{bt}O_2$ directed), AED 1weeks, CPP > 60mmHg, Hgb>7g/dL, avoid Hyponatremia, ABP monitoring, SpO_2>94%		
B	$PaCO_2$ 35~38mmHg CPP 60-70mmHg Mannitol / HTS intermittent CSF drainage(EVD) EEG monitoring	$PaCO_2$ 32~35mmHg Neuromuscular paralytics MAP challenge (access autoregulation) Raise CPP	$PaCO_2$ 30~32mmHg Pentobarbital/Thiopental coma Mild hypothermia (35~36°C)
C	$PaCO_2$ > 35mmHg CPP 60-70mmHg (max to 70) Increasing $FiO_2$to 60% EEG monitoring	PaO_2 as high as 150 mmHg Decrease ICP < 22 mmHg Neuromuscular paralytics CSF drainage MAP challenge (access autoregulation) Increase CPP above 70mmHg	**$PaCO_2$ 45~50mmHg** PaO_2 > 150mmHg pRBC if Hgb<9g/dL
D	$PaCO_2$ > 35mmHg CPP 60-70mmHg (max to 70) Increasing FiO_2 to 60% EEG monitoring CSF drainage(EVD)	PaO_2 as high as 150 mmHg Neuromuscular paralytics MAP challenge (access autoregulation) Increase CPP above 70mmHg	PaO_2 > 150mmHg pRBC if Hgb<9g/dL Pentobarbital/Thiopental coma Secondary Decompressive craniectomy

Chestnut et al. A management algorithm for adult patients with both brain oxygen and intracranial pressure monitoring: the **Seattle International Severe Traumatic Brain Injury Consensus Conference (SIBICC)** Intensive Care Med (2020) 46:919–929

THRESHOLD

- Blood pressure
  - Maintaining **SBP at ≥100** mm Hg for patients 50 to 69 years old or at ≥110 mm Hg or above for patients 15 to 49 or over 70 years old may be considered to decrease mortality and improve outcomes. (Level III)
- ICP
  - Treating ICP above **22** mm Hg is recommended because values above this level are associated with increased mortality. (Level II B)
  - A combination of ICP values and clinical and brain CT findings may be used to make management decisions. (Level III)
- CPP
  - The recommended target cerebral perfusion pressure (CPP) value for survival and favorable outcomes is between **60 and 70 mm Hg**. Whether 60 or 70 mm Hg is the minimum optimal CPP threshold is unclear and may depend upon the patient's autoregulatory status. (Level II B)
  - Avoiding aggressive attempts to maintain CPP above 70 mm Hg with fluids and pressors may be considered because of the risk of adult respiratory failure. (Level III)

TREATMENT

- DECOMPRESSIVE CRANIECTOMY (update 2020)

- Prophylactic Hypothermia
  - Early (within 2.5 hours), short-term (48 hours post-injury) prophylactic hypothermia is not recommended to improve outcomes in patients with diffuse injury (Level II B)
- Hyperosmolar therapy
  - Although hyperosmolar therapy **may lower intracranial pressure**, there was insufficient evidence about effects on clinical outcomes to support a specific recommendation, or to support use of any specific hyperosmolar agent, for patients with severe traumatic brain injury (Level I, II, and III)

HYPEROSMOLAR THERAPY

- HYPERTONIC SALINE vs MANNITOL

Table 1
Comparison of mannitol and sodium chloride

Mannitol	Sodium Chloride
Molecular weight: 182.17 g/mol Reflection coefficient: 0.9 Sodium content: none Osmolarity: • 20%: 1100 mOsm/L • 25%: 1375 mOsm/L	Molecular weight: 58.45 g/mol Reflection coefficient: 1.0 Sodium content • 0.9%: 154 mEq/L • 3%: 513 mEq/L • 7.5%: 1283 mEq/L • 23.4%: 4004 mEq/L Osmolarity • 0.9%: 308 mOsm/L • 3%: 1026 mOsm/L • 7.5%: 2565 mOsm/L • 23.4%: 8008 mOsm/L

HYPERTONIC SALINE

- 3~23.4% infusion via central line, within 15~30min
- Regular infusion < **intermittent infusion**
- Limit : serum Na <155~160 mMol/L or Serum Osmol < 320 mOsm/L

HTS is superior to mannitol in the treatment of intracranial hypertension after severe TBI

TABLE 3. ICP and CPP Burden Comparisons Between HTS and Mannitol Groups in 1:2 Matched Group

	HTS (n = 24)		Mannitol (n = 48)		
	Mean ± SD	Med (IQR)	Mean ± SD	Med (IQR)	*P*-value
ICP monitoring duration (days)	6.6 ± 2.6	5.5 (4.5-9.5)	7.1 ± 2.70	8 (5-10)	.46
No. of days with $ICP_{high} + CPP_{low}$	0.7 ± 0.8	0 (0-1)	2.2 ± 2.1	1.5 (0.5-4)	<.01*
% days with $ICP_{high} + CPP_{low}$	9.2 ± 10.7	0 (0-20)	30.2 ± 26.7	23.6 (5-50)	<.01*
Total hours with $ICP_{high} + CPP_{low}$	11.54 ± 14.26	7 (1-18)	32.98 ± 35.56	17 (8.5-49)	<.01*
No. of days with CPP_{low}	2.0 ± 1.8	1 (1-3)	3.6 ± 2.6	3 (2-5)	.01*
% of days with CPP_{low}	32.1 ± 24.1	27.5 (20-41.4)	57.1 ± 52.6	50 (21.1-80)	.01*
Total hours with CPP_{low}	9.21 ± 12.03	6 (1-15)	18.85 ± 19.19	12 (4-28.5)	.01*
Averaged daily duration of CPP_{low} (hours)	1.5 ± 2.2	0.7 (0.3-1.9)	3.4 ± 5.1	1.9 (0.6-4)	.01*

HTS, hypertonic saline; SD, standard deviation; IQR, interquartile range; ICP, intracranial pressure; CPP, cerebral perfusion pressure. *$p < .05$.

Mangat et al. Hypertonic Saline is Superior to Mannitol for the Combined Effect on Intracranial Pressure and Cere bral Perfusion Pressure Burdens in Patients With Severe Traumatic Brain Injury. Neurosurgery 86:221–230, 2020

TREATMENT

- CSF drainage (Level III)
  - An EVD system zeroed at the midbrain with continuous drainage of CSF may be considered to lower ICP burden more effectively than intermittent use.
  - Use of CSF drainage to lower ICP in patients with an initial Glasgow Coma Scale (GCS) <6 during the first 12 hours after injury may be c onsidered.

- Ventilation therapy
  - Prolonged prophylactic hyperventilation with partial pressure of carbon dioxide in arterial blood (PaCO2) **of 25 mm Hg or less** is not recommended (Level II B)

TREATMENT

- Anesthetics, Analgesics, and Sedatives (Level II B)
  - Administration of barbiturates to induce burst suppression measured by EEG as prophylaxis against the development of intracranial hypertension is not recommended.
  - High-dose barbiturate administration is recommended to control elevated ICP **refractory to maximum standard medical and surgical treatment**. **Hemodynamic stability** is essential before and during barbiturate therapy.
  - Although **propofol** is recommended for the control of ICP, it is not recommended for improvement in mortality or 6-month outcomes. Caution is required as high-dose propofol can produce significant morbidity.
- **Steroids** (Level I)
- Early tracheostomy is recommended to reduce mechanical ventilation days when the overall benefit is felt to outweigh the complications associated with such a procedure. However, there is no evidence that early tracheostomy reduces mortality or the rate of nosocomial pneumonia. (Level II A)

END