Decision Caddy in Neurocritical Care
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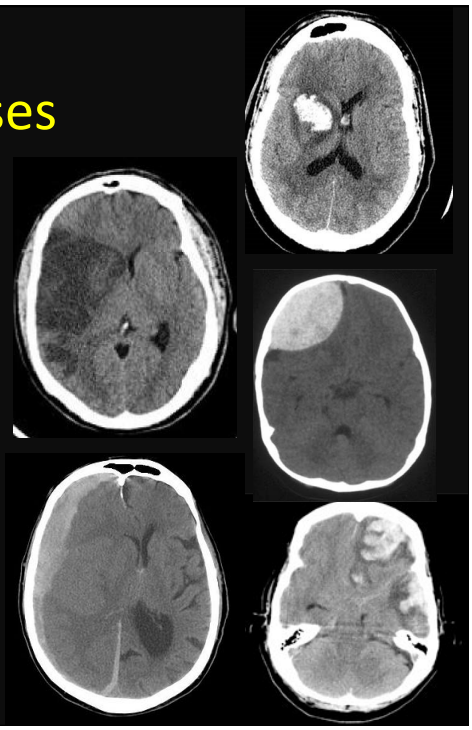
Critical Neuro Cases

- Stroke
- Ruptured Aneurysm
- Brain Hemorrhage
- Subdural Hematoma
- Epidural Hematoma
- Brain Trauma



Who it affects

- Stroke
  - 3rd leading cause of death in U.S. and the leading cause of long-term disability
- Traumatic Brain Injury
  - A third of all injury-related deaths in U.S.
- Can result in significant disability paralysis, speech difficulty, and emotional problems.
- Large impact on society

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There may be no external signs of secondary injury (limited physical exam)

One of the more complex clinical environments

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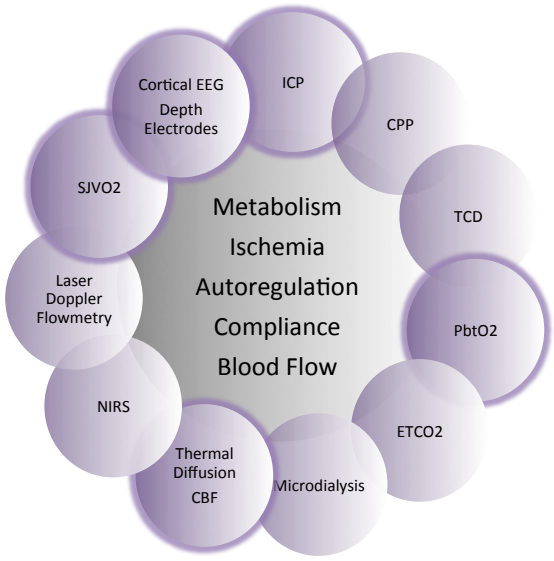

Snapshot
Vs.
Continuous

Integration and Interpretation
of Multiple Modalities

To Get at Underlying Physiology

Global
Vs.
Regional

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Secondary Injury
…Time is Brain…

- Fever
- Oligemia/Hyperemia
- Hypoperfusion
- Brain hypoxia
- Intracranial Hypertension
- Pressure on normal structures

- Secondary injury occurs in **minutes**
- External signs are subtle
- Reliance on MONITORS

Limitations of Monitors

- Threshold-based Alarms
  - at level of device rather than clinician
- Lack of integration – interpreted univariately
- Lack of context
- Dependent on geography

There are no common platform or standards

- Open Source
- Interoperable Apps
- Agnostic to legacy systems

http://www.uoguelph.ca/plant/performance_recommendations/ofcc/pub/silo.htm

Silos

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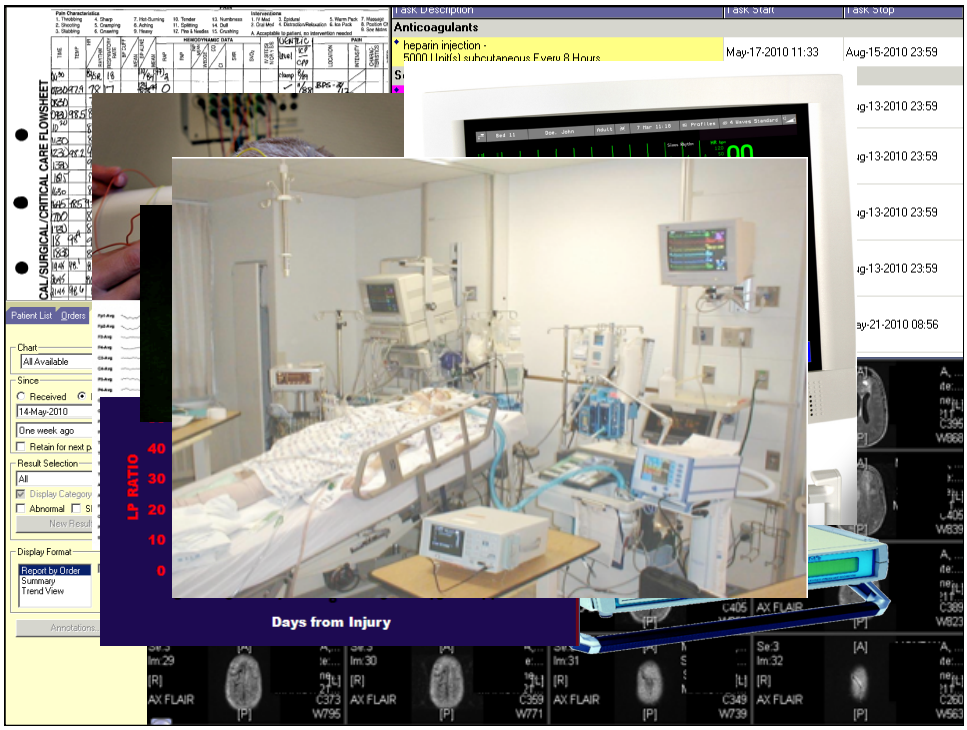

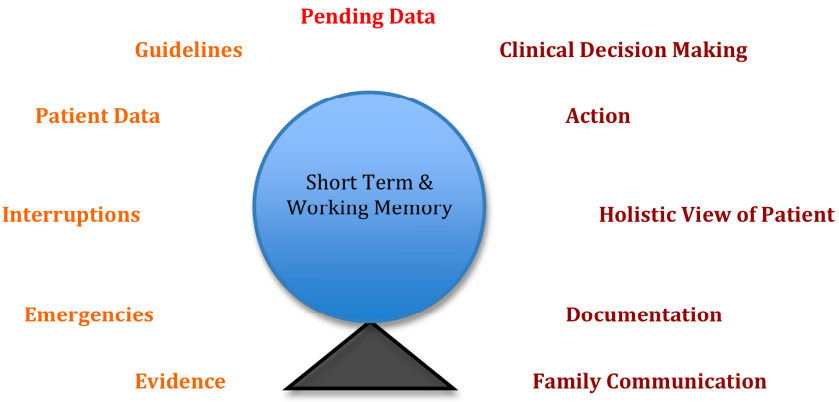

The Clinician is still the Sensor, Integrator, Complex Data Analyzer.

With Many Competing Demands

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Distributed Cognition

- ICU = organism
  - People with hierarchy/culture
  - Physical space vs. Cognitive place
  - Geography shared/overlapping
  - Different goals but Same vector
  - Interacting with each other and Interfacing with technology
- Cognition of this organism is distributed
  - Artifacts (memory, fact, knowledge)
  - Objects, individuals, environment

Critical Zones in an ICU

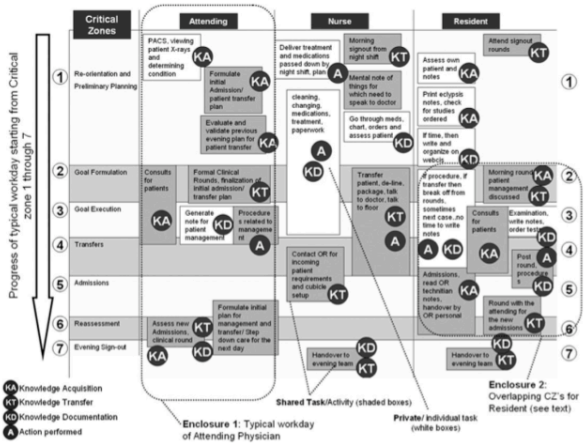

Fig. 4. Stage 2: Integrating individual pieces of the workflow (see text for description).

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Malhotra, Jordan, Shortliffe, Patel. Journal of Biomedical Informatics 2007.

Disruptive cognitive environment

- 987 communication events over 1.5 days
  - 42% were interruptions

Edwards, Fitzpatrick, Augustine et al. International Journal of Medical Informatics 2009

- Nurses preparing/admin meds in ED
  - Interruptions in 53.1% med admins, each with ~12.1% incr in errors (as opposed to 2.3%)
- 44 physicians in ED

Westbrook, Woods, Rob et al. Arch Intern Med 2010

  - 11% tasks interrupted
  - Failed to return to interrupted task 18.5% of the time

Westbrook, Colera, Dunsmuir et al. Qual Saf Health Care 2009

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Interaction with patient monitors

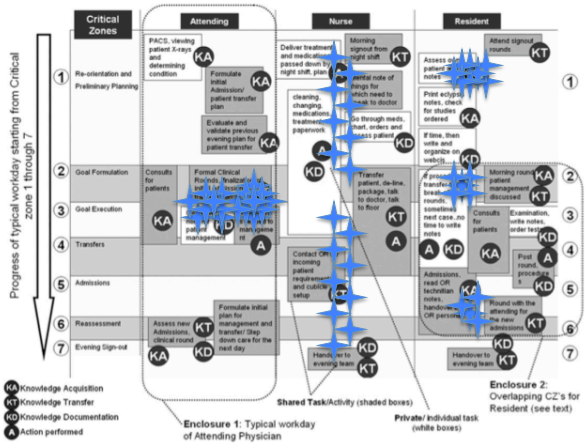

Fig. 4. Stage 2: Integrating individual pieces of the workflow (see text for description).

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Patient care is necessarily driven by interruptions…

Second Order Bedside Alarm Is The Nurse

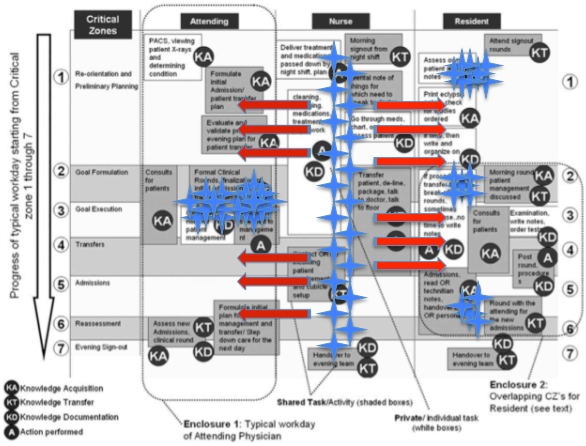

Fig. 4. Stage 2: Integrating individual pieces of the workflow (see text for description).

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Goals of Knowledge-Based Clinical Decision Support

- Reduce Cognitive Burden
- Distill abundant data
- Prioritize attention
- Early event detection
- Assistance with diagnosis
- Critiquing

Success ≠ effective analytic tool
Success = affect care delivery

- Reduced errors
- Cost savings
- Mortality/Morbidity

- **Time metric**
- **Reliability**
- **Cognitive stress**

Monitors → Alarms & Caddies

- Smart Alarm
  - Modifying existing alarms
  - Method: synchronize & filter data from multiple monitors within clinical context
  - Goal: Reduce alarm fatigue at bedside
- Decision Caddy
  - Creating alerts that do not currently exist
  - Geography independent
  - Beyond single device → multivariate analysis
  - Method: synchronize & filter data from multiple monitors and other data sources within clinical context
  - Goal: Reduce cognitive complexity of managing ICU

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Challenges and Research Directions in Medical Cyber-Physical Systems

Insup Lee, *Fellow, IEEE*, Oleg Sokolsky, *Member, IEEE*, Sanjian Chen, *Student Member, IEEE*, John Hatcliff, Eunkyoung Jee, *Member, IEEE*, BaekGyu Kim, Andrew King, Margaret Mullen-Fortino, Soojin Park, Alexander Roederer, and Krishna Venkatasubramanian, *Member, IEEE*

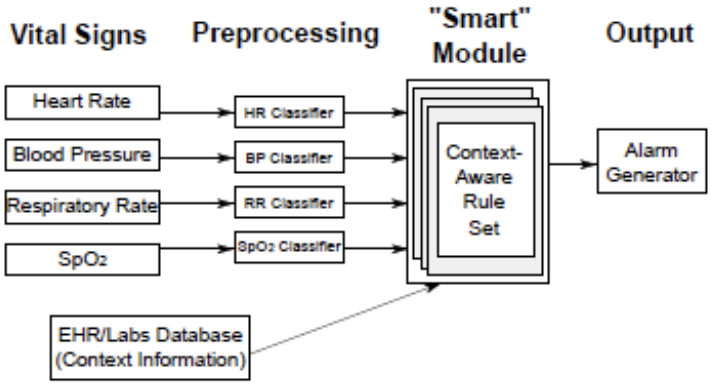

Fig. 5. Generic Smart Alarm Architecture, instantiated as a smart alarm for CABG patients

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Proceedings of the IEEE, 2011

Monitors → Alarms & Caddies

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Research in Progress

- Decision Caddies (Clinical Decision Support)
  - Data Sifting

sifting present participle of **sift** (Verb)

Verb:
1. Put (a fine, loose, or powdery substance) through a sieve so as to remove lumps or large particles.
2. Examine (something) thoroughly so as to isolate that which is most important or useful: "we sifted the evidence ourselves".

  - Combine Heterogeneous Data Sources
  - **Intuitive Presentation of Information**
  - Clinical Research Objective:
    - Dynamic Risk Assessment
    - Detection of State Change

Model Case:
Dynamic Vasospasm Detection
in Aneurysmal Subarachnoid Hemorrhage

- Risk Assessment for Vasospasm
  - Stratification based on initial assessment (Clinical Exam & Initial CT)
  - Followed by daily risk assessment in rounds and ad lib notification by bedside nurse for clinical events
- Clinical Workflow in Busy Neurocritical Care Unit
  - Moving parts of determining vasospasm
  - Importance of trends
  - Similar algorithm for multiple patients off-phase
  - Time is brain; Standardization

Dynamic VSP Detection
in aneurysmal subarachnoid hemorrhage

- Real time statistical probability of VSP (currently based on 80 patients)
- Visual display of location-specific composite index of VSP risk

Decision Caddy Steps

- Combining data sources
  - Requires interoperability and coordination
- Filtering, Preprocessing
  - Understanding data sources, types
  - Mapping to Ontology
- Statistical Analysis
  - Building patient models
- Presentation
  - Intuitive visual presentation
  - Alerts and Dynamic Risk Assessments

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Data Sources

Differing Sources, Frequency, Regularity

- Baseline Risk
  - Query Hospital Database (Baseline)
- Periodic Clinical Data
  - Exams (Hourly, Sub-hourly)
  - TCDs (Daily)
  - EEG (Twice Daily)
- Labs
  - Query Hospital Database (Varied)
- Continuous Data
  - Stream from medical devices (Continuous)

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Clinical Decision Support: Pitfalls

- Baseline mistrust of black box decision support
- Level of safety required for decision support (predictive value)
- Intrusiveness into workflow
  - Data entry portals (distributed cognition of ICU and staff)
  - CDS alert
- Intuitiveness of data presentation

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3-pronged approach to Data Delivery

Hospital Protocol & Guidelines	Survey/Emulate Clinicians	Unsupervised/ Automatic
Result: Rule Based	Result: Series of Rules combined additively or multiplicatively depending on consensus from surveys	Result: Ensemble Classifier (LR, Naïve Bayes, Multilayer Perceptron, Naïve Bayes Tree, Bayesian Network)
Provides: Best Practice	Provides: Expert Opinion	Provides: Data-Driven Practice
TCD	Exam, TCD, cEEG	Baseline RFs, TCD, Time since SAH, will include NIRS indices and BP trends

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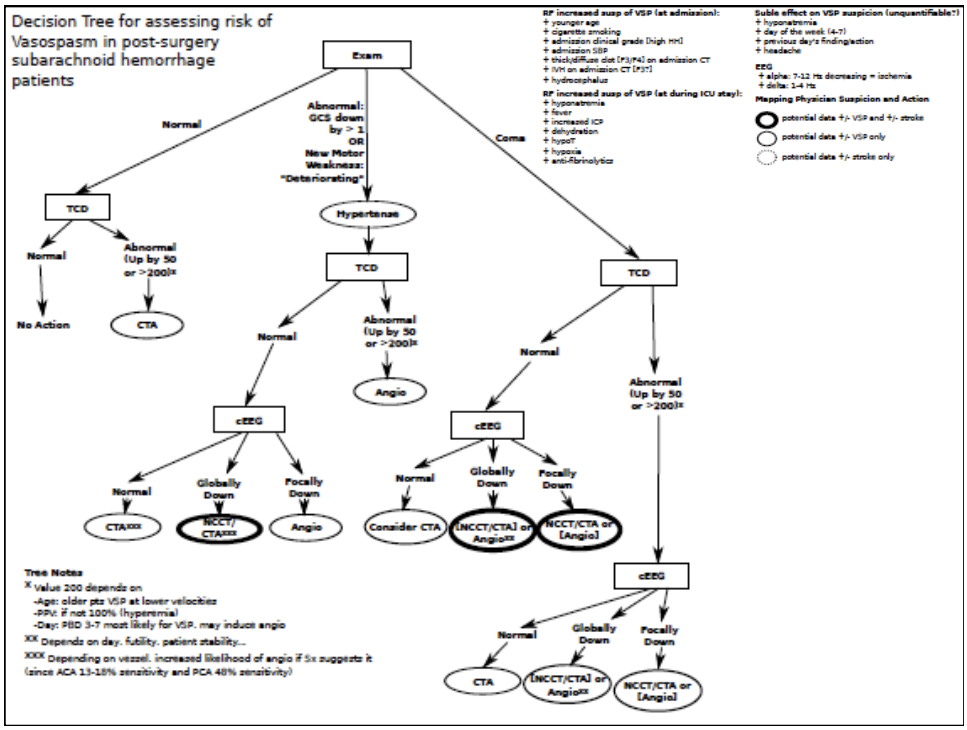
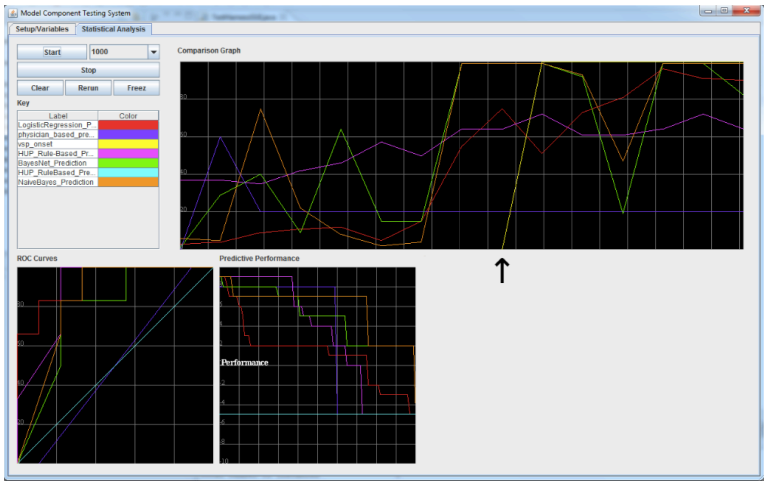


Bring Transparency to Black Box



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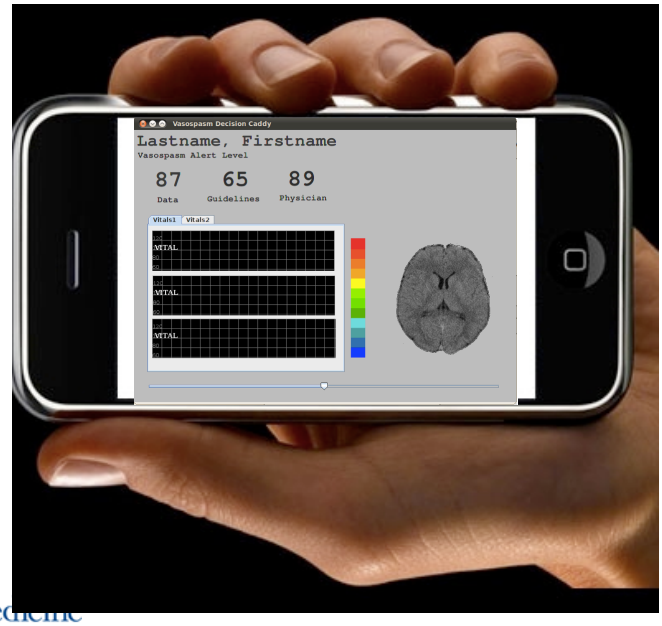

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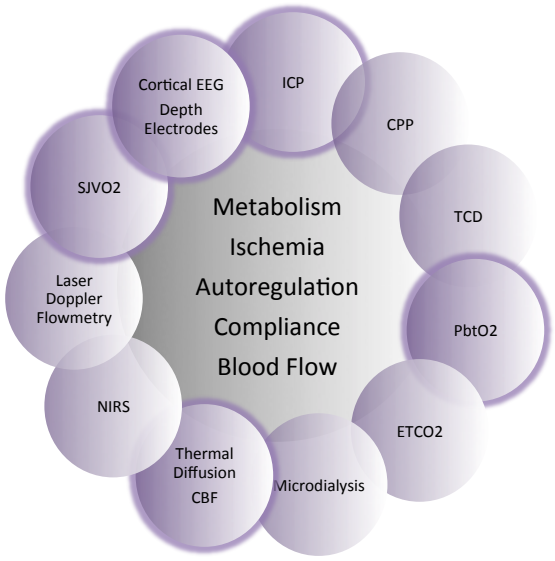

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	Invasiveness	RealTime	What is Measured	Individualized Therapy
ICP	x	EVD (intermittent) Bolt (continuous)	Pressure, Compliance	RAP PAx (ICP AMP, ABP) PRx (mICP, ABP) SLOW
TCD		Intermittent (1hr continuous)	Flow Velocity	Mx (FV, CPP) nICP (TCD, ABP)
cEEG		Continuous	Ischemia, Non-convulsive Seizure	AV (alpha variability) ADR (Alpha:Delta Ratio)
Microdialysis	x	Intermittent, Frequent (q1h or less)	Metabolism	LPR (Lactate/Pyruvate Ratio)
Licox	x	Continuous	Tissue Oxygen	ORx (PbtO2, CPP)
NIRS		Continuous or intermittent	Blood Flow, Blood Volume	COx (cerebral oximetry, CPP) TOx (cerebral oximetry, CPP)

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Index	Moving Pearson's Correlation	TBI	aSAH
Mx	TCD mean FV CPP (30 x 10 s; 5 min TW)	Correlates with outcome (Czosnyka Stroke 1996)	Correlates with incidence/severity of VSP (Soehle Anesth Analg 2004)
Sx	TCD systolic FV CPP 30 x 10 s (5 min TW)	Correlates with outcome (Czosnyka Stroke 1996)	
FRx (Barth NCC 2010)	rCBF (hemedex) CPP (30 x 10s; 5 min TW)		
PRx	MAP ICP (120 x 30s; 1hr TW)	Correlates with outcome (>0.2) (Czosnyka Neurosurgery 1997)	
Orx	PbtO2 CPP 120 x 30 s (1 hr TW)	Conflicting studies re: correlation with outcome (+ Radolovich Neurocritical Care 2009) (- Jaeger Crit Care Med 2006)	Correlates with cerebral infarction (>0.4) (Jaeger Stroke 2007)

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