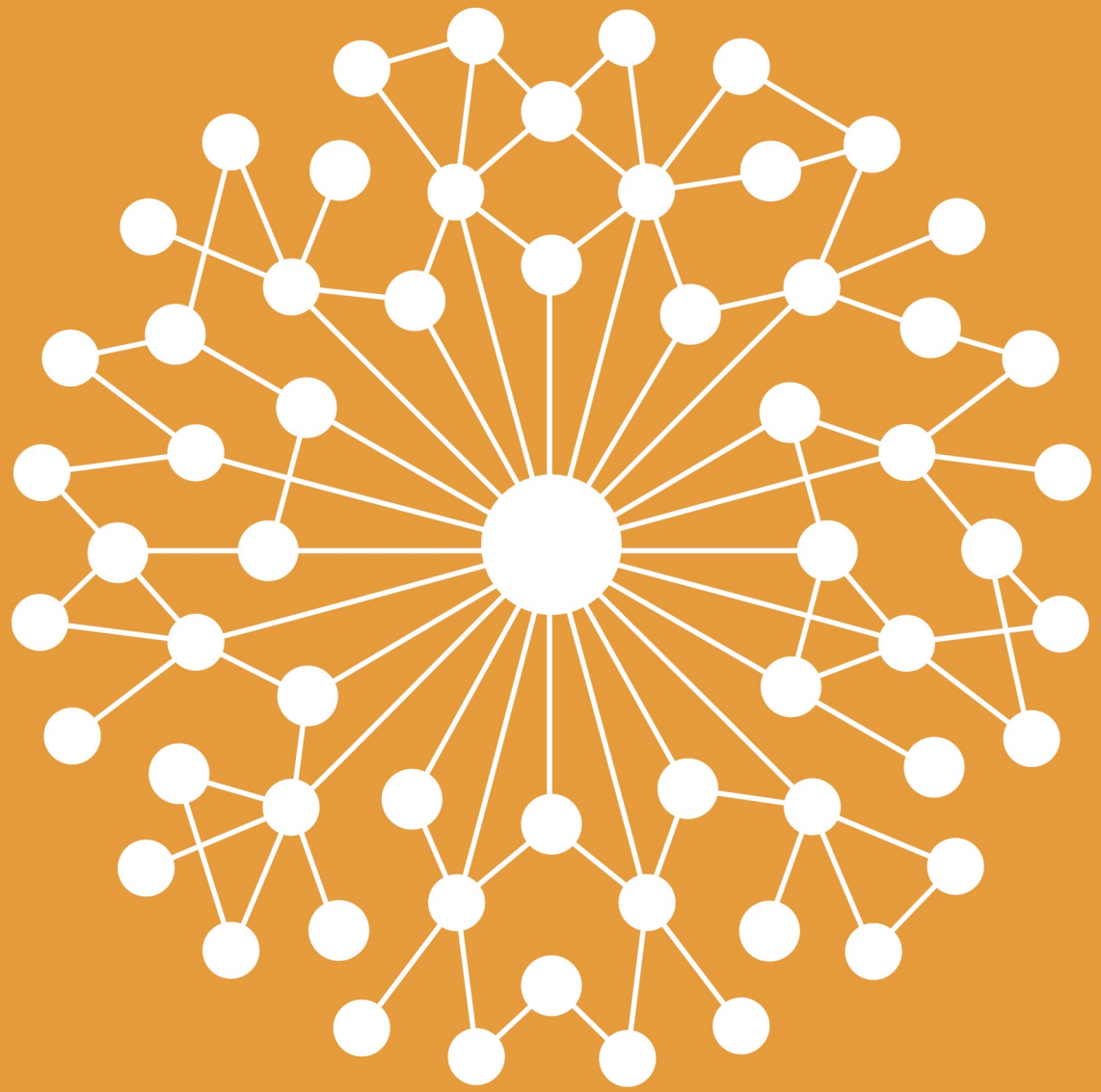


DNC / Service SUN

TRAUMATISMES CÉRÉBRAUX

JM Pignat

Unité de Neuroréhabilitation Aigue (NRA)

Service Universitaire de Neuroréhabilitation

(SUN)

1. Introduction
2. Biophysique, physiopathologie et imagerie
3. Définition et classification de la sévérité
4. Type et sévérité de symptoms
5. Outcome
6. Traitement



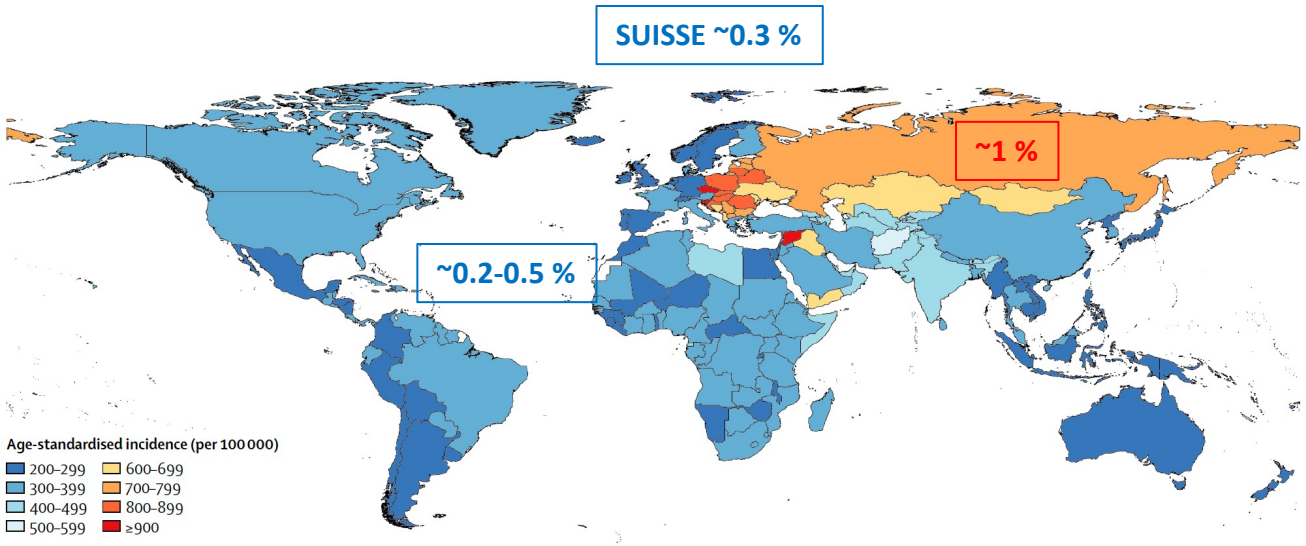
1. INTRODUCTION

1. INTRODUCTION

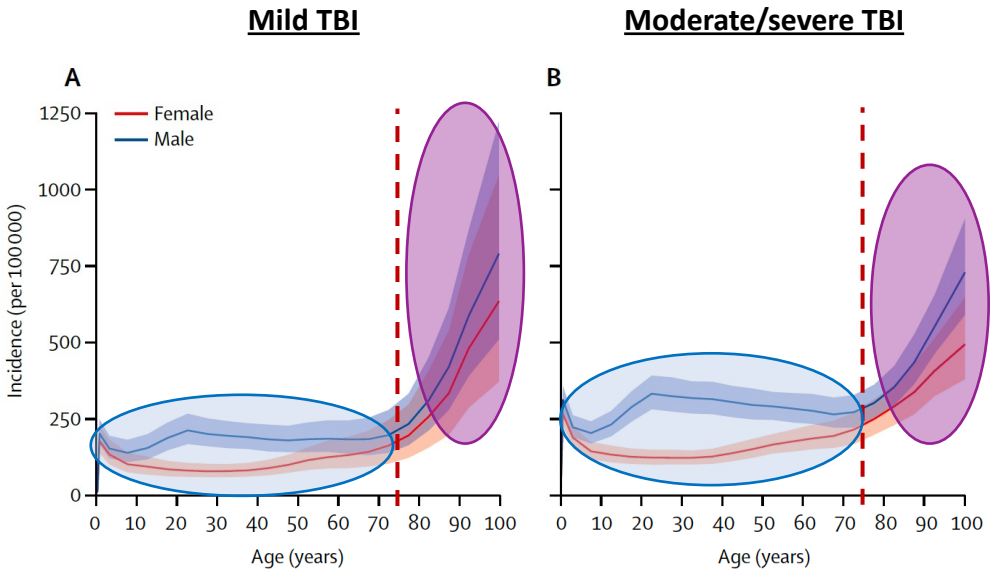
1.1. ÉPIDÉMIOLOGIE

Épidémiologie: Incidence Annuelle

INCIDENCE ANNUELLE ELEVEE : ~0.3%



INCIDENCE ANNUELLE >75 ANS



GBD, Lancet Neurol, 2019

Épidémiologie: Incidence Annuelle Vaud

STATISTIQUE VAUD
Département des finances et de l'agriculture (DFA)

Population résidante permanente par classe d'âges, sexe et état civil, Vaud, 2023

Classe d'âges	Total (1)
Effectif	
Population totale	846 303
0 à 24 ans	236 799
25 à 39 ans	181 118
40 à 49 ans	120 669
50 à 69 ans	202 771
70 ans et +	104 946
Hommes	415 802
0 à 24 ans	121 835
25 à 39 ans	91 251
40 à 49 ans	59 382
50 à 69 ans	99 387
70 ans et +	43 947
Femmes	430 501
0 à 24 ans	114 964
25 à 39 ans	89 867
40 à 49 ans	61 287
50 à 69 ans	103 384
70 ans et +	60 999

16-24: ~*75766*
25-39: 181118
40-49: 120669
50-69: 202771
70-75: ~~*35000*

TOTAL: 615324

0.3%: 1846 mTBI
0.026%: 160 msTBI

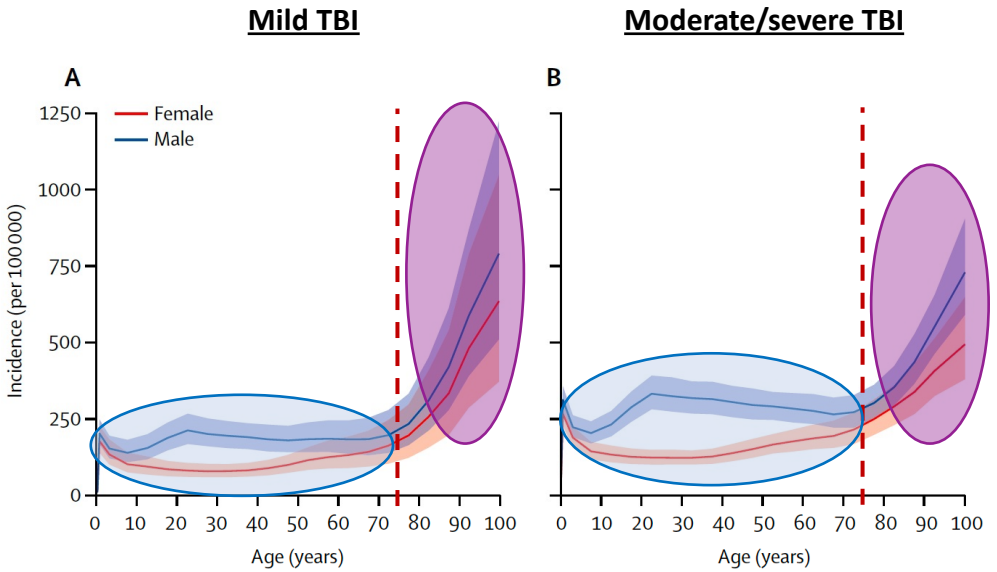
ANNUAL INCIDENCE (16-59) NORWAY

MALE 0,357%

FEMALE 0,242%

TOTAL 0,302%

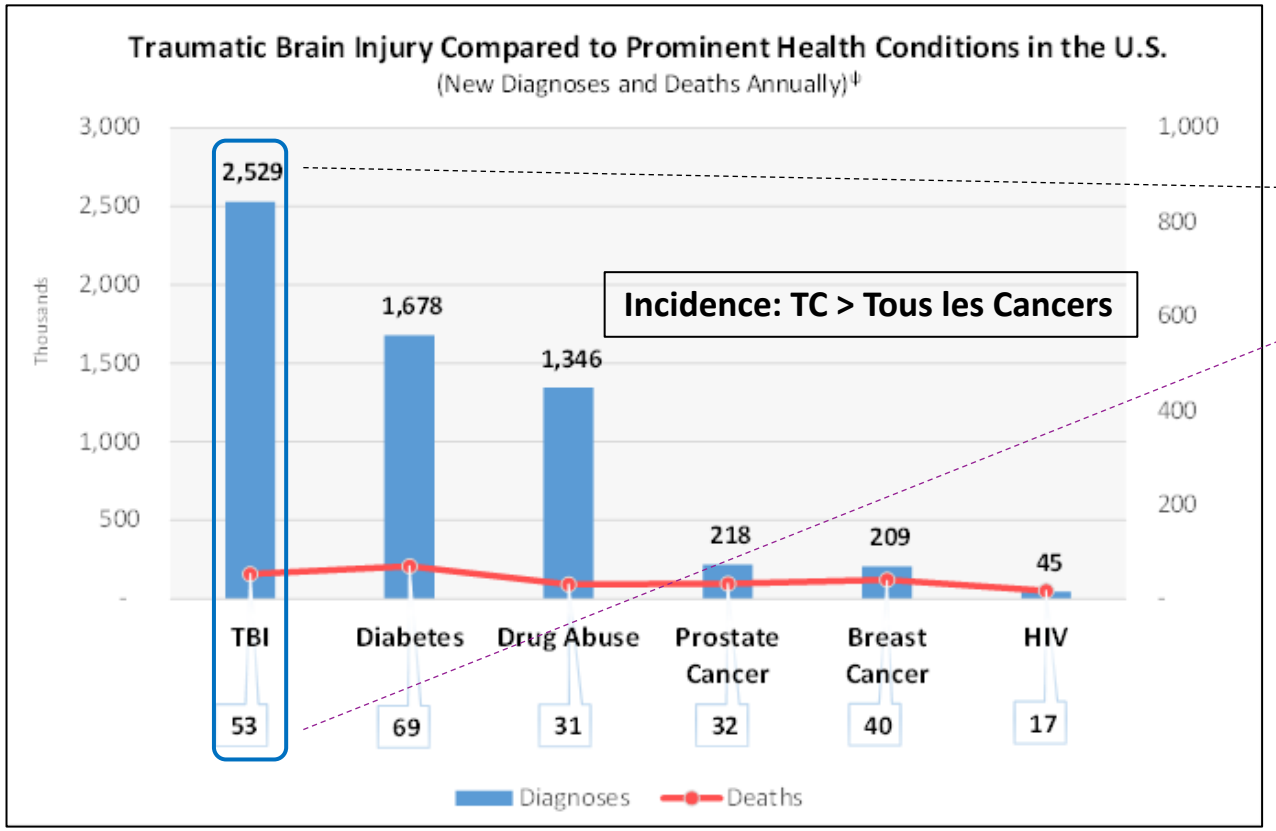
ANNUAL INCIDENCE >75 yo



Skandsen et al., Front Neurol, 2019

GBD, Lancet Neurol, 2019

Épidémiologie: Handicap



- **INCIDENCE ANNUELLE ELEVEE**
- **TAUX de MORTALITE BAS**

RISQUE
d'un TAUX ELEVE
de "HANDICAP"
(dans la population)

CDC Report, 2018

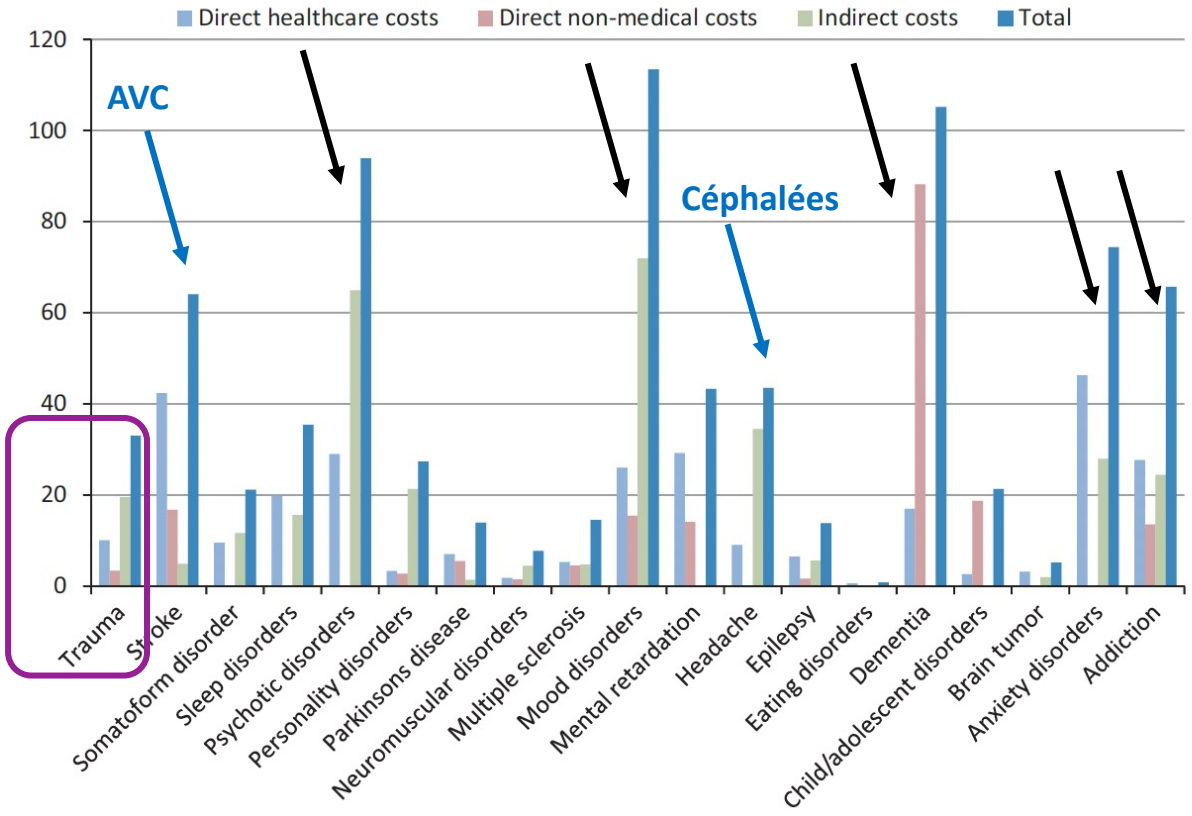


1. INTRODUCTION

1.2. COUTS

Epidémiologie: Coûts

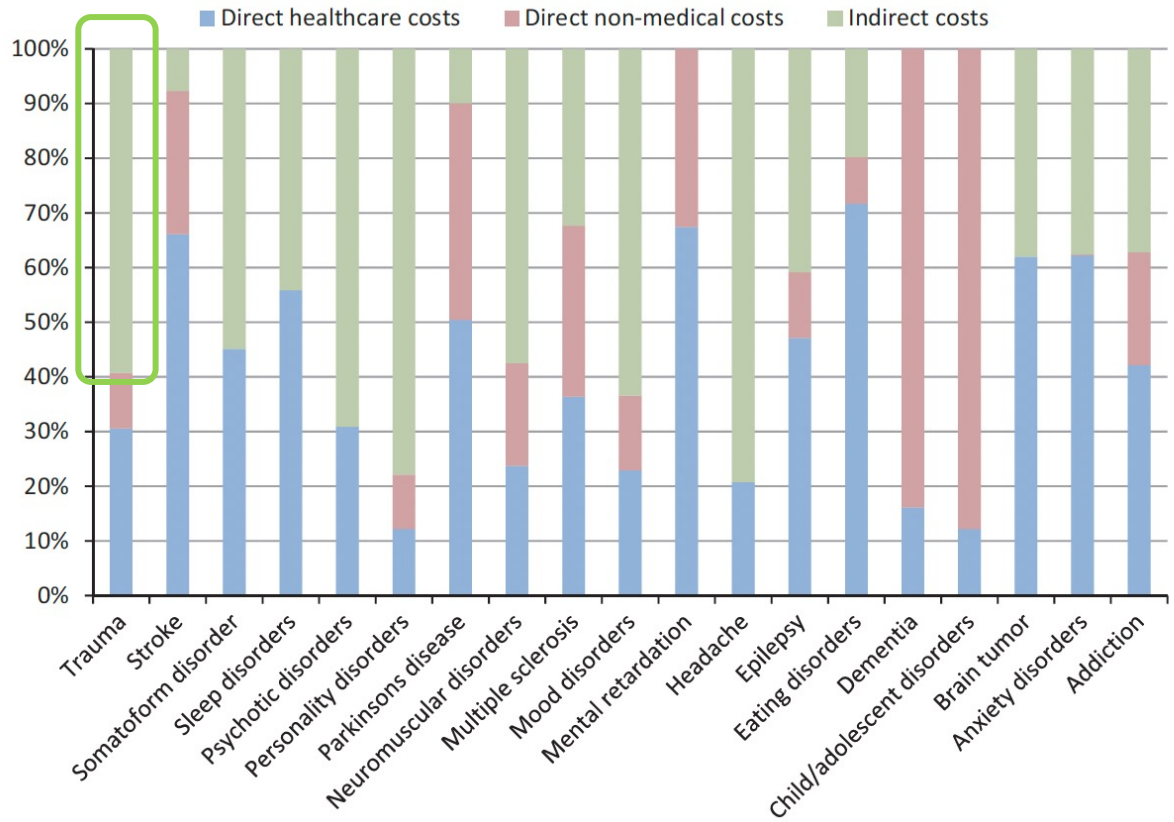
3ème cause de coût parmi les maladies neurologiques



→ **Maladies Psychiatriques**

→ **Maladies Neurologiques**

COUTS INDIRECT : ~60% (DIRECT : ~30%)



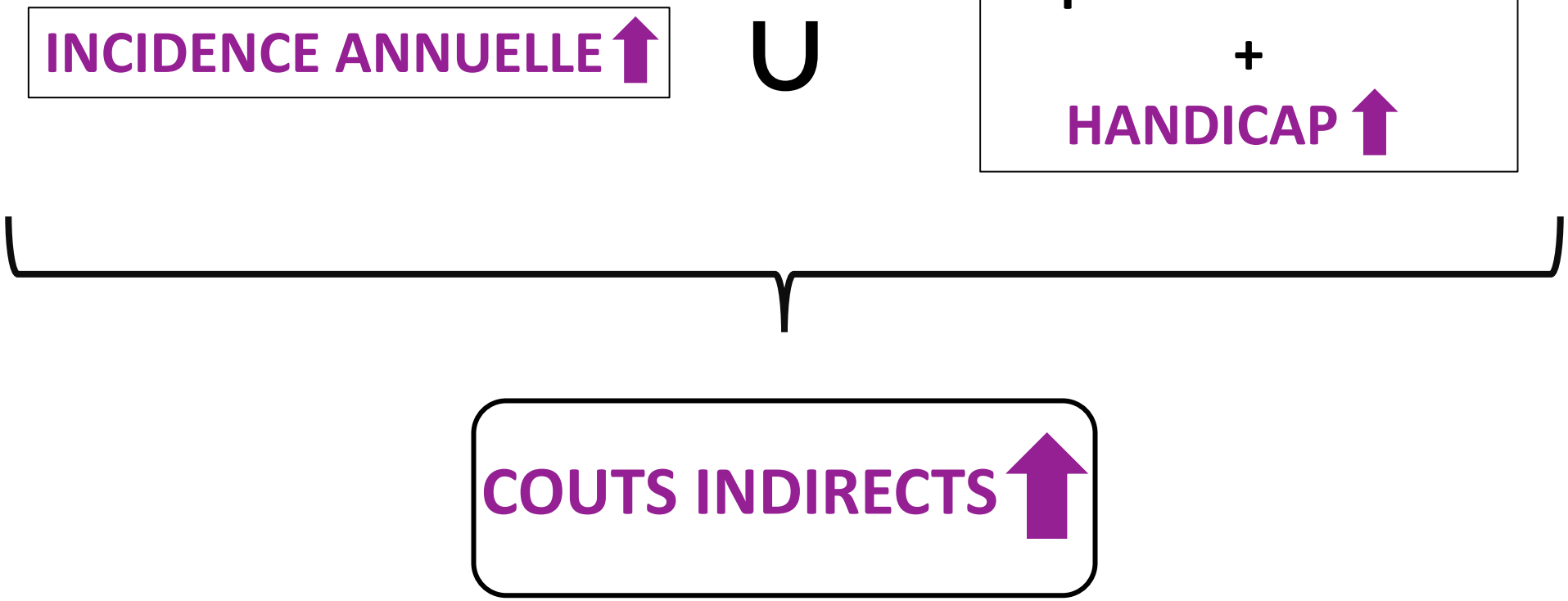
Olesen et al. , Eur J Neurol, 2012



1. INTRODUCTION

1.3. RÉSUMÉ

Épidémiologie Particulière



2. BIOPHYSIQUE, PHYSIOPATHOLOGIE, IMAGERIE

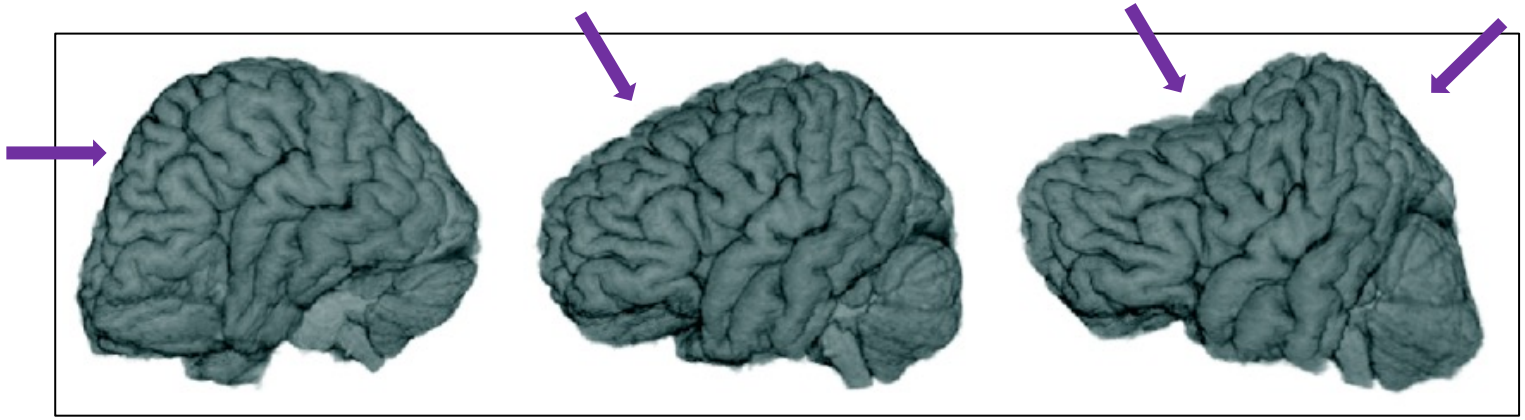
2. BIOPHYSIQUE, PHYSIOPATHOLOGIE, IMAGERIE

2.1. Des forces mécaniques à la lésion cérébrale

Cerveau: "Tissu solide viscoélastique déformable"



Tissu solide mou
à comportement viscoélastique



CERVEAU

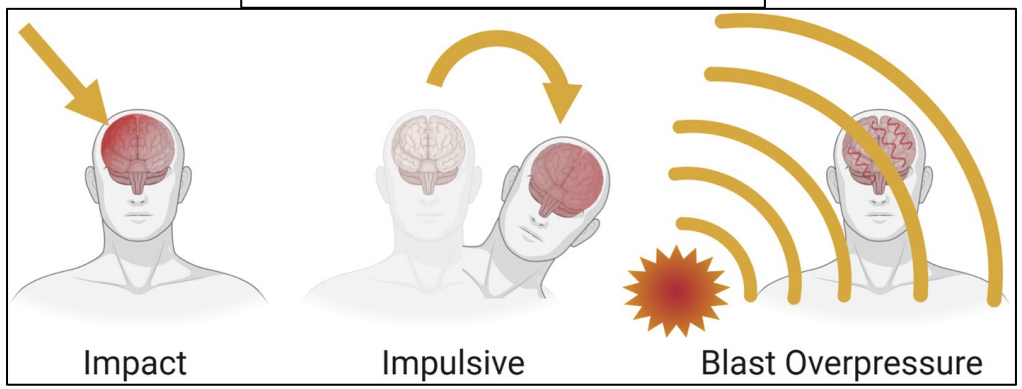
=

- Tissu **HAUTEMENT DEFORMABLE**
- Déformation **NON linéaire**

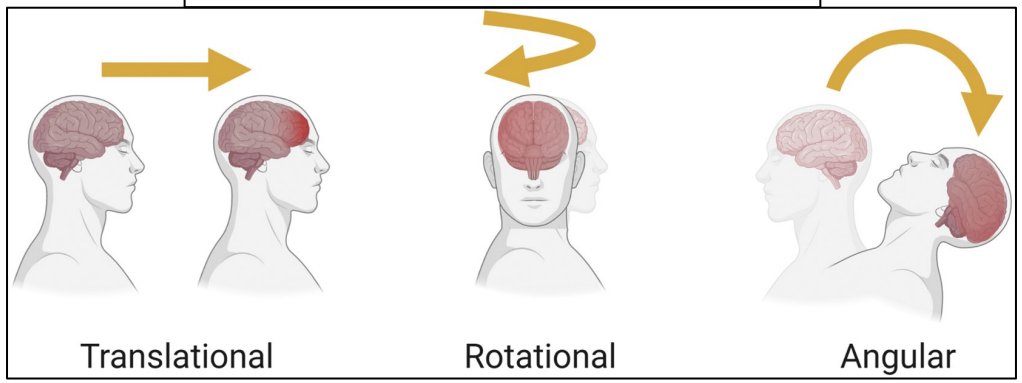
Chatelin et al., Biorheology, 2010

De la Charge aux Contraintes Intracérébrales

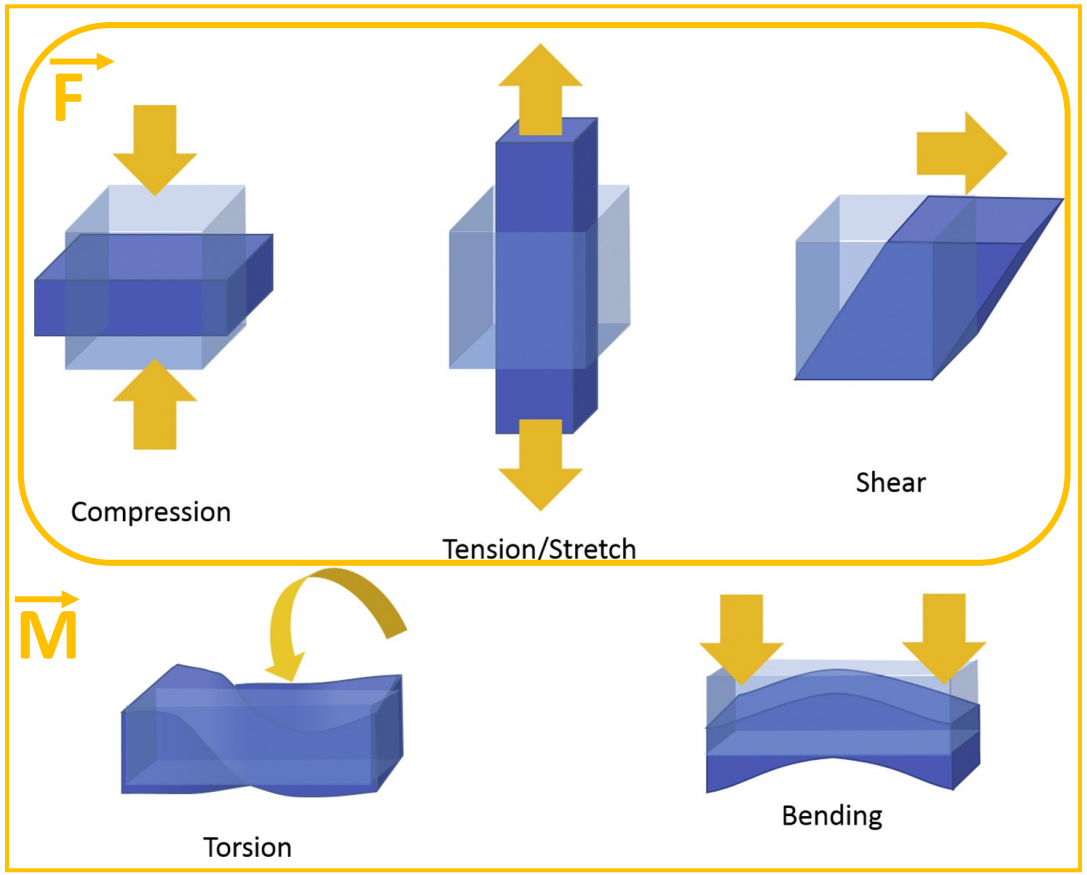
1. ***CHARGE DYNAMIQUE***



2. ***ACCELERATIONS de la TÊTE***



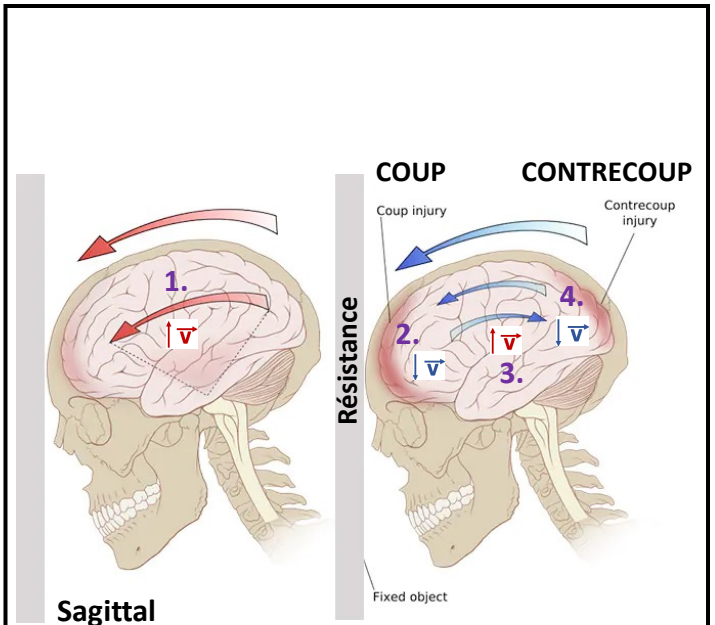
3. ***FORCE ($\vec{F}$) et MOMENTS ($\vec{M}$)***



Keating, Neurobiol Dis, 2021

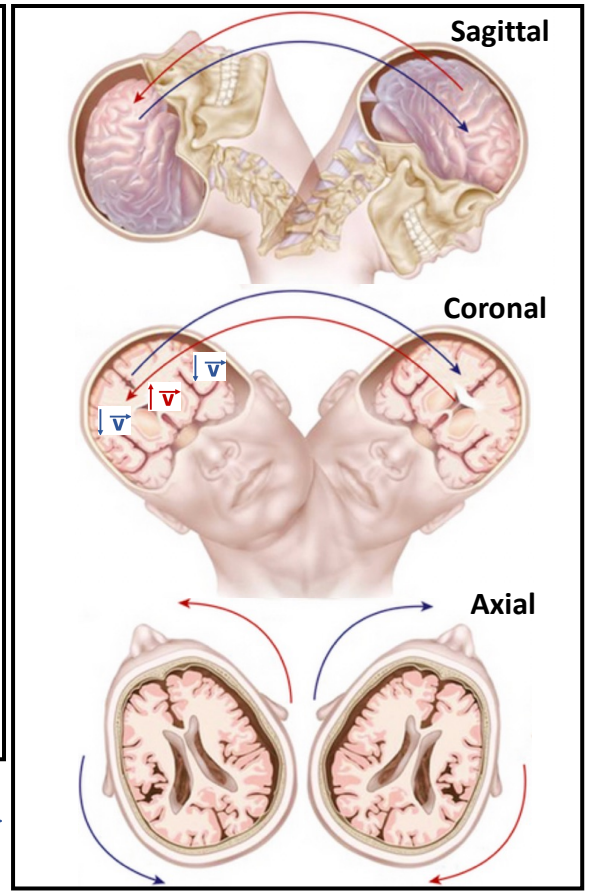
Accélération Translationnelle/Rotationnelle et Forces

Translationnelle



ACCÉLÉRATION
DÉCÉLÉRATION

Rotationnelle/Angulaire



ACCÉLÉRATIONS

- ***TRANSLATIONNELLE***
- ***ROTATIONNELLE/ANGULAIRE***

FORCES

- ***COMPRESSION***
- ***TENSION***

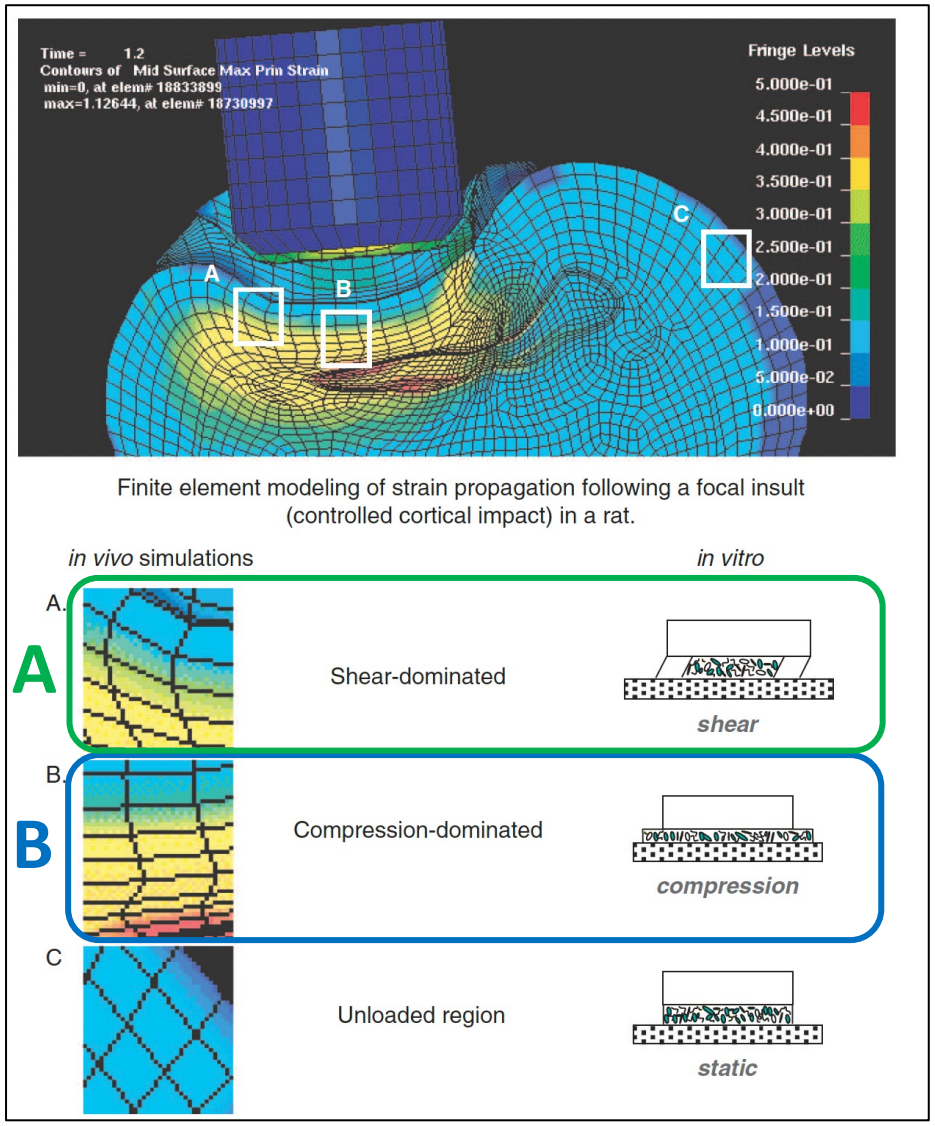
B

- ***CISAILLEMENT***

A

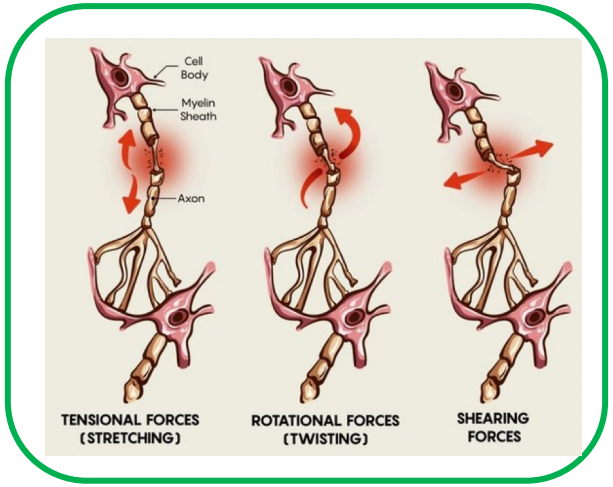
Pavlovic et al., Pituitary, 2019

Contraintes Mécaniques

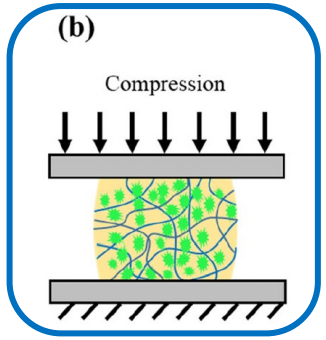


LaPlaca, Prog Brain Res, 2007

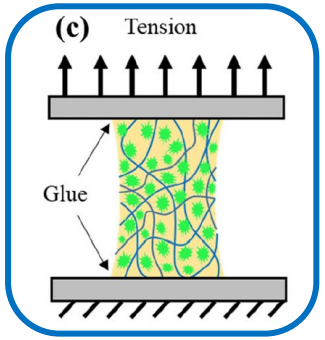
CISAILLEMENT
TENSION



COMPRESSION



TENSION

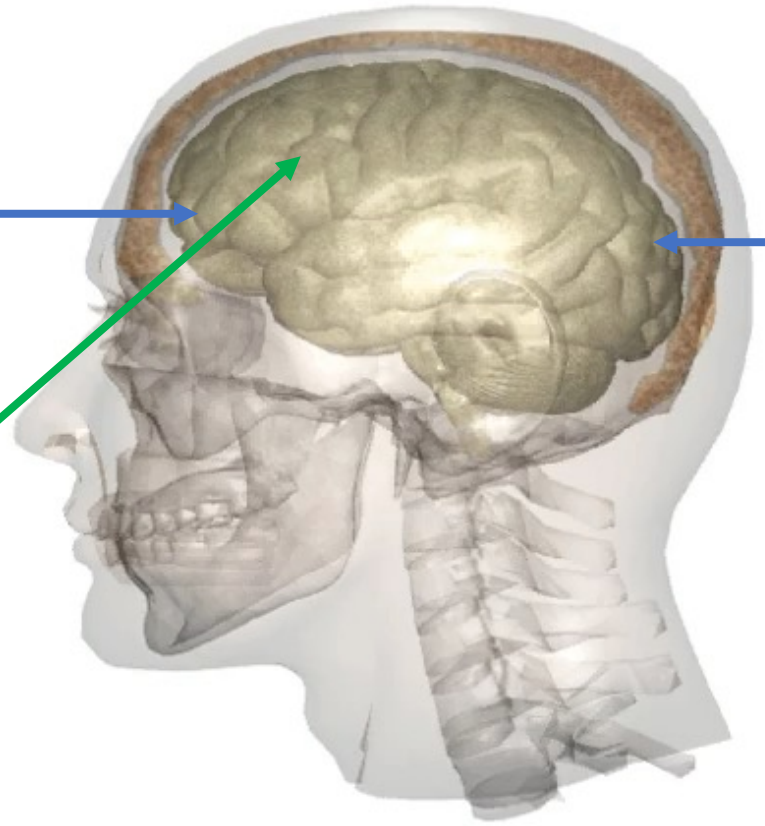


Contraintes Mécaniques

Accélérations Translationnelles + Angulaires

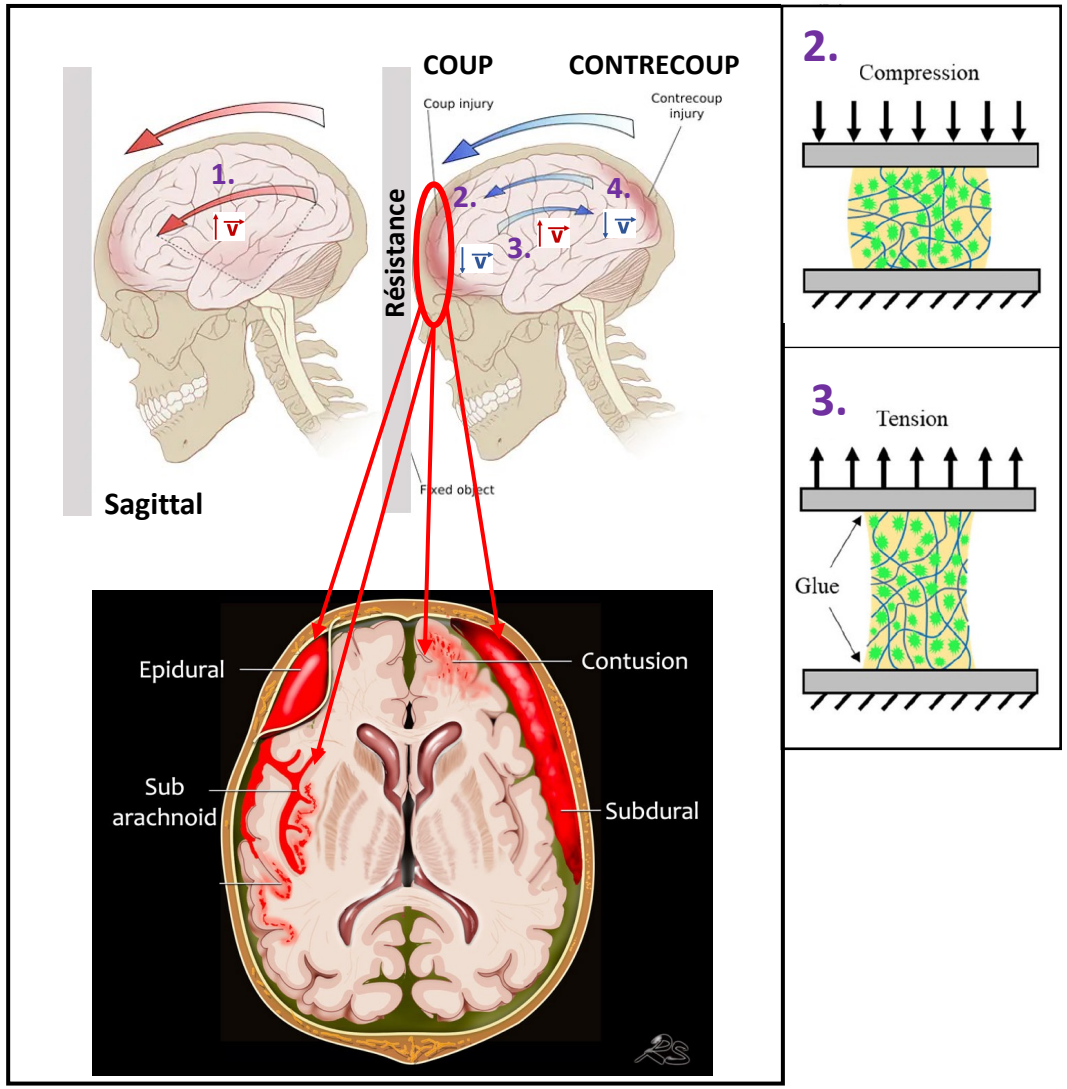
- ***COMPRESSION***
- ***TENSION***

- ***CISAILLEMENT***



- ***COMPRESSION***
- ***TENSION***

Forces Mécaniques Déterminant le Type de Lésion

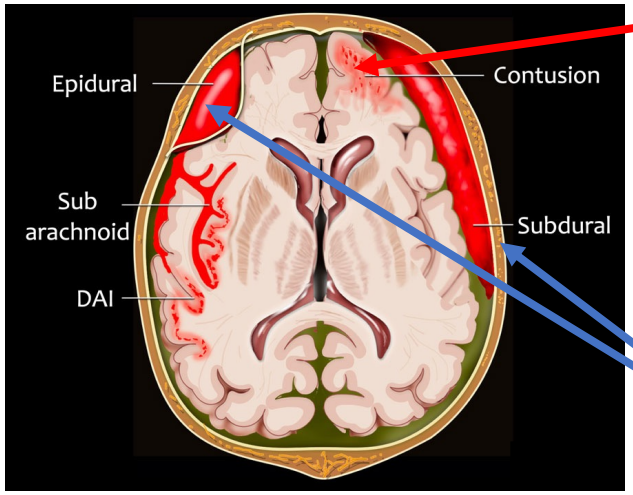


COMPRESSION / TENSION <-> FOCAL

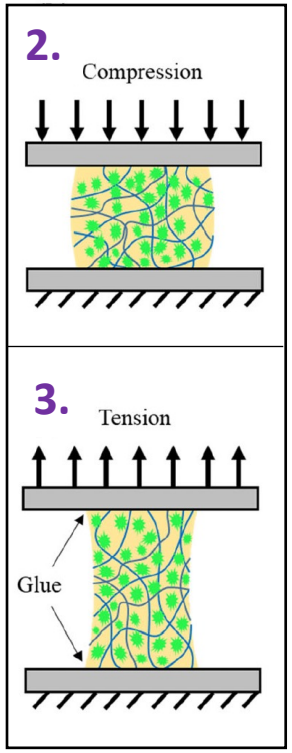
LÉSIONS au POINT d'IMPACT :

- ***HÉMORRAGIE:***
  - ***CONTUSIONS CÉRÉBRALES***
  - ***Hémorragie EXTRA-Cérébrale :***
    - **Hématome épidural**
    - **Hématome sous-dural**
    - **Hémorragie sous-arachnoïdienne**

Forces Mécaniques Déterminant le Type de Lésion



CONTUSION



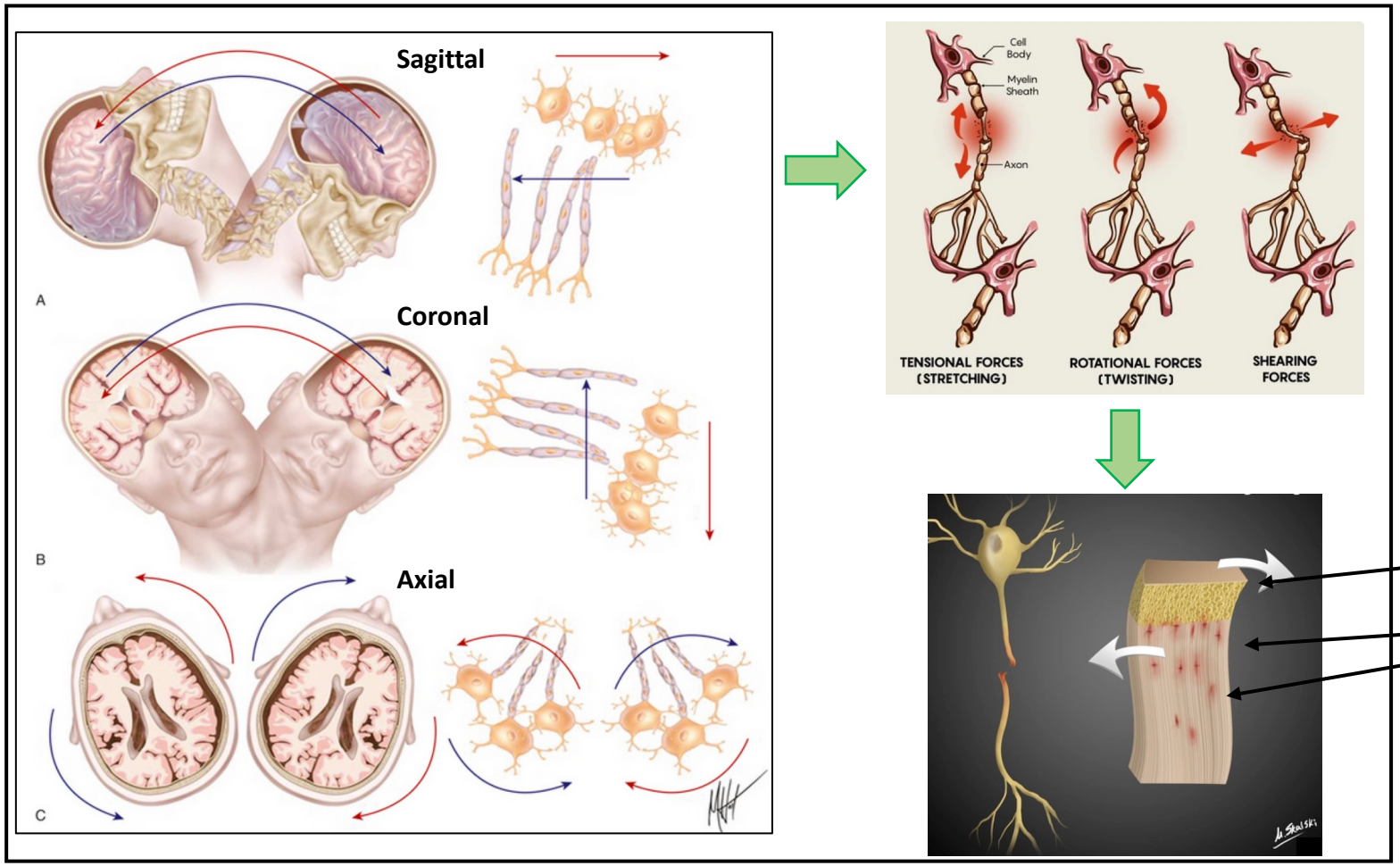
HEMORRHAGE

COMPRESSION / TENSION <-> FOCAL

LÉSIONS au POINT d'IMPACT :

- ***HÉMORRAGIE:***
  - ***CONTUSIONS CÉRÉBRALES***
  - ***Hémorragie EXTRA-Cérébrale :***
    - **Hématome épidural**
    - **Hématome sous-dural**
    - **Hémorragie sous-arachnoïdienne**

Forces Mécaniques Déterminant le Type de Lésion



CISAILLEMENT/TENSION <-> DIFFUS

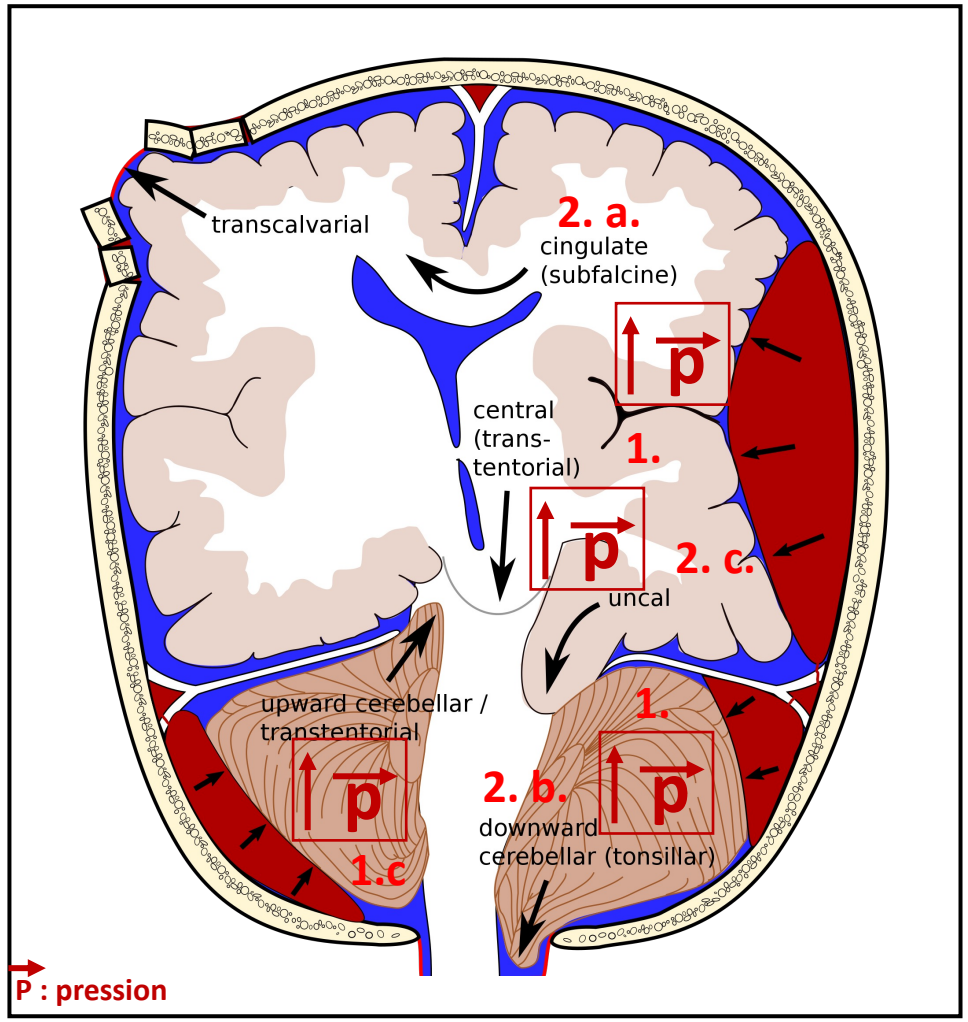
LÉSIONS DIFFUSES :

- ***LÉSIONS AXONALES:***
  - ***PETITES***
  - ***MULTIPLES***

"DÉCHIREMENT DU TISSU CÉRÉBRAL"

Pavlovic et al., Pituitary, 2019

Complications Aiguës



1. **HYPERTENSION INTRACRÂNIENNE** $\uparrow \vec{p}$
2. **HERNIATION**
   a. Sous-falcorielle
   b. Amygdalienne
   c. Uncale (Parahippocampe)

⇩

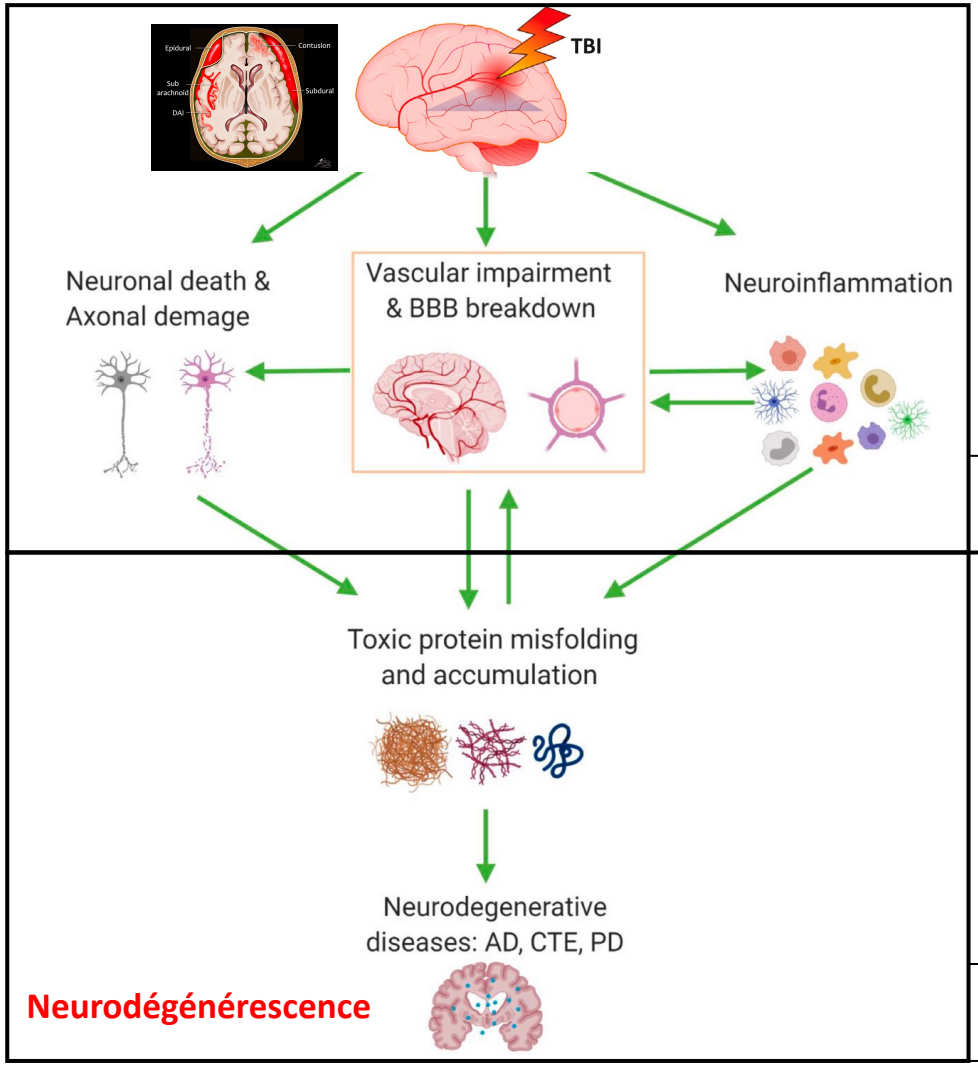
SITUATION ENGAGEANT le PRONOSTIC VITAL

Pavlovic, Pituitary, 2019

2. BIOPHYSIQUE, PHYSIOPATHOLOGIE, IMAGERIE

2.2 PHYSIOPATHOLOGIE

Physiopathologie Cérébrale



AIGUE

PHASE <u>AIGUE</u>

- Mort cellulaire
- Rupture axonale
- Barrière hémato- encéphalique (rupture)
- Réaction inflammatoire

CHRONIQUE

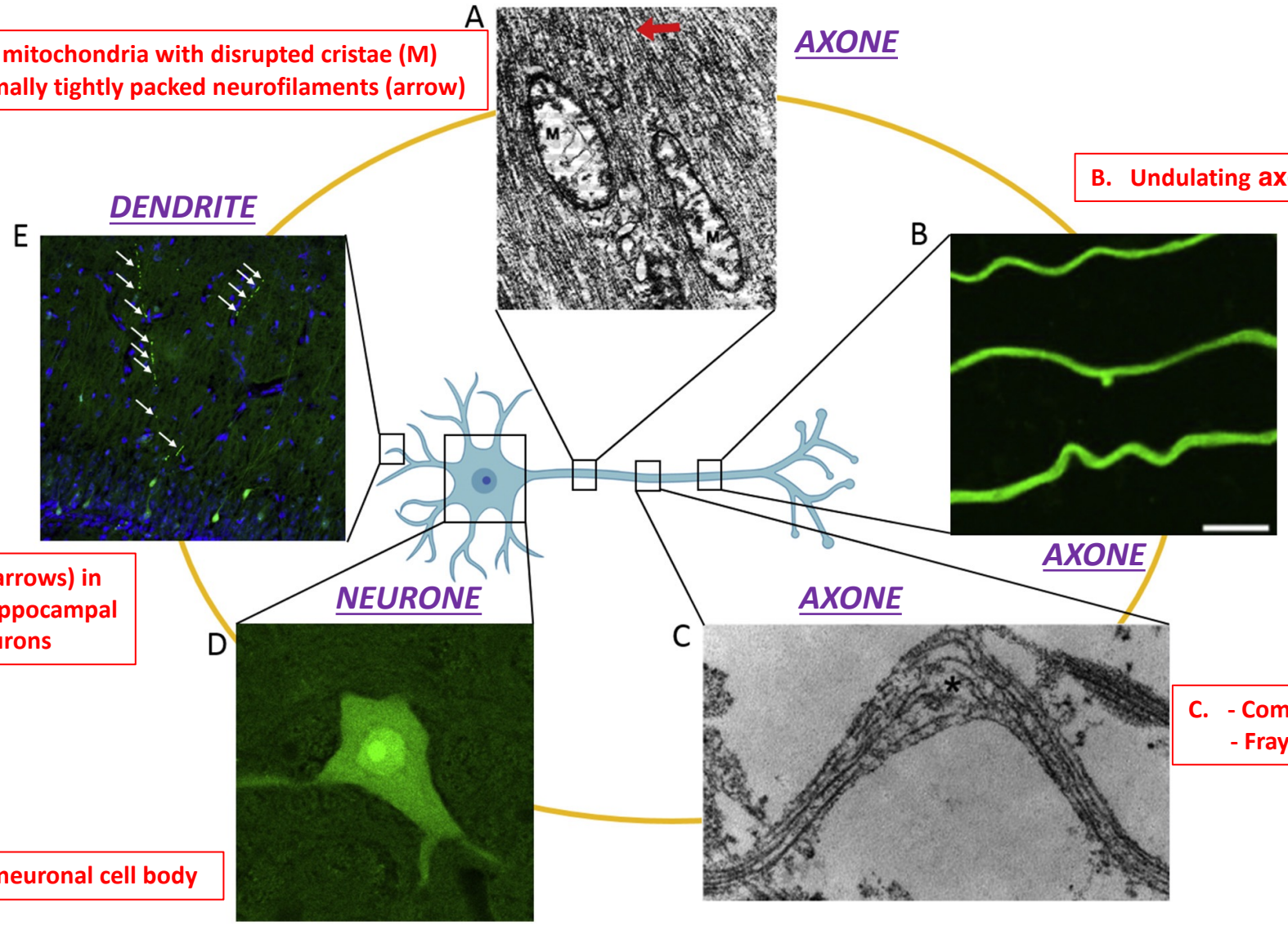
PHASE <u>CHRONIQUE</u> (possible)

- Accumulation de protéines toxiques
- **NEURODÉGÉNÉRESCENCE:**
  - Maladie d'Alzheimer/Parkinson
  - **Encéphalopathie traumatique chronique**

Wu et al., Front Physiol, 2021

Physiopathologie Cérébrale

A. - Dilated mitochondria with disrupted cristae (M)
- Abnormally tightly packed neurofilaments (arrow)



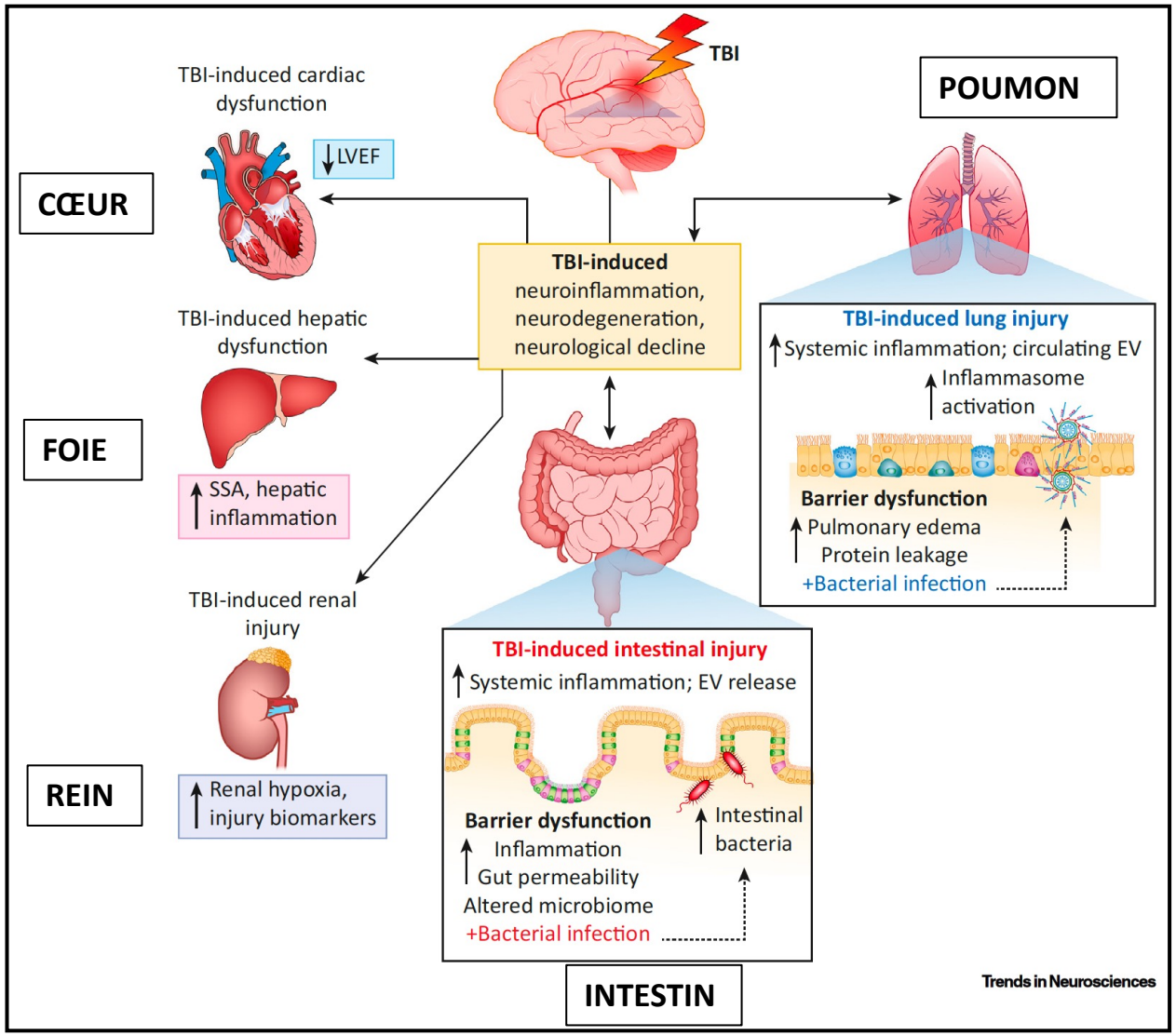
E. Dendritic beading (arrows) in mechanoporated hippocampal dentate granule neurons

C. - Compaction + misalignment of axon microtubules
- Frayed broken ends (asterisk)

D. Permeabilized neuronal cell body

Keating, Neurobiol Dis, 2021

Physiopathologie Systémique



DYSFONCTION HORMONALE/IMMUNITAIRE :

- ***COEUR*** *(Takotsubo)*
- ***Foie***
- ***Rein***
- ***Poumon***
- ***Intestin***

Habituellement réversible

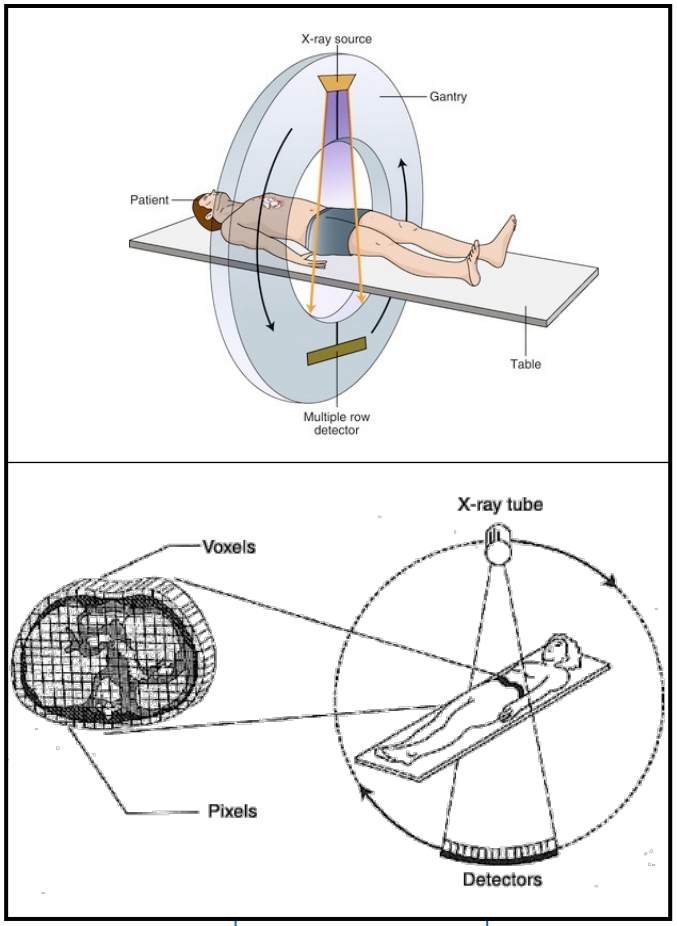
Faden et al., Trends Neurosci, 2021

2. BIOPHYSIQUE, PHYSIOPATHOLOGIE, IMAGERIE

2.3. IMAGERIE CÉRÉBRALE

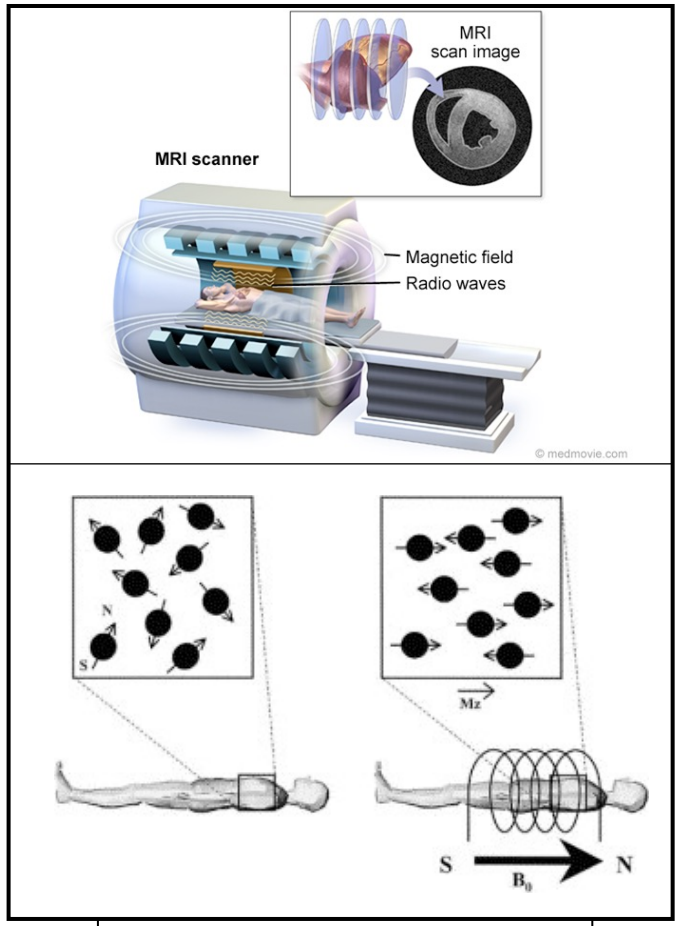
Techniques d'Imagerie Cérébrale

TDM



RAYONS X

IRM



CHAMP MAGNÉTIQUE

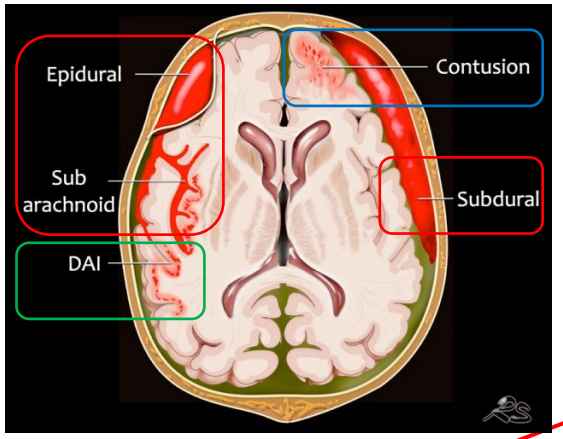
IMAGERIE PAR RÉSONANCE MAGNÉTIQUE (IRM)

TOMODENSITOMÉTRIE (TDM)

RÉSOLUTION : IRM > TDM

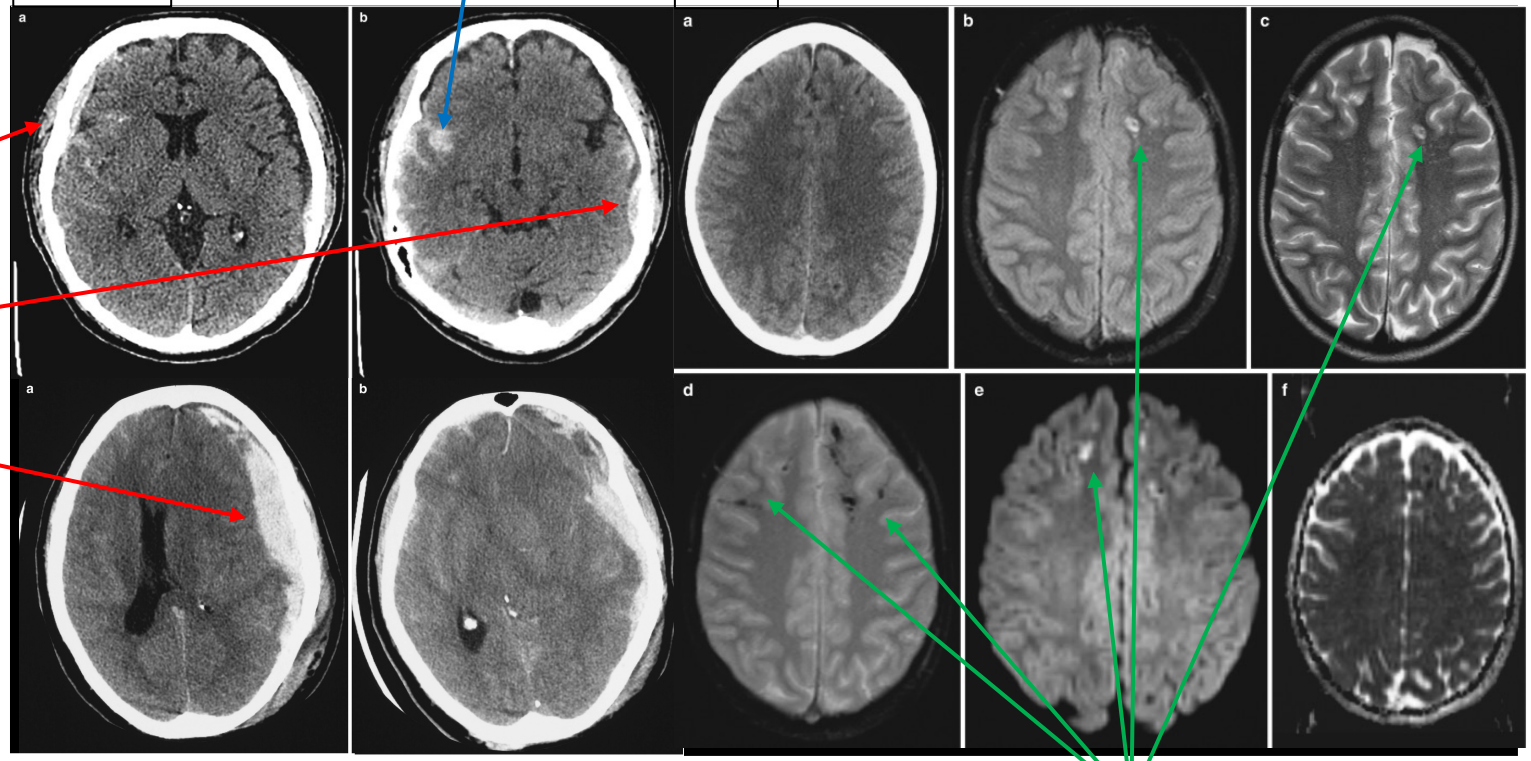
(IRM -> lésions axonales, petites contusions)

Imagerie Cérébrale



Contusion cérébrale

TDM **IRM**



Hémorragie sous-arachnoïdienne
Hématome épidural
Hématome sous-dural

Lésions axonales

3. DÉFINITION et CLASSIFICATION (sévérité)

3. DÉFINITION et CLASSIFICATION (sévérité)

3.1. DÉFINITION

Définition du Traumatisme Cérébral

1. ***TROUBLE FONCTIONNEL*** **(SÉMIOLOGIE)**

   OU

2. Mise en évidence d'une ***PATHOLOGIE***

} ***CAUSÉ*** par une ***FORCE EXTERNE***

⇕

1. ***TROUBLE FONCTIONNEL***, comprenant au moins :

   1. Episode de ***TROUBLE*** *de la* ***CONSCIENCE***
   2. ***PERTE*** *de* ***MÉMOIRE*** (immédiate rétrograde ou post-traumatique amnésie)
   3. Déficits neurologiques
   4. ***Trouble de l'état mental*** au moment de l'accident

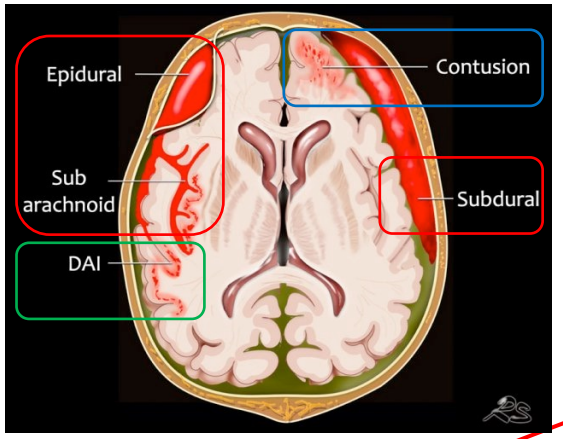
2. Mise en évidence d'une ***PATHOLOGIE***

   Confirmation non clinique d'une ***ATTEINTE*** cérébrale :

   - Anomalie ***NEURORADIOLOGIQUE***
   - (Laboratoire)

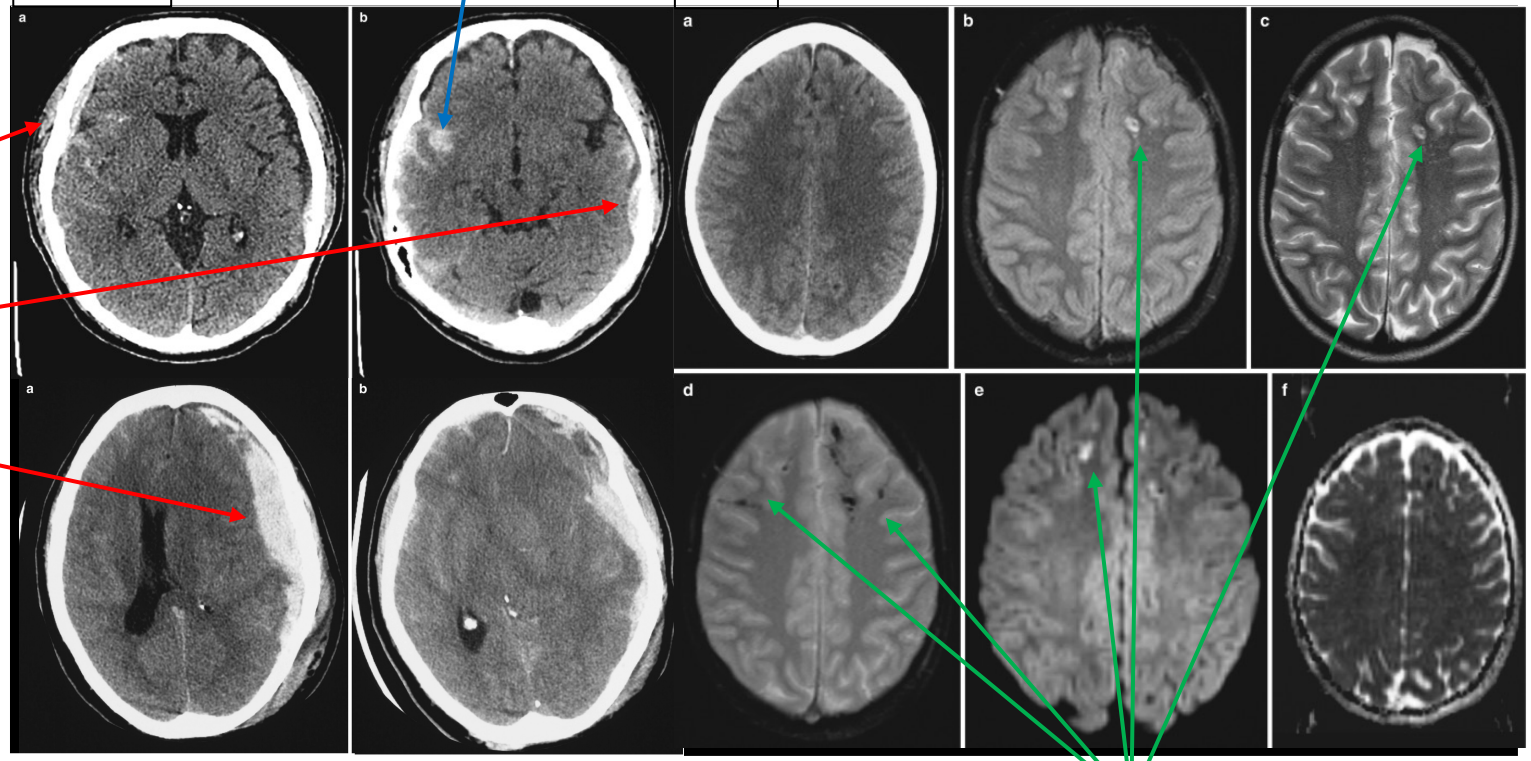
Menon, Arch Phys Med Rehabil, 2010

Imagerie Cérébrale



Contusion cérébrale

TDM **IRM**



Hémorragie sous-arachnoïdienne
Hématome épidural
Hématome sous-dural

Lésions axonales

3. DÉFINITION et CLASSIFICATION (sévérité)

3.2. CLASSIFICATION de la SEVERITE

Critères de Classification de la Sévérité

1. ***TROUBLE FONCTIONNEL***, comprenant au moins :

1. Episode de ***TROUBLE*** *de la* ***CONSCIENCE***
2. ***PERTE*** *de* ***MÉMOIRE*** (immédiate rétrograde ou post-traumatique amnésie)
3. Déficits neurologiques
4. ***Trouble de l'état mental*** au moment de l'accident

2. Mise en évidence d'une ***PATHOLOGIE***

Confirmation non clinique d'une ***ATTEINTE*** cérébrale :

- Anomalie ***NEURORADIOLOGIQUE***
- (Laboratoire)

- *Trouble de la CONSCIENCE*
- *PERTE de MÉMOIRE*
- *Altération* ***de l'****État Mental*

- ***Anomalies*** *ANATOMIQUES*

ÉLÉMENTS de la Définition

CRITÈRES pour classer le degré de SÉVÉRITÉ
(Classification de la sévérité)

Critères de Classification de la Sévérité

Exemples de Guidelines de Classification (>40)

Peu d'indicateurs

Plus d'indicateurs

Table 1 | Classification of traumatic brain injury severity.

Criteria	Mild	Moderate	Severe
ARLINGHAUS ET AL. (16)			
Glasgow coma scale	13–15	9–12	≤8
Loss of consciousness	30 min or less or none	30 min to 1 week	More than 1 week
Post-traumatic amnesia	Less than 24 h	More than 24 h less than 1 week	More than 1 week
VA/DoD			
Glasgow coma scale	13–15	9–12	≤8
Loss of consciousness	0–30 min	30 min to 24 h	More than 24 h
Post-traumatic amnesia	Less than 24 h or none	More than 24 h less than 1 week	More than 1 week
Alteration of consciousness/mental state	A moment up to 24 h	>24 h, severity based on other criteria	>24 h, severity based on other criteria

Table 2 | Comparison of TBI classification criteria.

Class of injury	Greenwald et al. (18)	Rao and Lyketsos (19)
Mild	Cognitively altered or loss of consciousness less than 30 min	Loss of consciousness less than 30 min
Moderate	Cognitively altered or loss of consciousness 30 min to 6 h	Loss of consciousness 1–24 h
Severe	Loss of consciousness greater than 6 h	Loss of consciousness more than 24 h

Multi-d'indicateurs

TABLE 1. MAYO TBI SEVERITY CLASSIFICATION SYSTEM

A. Classify as Moderate-Severe (Definite) TBI if one or more of the following criteria apply:
1. Death due to this TBI
2. Loss of consciousness of 30 minutes or more
3. Post-traumatic anterograde amnesia of 24 hours or more
4. Worst Glasgow Coma Scale full score in first 24 hours <13 (unless invalidataed upon review, e.g., attributable to intoxication, sedation, systemic shock)
5. One or more of the following present:
   - Intracerebral hematoma
   - Subdural hematoma
   - Epidural hematoma
   - Cerebral contusion
   - Hemorrhagic contusion
   - Penetrating TBI (dura penetrated)
   - Subarachnoid hemorrhage
   - Brain Stem Injury

B. If none of Criteria A apply, classify as Mild (Probable) TBI if one or more of the following criteria apply:
1. Loss of consciousness of momentary to less than 30 minutes
2. Post-traumatic anterograde amnesia of momentary to less than 24 hours
3. Depressed, basilar or linear skull fracture (dura intact)

C. If none of Criteria A or B apply, classify as Symptomatic (Possible) TBI if one or more of the following symptoms are present:
- Blurred vision
- Confusion (mental state changes)
- Dazed
- Dizziness
- Focal neurologic symptoms
- Headache
- Nausea

CRITÈRES

- ***Trouble de la CONSCIENCE***
- ***AMNÉSIE POST-TRAUMATIQUE***
- ***ÉCHELLE DE GLASGOW***
- Altération de l'État Mental

\+

- **ANATOMIQUES anomalies**

Malec et al., J Neurotrauma, 2007; Rapp et al., Front Neurol, 2013

Classification de la Sévérité du TC

Peu d'indicateurs

Plus d'indicateurs

Table 1 | Classification of traumatic brain injury severity.

Criteria	Mild	Moderate	Severe
ARLINGHAUS ET AL. (16)			
Glasgow coma scale	13–15	9–12	≤8
Loss of consciousness	30 min or less or none	30 min to 1 week	More than 1 week
Post-traumatic amnesia	Less than 24 h	More than 24 h less than 1 week	More than 1 week
VA/DoD			
Glasgow coma scale	13–15	9–12	≤8
Loss of consciousness	0–30 min	30 min to 24 h	More than 24 h
Post-traumatic amnesia	Less than 24 h or none	More than 24 h less than 1 week	More than 1 week
Alteration of consciousness/mental state	A moment up to 24 h	>24 h, severity based on other criteria	>24 h, severity based on other criteria

Table 2 | Comparison of TBI classification criteria.

Class of injury	Greenwald et al. (18)	Rao and Lyketsos (19)
Mild	Cognitively altered or loss of consciousness less than 30 min	Loss of consciousness less than 30 min
Moderate	Cognitively altered or loss of consciousness 30 min to 6 h	Loss of consciousness 1–24 h
Severe	Loss of consciousness greater than 6 h	Loss of consciousness more than 24 h

Multi-d'indicateurs

TABLE 1. MAYO TBI SEVERITY CLASSIFICATION SYSTEM

A. Classify as Moderate-Severe (Definite) TBI if one or more of the following criteria apply:
1. Death due to this TBI
2. Loss of consciousness of 30 minutes or more
3. Post-traumatic anterograde amnesia of 24 hours or more
4. Worst Glasgow Coma Scale full score in first 24 hours <13 (unless invalidataed upon review, e.g., attributable to intoxication, sedation, systemic shock)
5. One or more of the following present:
   - Intracerebral hematoma
   - Subdural hematoma
   - Epidural hematoma
   - Cerebral contusion
   - Hemorrhagic contusion
   - Penetrating TBI (dura penetrated)
   - Subarachnoid hemorrhage
   - Brain Stem Injury

B. If none of Criteria A apply, classify as Mild (Probable) TBI if one or more of the following criteria apply:
1. Loss of consciousness of momentary to less than 30 minutes
2. Post-traumatic anterograde amnesia of momentary to less than 24 hours
3. Depressed, basilar or linear skull fracture (dura intact)

C. If none of Criteria A or B apply, classify as Symptomatic (Possible) TBI if one or more of the following symptoms are present:
- Blurred vision
- Confusion (mental state changes)
- Dazed
- Dizziness
- Focal neurologic symptoms
- Headache
- Nausea

CLASSIFICATION

- ***LÉGER*** ***(B)***
- ***MODÉRÉ*** ***(A)***
- ***SÉVÈRE*** ***(A)***
- (Symptomatique (C))

Malec et al., J Neurotrauma, 2007; Rapp et al., Front Neurol, 2013

Exemple de Classification de la Sévérité

Exemple de Classification : ***MAYO***

TABLE 1. MAYO TBI SEVERITY CLASSIFICATION SYSTEM

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   - Hemorrhagic contusion
   - Penetrating TBI (dura penetrated)
   - Subarachnoid hemorrhage
   - Brain Stem Injury

B. If none of Criteria A apply, classify as Mild (Probable) TBI if one or more of the following criteria apply:
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2. Post-traumatic anterograde amnesia of momentary to less than 24 hours
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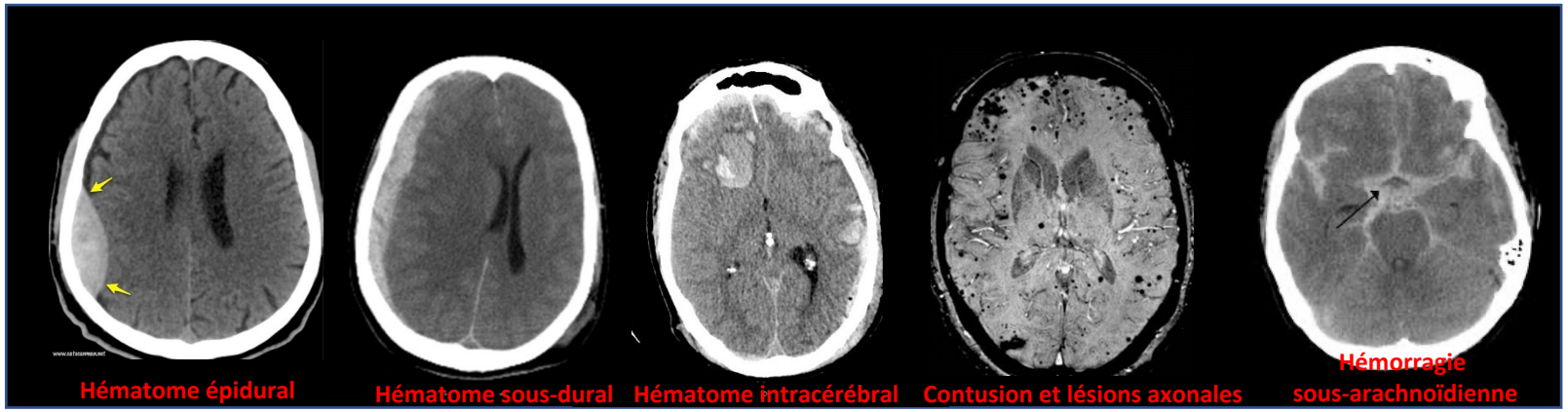
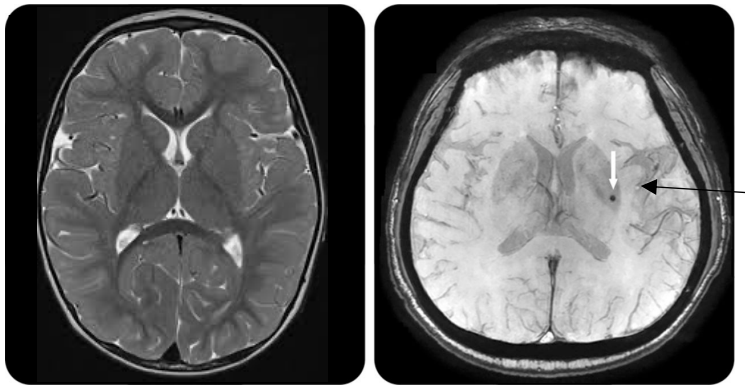
C. If none of Criteria A or B apply, classify as Symptomatic (Possible) TBI if one or more of the following symptoms are present:
- Blurred vision
- Confusion (mental state changes)
- Dazed
- Dizziness
- Focal neurologic symptoms
- Headache
- Nausea

TC SÉVÈRE (/MODÉRÉ)





Lésion trop “limite” pour une classification “modérée”

TC LÉGER

Répartition des Types de Sévérité

TABLE 2. Characteristics and overview of TBI severity studies

Parameter	Country	WHO Region	Income Level	Sample Size (no.)	Severity Index	Severity (% injuries)		
						Mild	Moderate	Severe
Authors & Year								
Selassie et al., 2014	US	AMR-US/Can	High	33,695	AIS	45.7	19.63	34.67
Bener et al., 2011	Qatar	EMR	High	1,952	GCS	82.94	9.528	7.53
Siman-Tov et al., 2016	Israel	EUR	High	2,419	GCS	72.59	9.384	18.02
Szarpak & Madziała, 2011	Poland	EUR	High	1,031	GCS	82.44	10.18	7.37
Ji et al., 2015	China	WPR	Middle	195,189	Other	78.87	18.51	2.62
Chiu et al., 2007	Taiwan	WPR	Middle	1,474	GCS	82.7	8.82	8.48
Chiu et al., 2007	Taiwan	WPR	Middle	5,754	GCS	87.46	5.89	6.64
Overall estimate				241,514		81.02	11.04	7.95

AIS = Abbreviated Injury Scale; GCS = Glasgow Coma Scale.

REPARTITION

- ***LÉGER*** ***~81%***
- ***MODÉRÉ*** ***~11%***
- ***SÉVÈRE*** ***~ 8%***

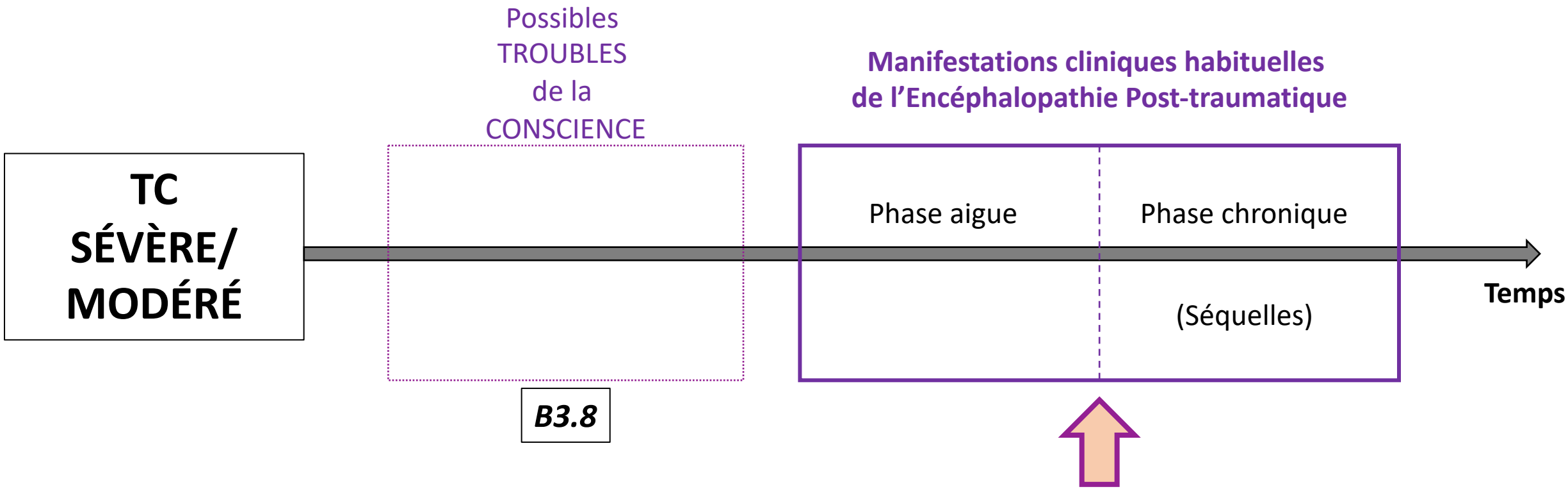
Dewan et al., J Neurosurg, 2018

4. TYPE et SÉVÉRITÉ des SYMPTÔMES

4. TYPE et SÉVÉRITÉ des SYMPTÔMES

4.0. PRÉAMBULE

Sémiologie (phases aigue et chronique)

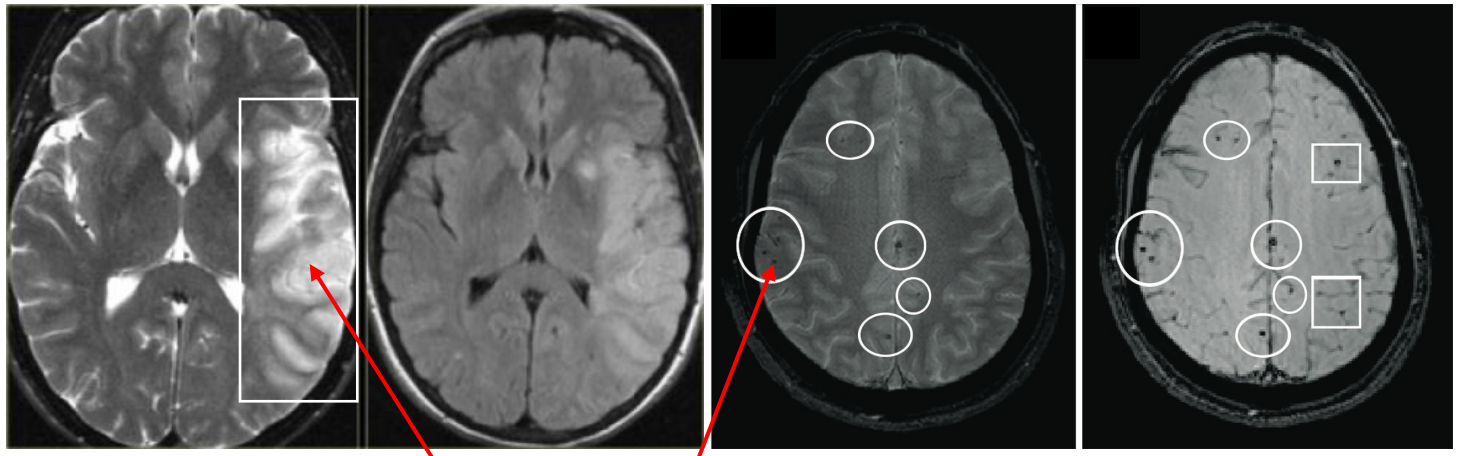


Symptomatologie (phases aigue et chronique)
dépend en priorité
des facteurs neurologique/cérébraux

4. TYPE et SÉVÉRITÉ des SYMPTÔMES

4.1. LIEN : LÉSIONS CÉRÉBRALES et SÉVÉRITÉ CLINIQUE/OUTCOME

Qu'est-ce qui Détermine la Sévérité des Symptômes ?



SÉVÉRITÉ DES SYMPTÔMES?

Quel est le LIEN

entre

LÉSIONS

&

SÉVÉRITÉ des SYMPTÔMES?

Lien en Général entre Lésions et Sévérité Clinique

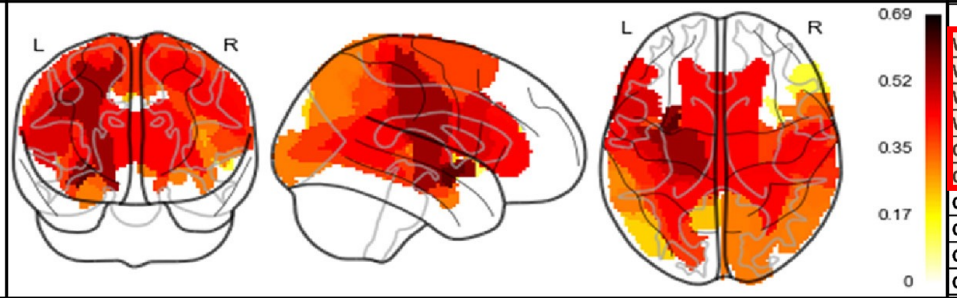
Aires Cognitives
(en part. Langage)

Aires Motrices primaires

Aires Sensitives primaires

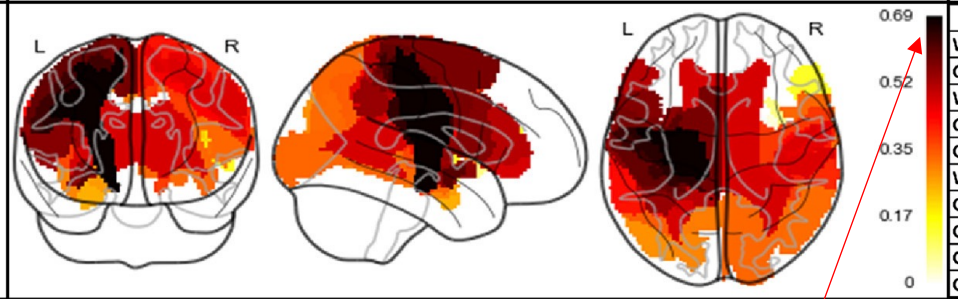
	Correlations by region	Top ten correlates

mRS 3 month



	Correlation
WM Uncinate fascicle L	0.604
WM Inferior occipito-frontal fascicle L	0.554
WM Corticospinal tract L	0.541
WM Superior longitudinal fascicle L	0.484
GM Primary somatosensory cortex BA3a L	0.482
GM Broca's area BA44 L	0.476
GM Primary auditory cortex TE1.2 L	0.463
GM Primary motor cortex BA4p R	0.45
GM Primary motor cortex BA4p L	0.449
GM Primary somatosensory cortex BA3b L	0.448

NIHSS 3 month



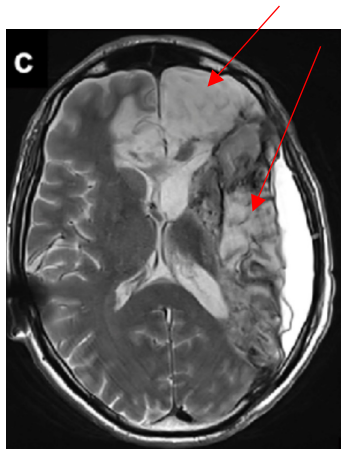
	Correlation
WM Corticospinal tract L	0.695
GM Primary somatosensory cortex BA3a L	0.662
WM Superior longitudinal fascicle L	0.65
GM Primary somatosensory cortex BA3b L	0.638
GM Primary motor cortex BA4p L	0.616
WM Uncinate fascicle L	0.609
GM Primary somatosensory cortex BA1 L	0.601
GM Primary motor cortex BA4a L	0.586
GM Primary somatosensory cortex BA2 L	0.58
GM Premotor cortex BA6 L	0.578

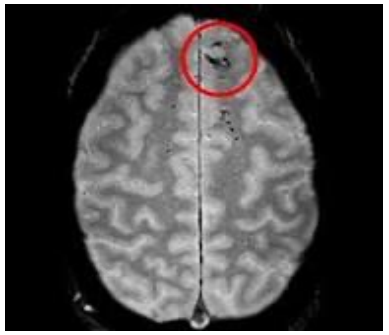
Sévérité clinique plus élevée

A. *LOCALISATION*
des
lésions

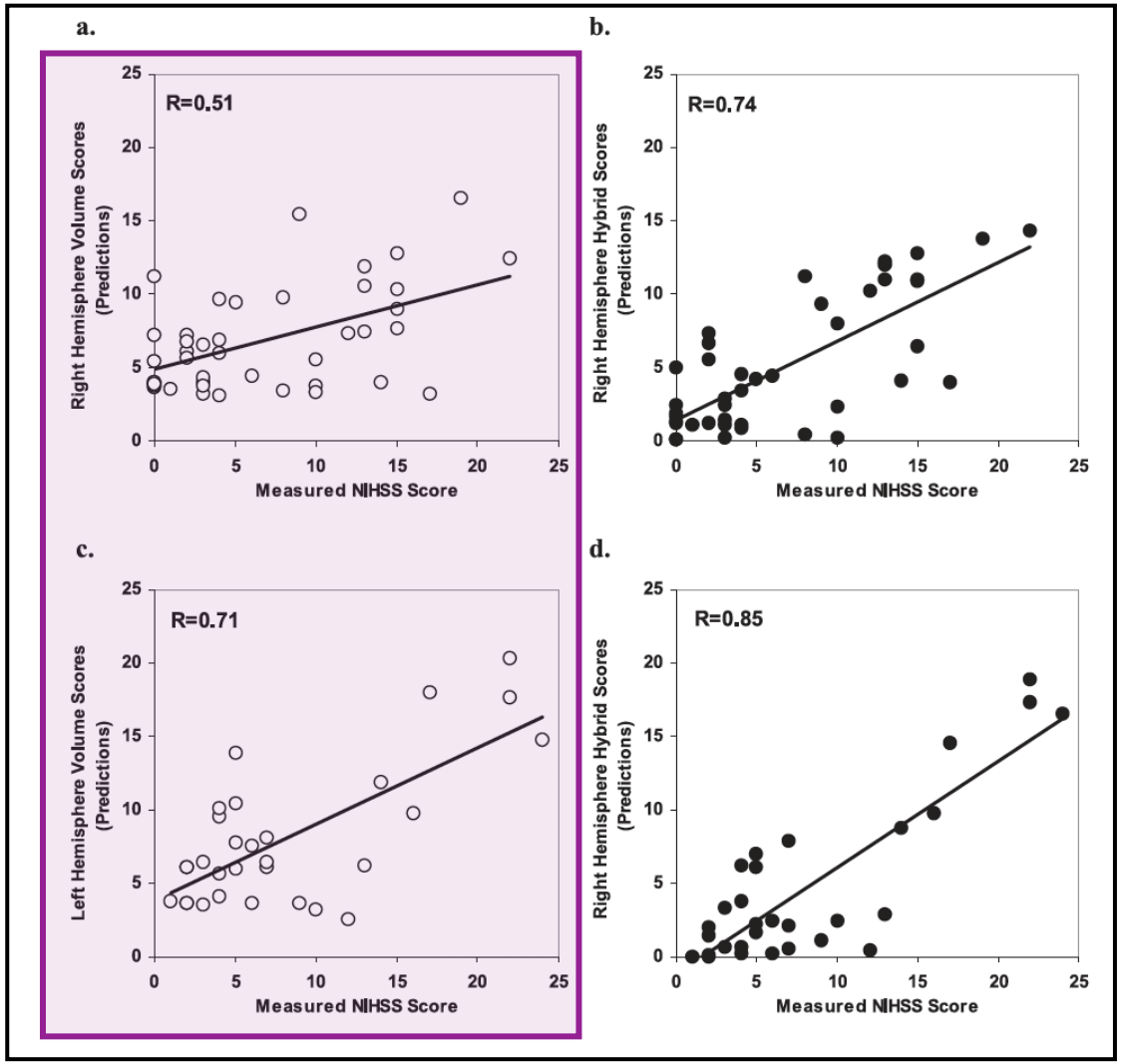
Habegger et al., Front Neurol 2018

Lien en Général entre Lésions et Sévérité Clinique





VOLUME DES LÉSIONS

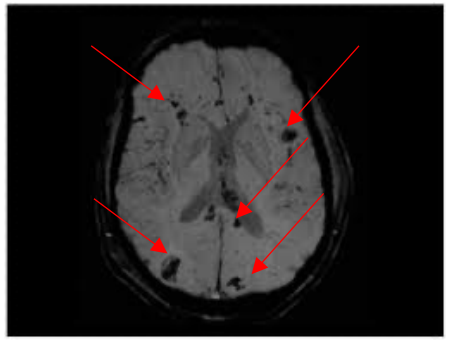


SÉVÉRITÉ CLINIQUE

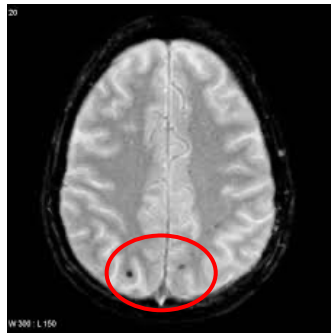
B. ***VOLUME*** des lésions

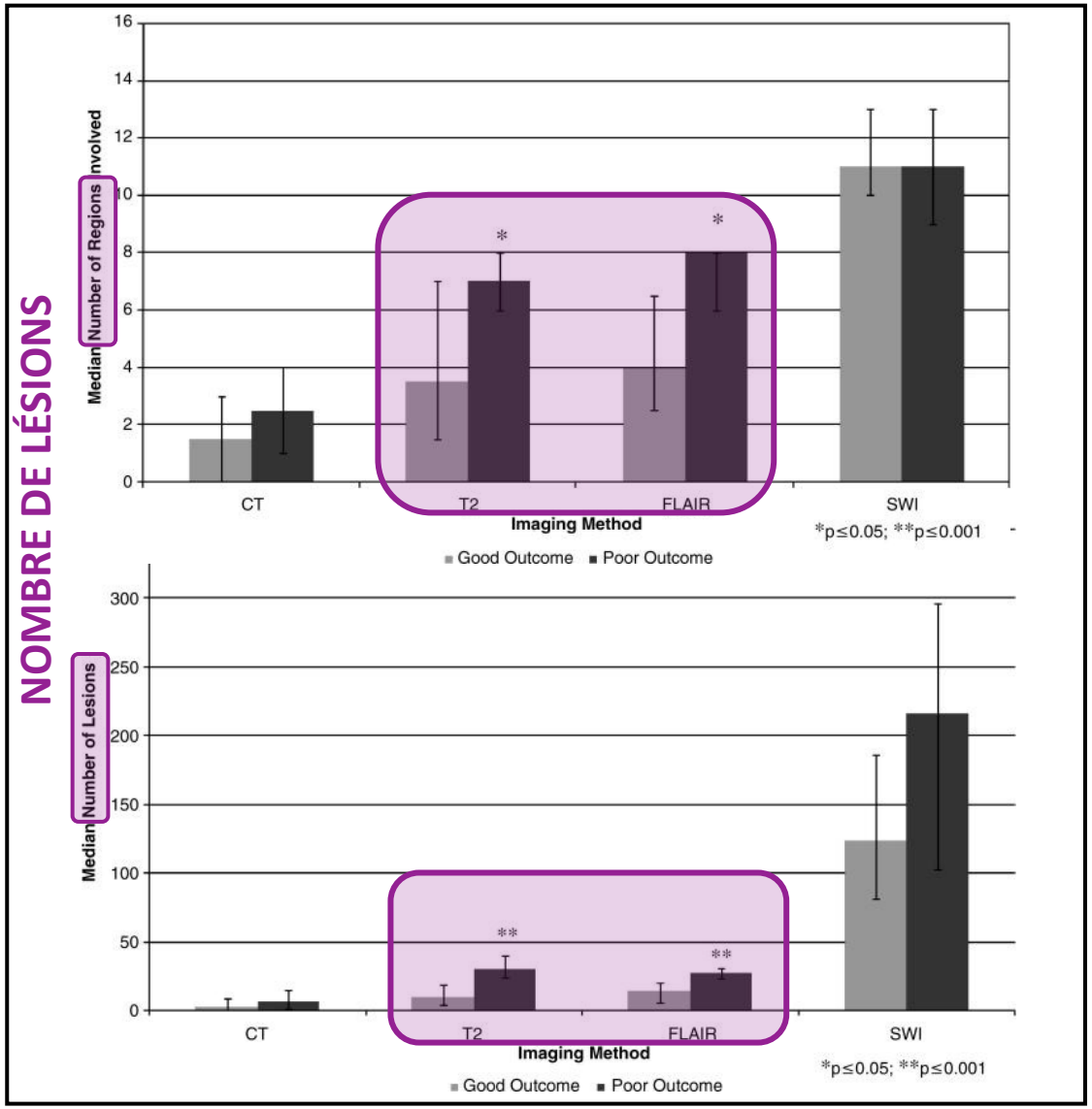
Menezes et al,. Stroke , 2007

Lien en Général entre Lésions et Sévérité Clinique



Par exemple :
LÉSIONS AXONALES





C. *NOMBRE* des lésions

Chastain et al., J Neurotrauma 2009

Lien entre Lésions et Sévérité Clinique/Outcome

SÉVÉRITÉ CLINIQUE liée à la/au **LOCALISATION** / **VOLUME** / **NOMBRE** des lésions

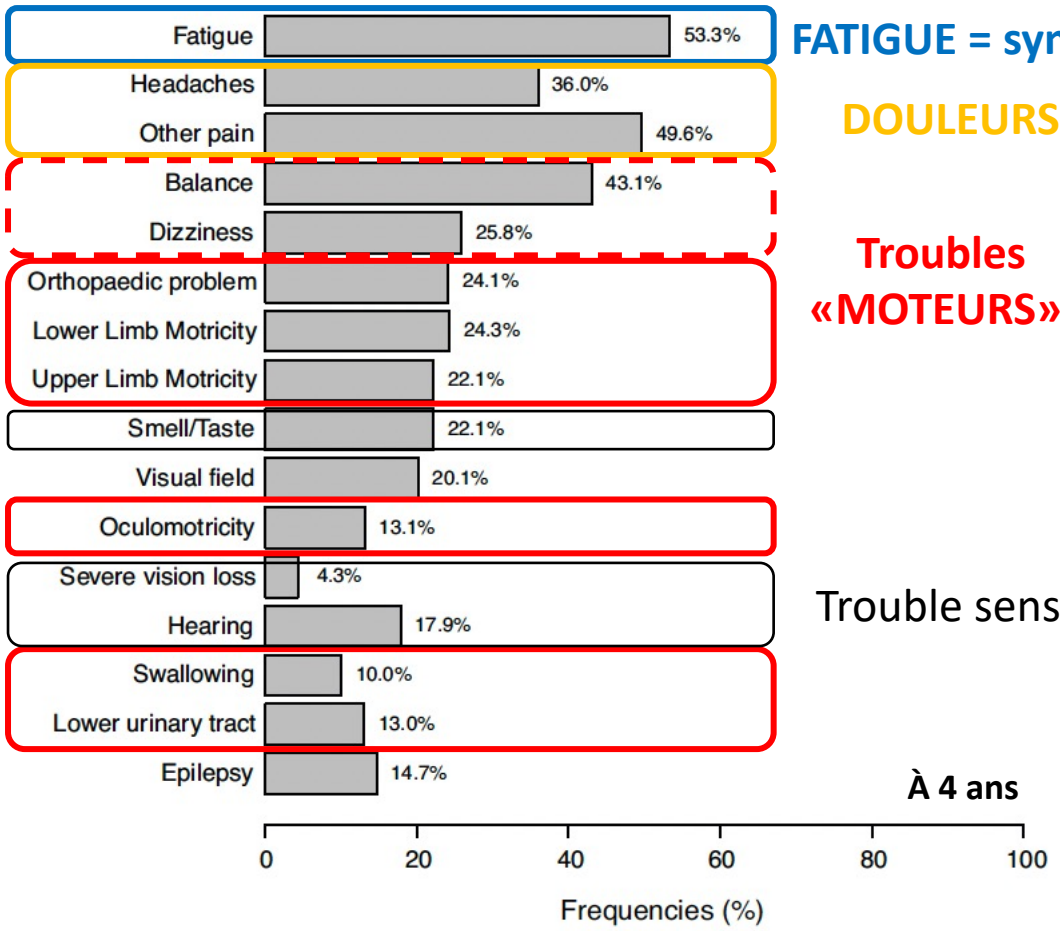


OUTCOME liée à la/au **LOCALISATION** / **VOLUME** / **NOMBRE** des lésions

4. TYPE et SÉVÉRITÉ des SYMPTÔMES

4.2. TC MODÉRÉ et SÉVÈRE

Séquelles Motrices et Physiques



FATIGUE = symptôme «UNIVERSEL» (>50 %)

DOULEURS (~50 %) – Céphalées (37%)

Troubles «MOTEURS»

• **ÉQUILIBRE**	**>40%**
• Motricité	<25%
• Oculomotricité	<15%
• Sphynctères	13 %
• Déglutition	10 %

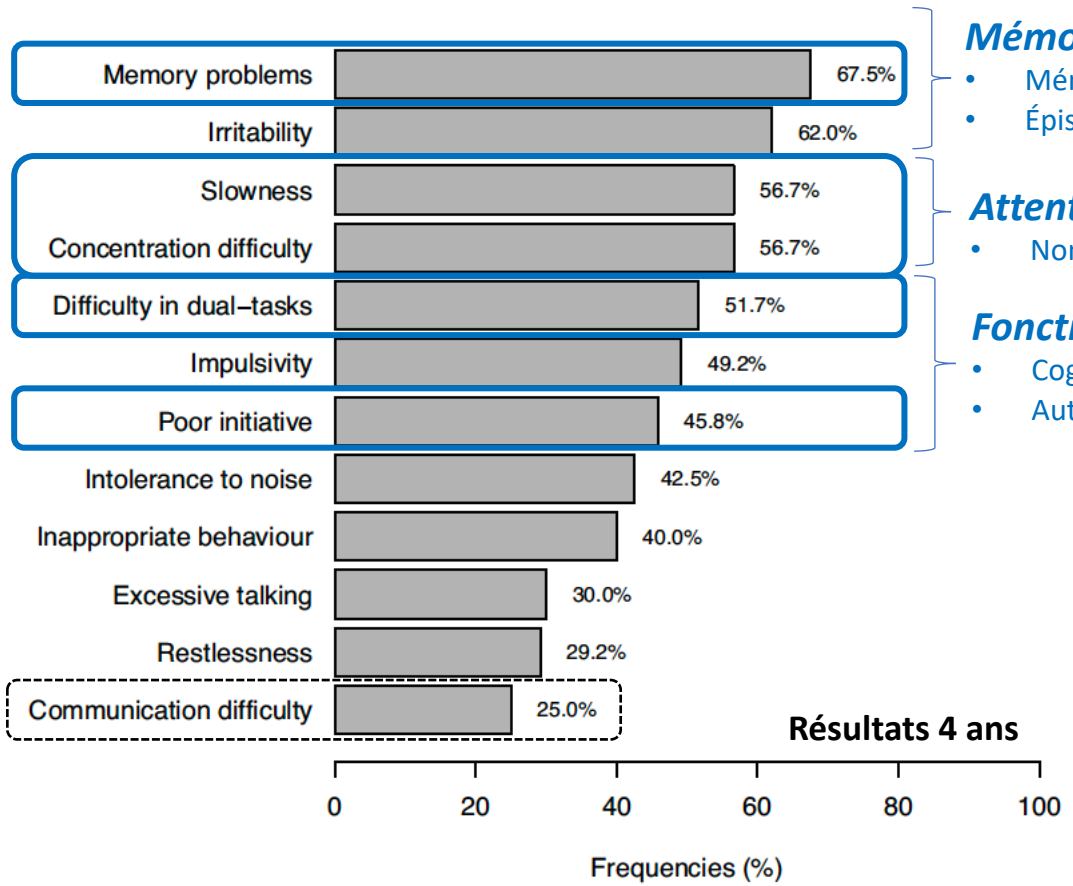
Trouble sensitif (<25 %)

↑ FATIGUE
↑ DOULEURS
↑ Trouble de l'ÉQUILIBRE

↓ Atteinte MOTRICE
↓ Trouble SENSITIF

Jourdan et al., Ann Phys Rehabil Med, 2016

Séquelles Neuropsychologiques



Mémoire
- Mémoire de travail
- Épisodique

Attention
- Non latéralisée

Fonctions exécutives
- Cognitif complexe
- Auto-initiation

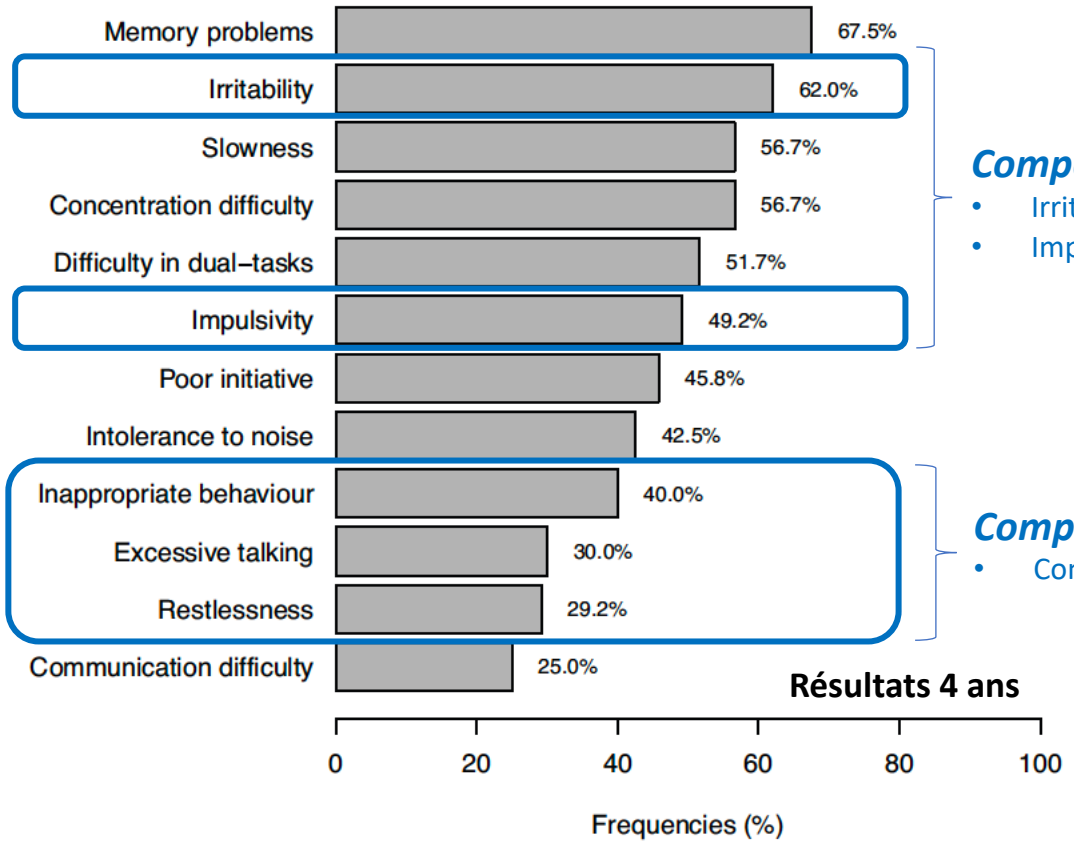
↑ Trouble de la MÉMOIRE
Trouble de l'ATTENTION
Dysfonction EXÉCUTIVE

↓ Trouble du LANGAGE

"Neuropsychologique
≃
Cognitif"

Jourdan et al., Ann Phys Rehabil Med, 2016

Séquelles Comportementales



Comportement (fréquent)

- Irritabilité (>60 %)
- Impulsivité (~50 %)

Comportement

- Comportement inapproprié

- **Irritabilité**
- **Impulsivité**
- **Comportement inapproprié**

“Comportement inclut Emotion”

Jourdan et al., Ann Phys Rehabil Med, 2016

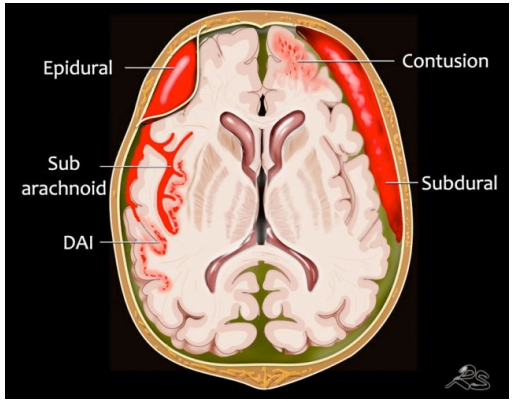
Pourquoi des Symptômes si Complexes dans le TC ?

Symptômes « complexes» :

- Troubles de l'***équilibre***
- Troubles de ***fonctions cognitives*** complexes
- Troubles du ***comportement***
- ***Fatigue***

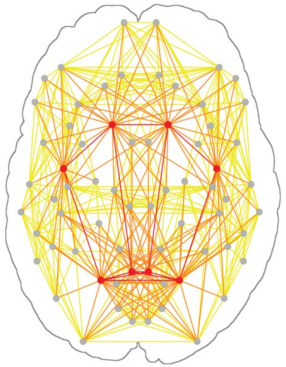
EN RAISON DE

1.



LÉSIONS MULTIPLES et DIFFUSES

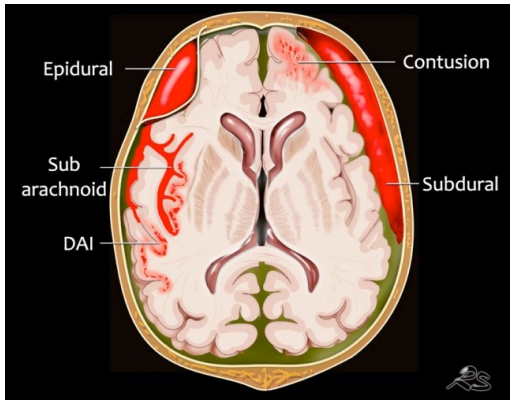
2.



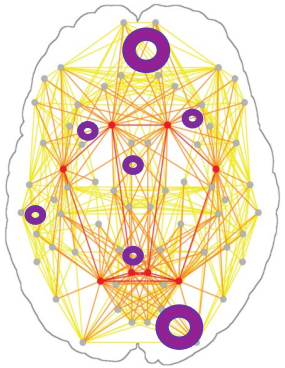
RÉSEAUX COMPLEXES soutenant des FONCTIONS CÉRÉBRALES COMPLEXES

Pourquoi des Symptômes si Complexes dans le TC ?

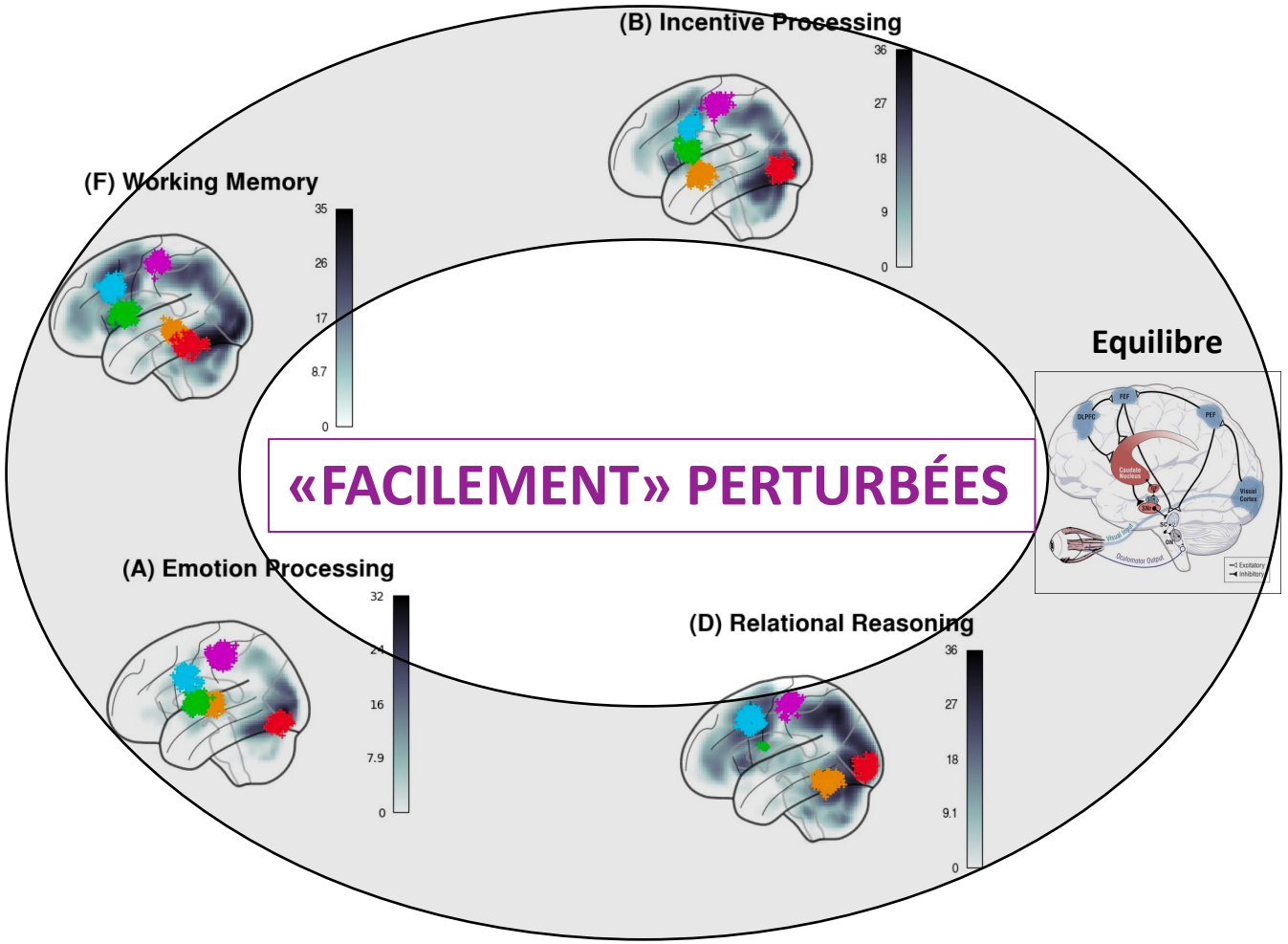
LÉSIONS MULTIPLES et DIFFUSES («petites»)



Lésion



PERTURBATION DU RÉSEAU COMPLEXE



PERTURBATION des FONCTIONS CÉRÉBRALES COMPLEXES car elles dépendent de grands réseaux complexes

Impact dans le lien avec les autres

Symptômes « complexes» :

- Troubles de l'***équilibre***
- Troubles de ***fonctions cognitives*** complexes
- Troubles du ***comportement***
- ***Fatigue***

SYMPTÔMES "CACHÉS"

SYMPTÔMES NON RECONNUS par les AUTRES

SOURCE de SOUFFRANCE

4. TYPE et SÉVÉRITÉ des SYMPTÔMES

4.3. TC LÉGER

Diagnostic du TC Léger (ACRM)

Table 2. Diagnostic Criteria for Mild Traumatic Brain Injury by the American Congress of Rehabilitation Medicine (ACRM)
A patient with mild traumatic brain injury is a person who has had a traumatically induced physiological disruption of brain function, as manifested by one or more of the following: • Any period of loss of consciousness for up to 30 minutes • Any loss of memory for events immediately before or after the accident for as much as 24 hours • Any alteration of mental state at the time of the accident (e.g., feeling dazed, disoriented, or confused) • Focal neurological deficit(s) that may or may not be transient
But where the severity of the injury does not exceed the following: • Loss of consciousness exceeding 30 minutes • Post-traumatic amnesia longer than 24 hours • A Glasgow Coma Scale (GCS) score falling below 13 after 30 minutes

Adapted from McCrea, 2008 and Ruff, 2005

Toute perturbation cérébrale, min. 1 signe:

- **Perte de connaissance <30min**
- **Amnésie criconstancielle <24h**
- **Tout changement mental (cognition/émotion/comportement)**
- **Tout changement neurologique**

Einarsen, J Neurotrauma, 2019

Sémiologie du TC Léger

1. Neurologiques

- Céphalées
- Vertiges
- Troubles visuels
- Troubles auditifs

2. Cognitifs

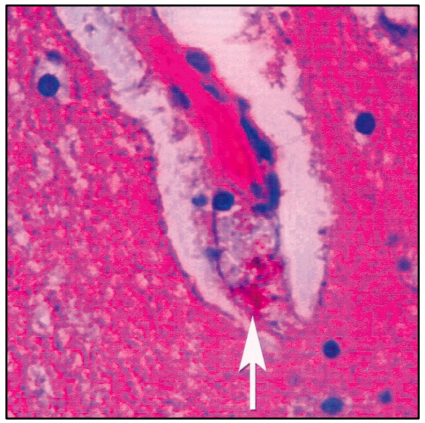
- Troubles de l'attention
- Troubles de la mémoire de travail

3. Emotionnels/comportementaux

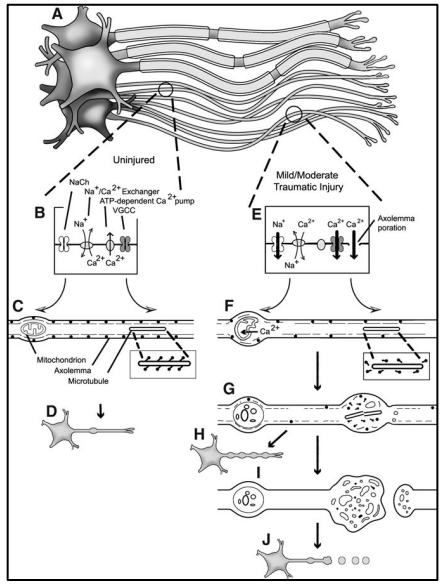
- Fatigue
- Troubles du sommeil
- Irritabilité
- Labilité émotionnelle

Symptômes de perception ("Subjectifs")

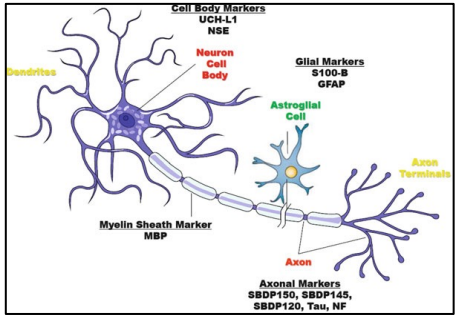
Physiopathologie du TC Léger



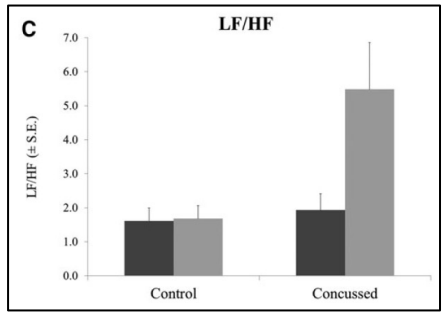
Micro-saignements



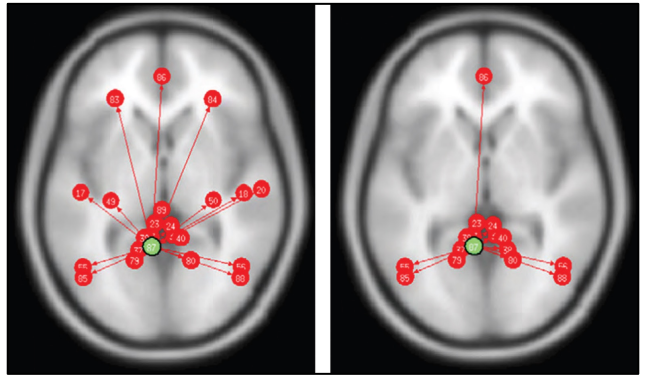
Perturbation axonale



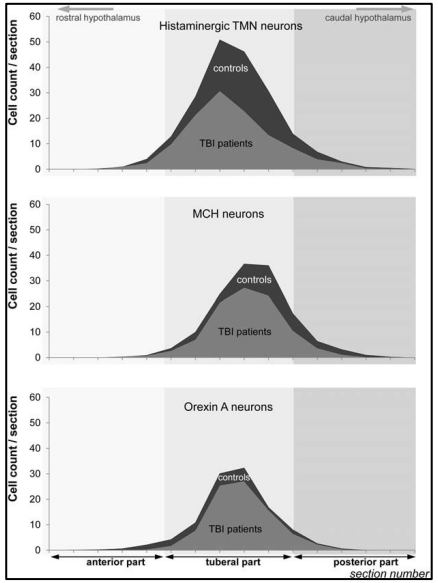
Perturbation cellulaire



Perturbation de la fréquence cardiaque



Perturbation du réseau cérébral

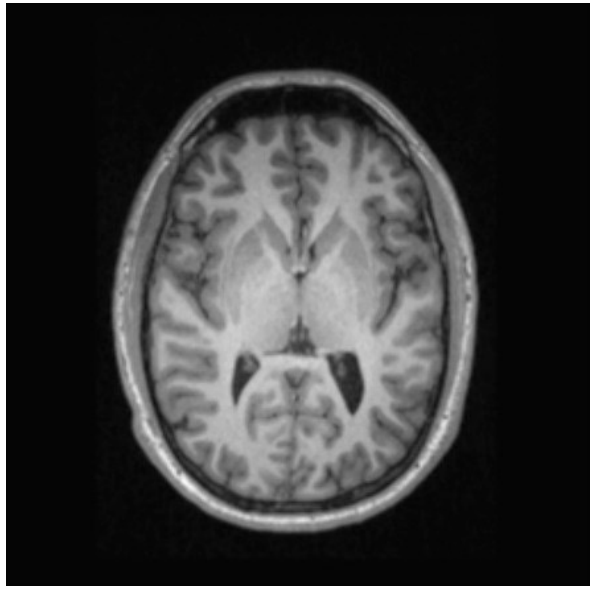


Perturbation des hormones du sommeil

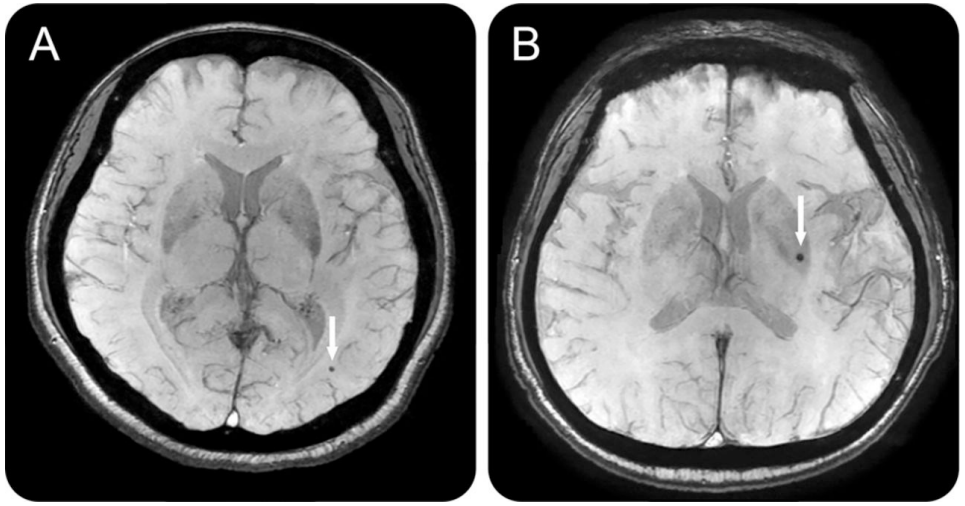
ETC.

Beaucoup de “MICRO-”Perturbations

Neuro-imagerie du TC Léger



OU



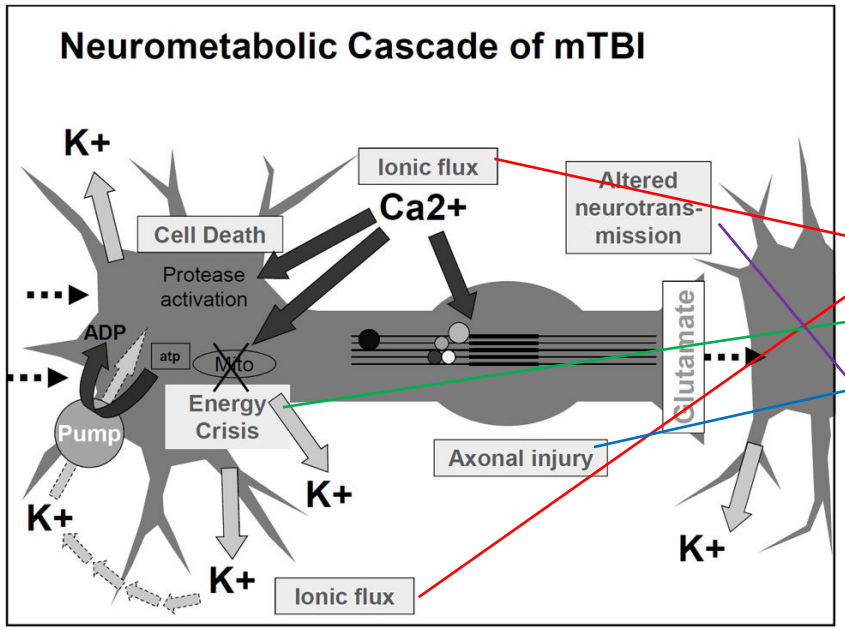
PAS de LESIONS : >88%

LESION millimétrique : <12%

Einarsen, J Neurotrauma, 2019

Beaucoup de *"MICRO-"PERTURBATIONS* MAIS non-visibles à l'imagerie

Mécanisme de la Symptomatologie



Physiological perturbations after concussion and proposed clinical correlates.

Post-TBI pathophysiology	Acute symptom / clinical correlate
Ionic flux	Migraine headache, photophobia, phonophobia
Energy crisis	Vulnerability to second injury
Axonal injury	Impaired cognition, slowed processing, slowed reaction time
Impaired neurotransmission	Impaired cognition, slowed processing, slowed reaction time
Protease activation, altered cytoskeletal proteins, cell death	Chronic atrophy, development of persistent impairments

- ***Perturbation du Flux Ionique*** → ***Céphalées, Phono-photophobie***
- ***Crise Énergétique*** → ***Fragilité aux Lésions, Fatigue***
- ***Lésion Axonale***
- ***Perturbation de la Neurotransmission***

→ ***Troubles Cognitifs/Compotementaux***

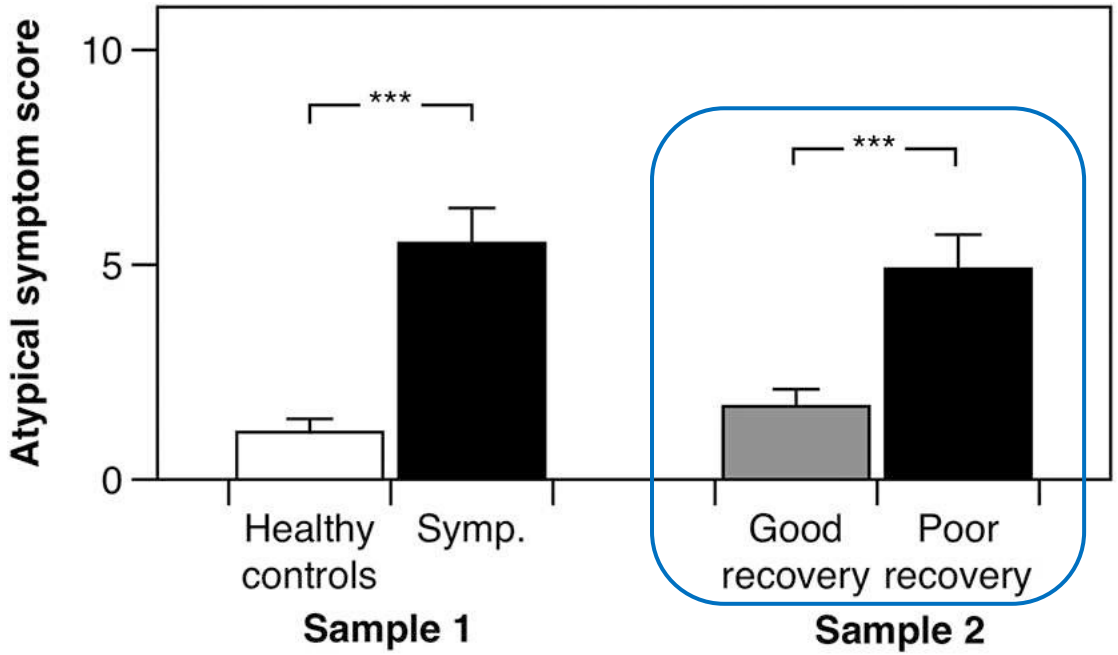
Giza et al., Neurosurg, 2014

Sémiologie Somatique Atypique

Troubles Gastrointestinaux

Plaintes Musculosquelettique

Plaintes Cardiorespiratoires



Stubbs, 2020



5. OUTCOME

5. OUTCOME

5.1. TC MODÉRÉ et SÉVÈRE

Quel Outcome avec des Symptômes "Complexes" ?

Symptômes « complexes» :

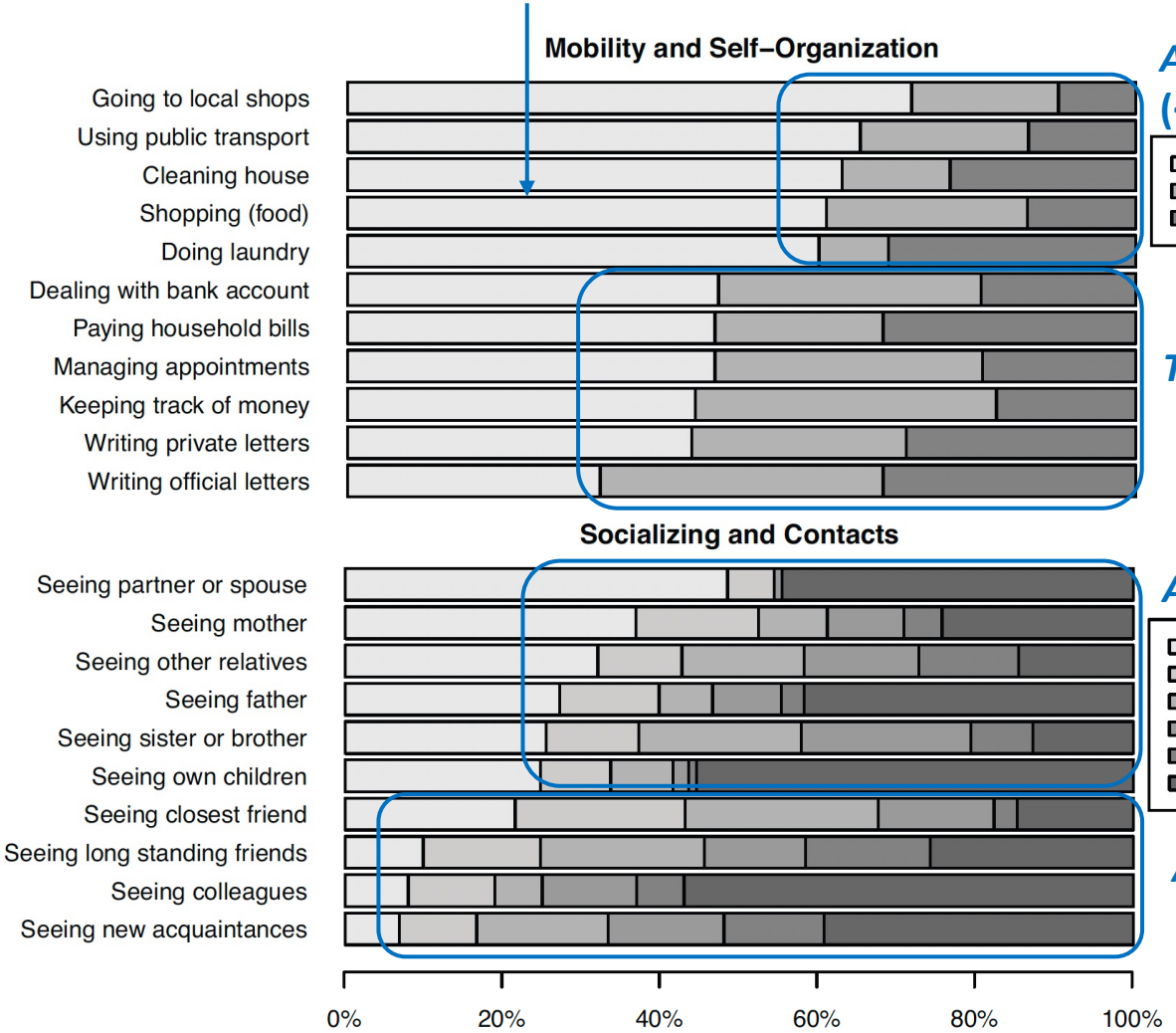
- Troubles de l'***équilibre***
- Troubles de ***fonctions cognitives*** complexes
- Troubles du ***comportement***
- ***Fatigue***



Difficultés dans les Activités "Complexes"

Indépendance Fonctionnelle à Long Terme

Indépendence



***Activités de la vie quotidienne* (<70%)**

***Tâches administratives* (<50%)**

***Activités familiales* (<50%)**

***Activités sociales* (<25%)**

INDÉPENDANCE

- **Activités complexes**
- **Tâches administratives**
- **Activités familiales**
- **Activités sociales**

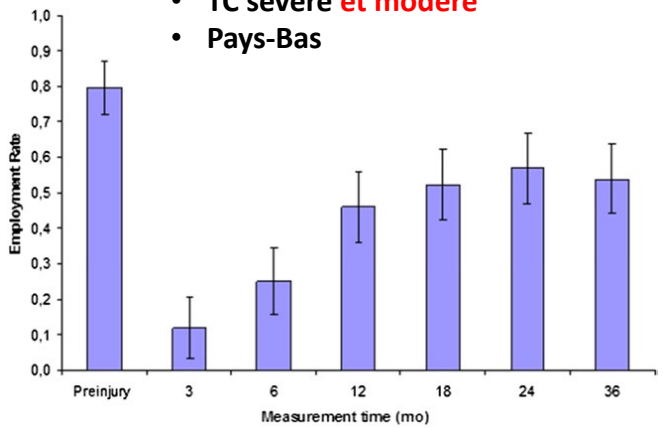
Jourdan et al., Ann Phys Rehabil Med, 2016

Reprise Professionnelle

INDÉPENDANCE

- **Activités complexes**
- **Tâches administratives**
- **Activités familiales**
- **Activités sociales**

- **3 ans post-TC**
- **TC sévère et modéré**
- **Pays-Bas**



- 53% taux d'emploi
- **40% taux d'emploi** (mêmes conditions prétrauma)

- **4 ans post-TC**
- **TC sévère**
- **France**

- 38% taux d'emploi
- **24% taux d'emploi >20h/sem**

REPRISE du TRAVAIL

Ruet et al., Disabil Rehabil, 2018
Grauwmeijer, Arch Phys Med Rehabil, 2013

Situation Financière

REPRISE du TRAVAIL

Table 4. Work status of those previously working

	Head-injured (*n*=24)			Friend control (*n*=55)
Returned to work	1 Month**	1 Year **	2 Years *	1 Year
No	24 (100%)	16 (67%)	13 (54%)	8 (15%)
Yes	0 (0%)	8 (33%)	11 (46%)	47 (85%)

Chi-square: $^{**}p < 0{\cdot}0001$; $^{*}p < 0{\cdot}001$.

Table 5a. Financial status of those previously working

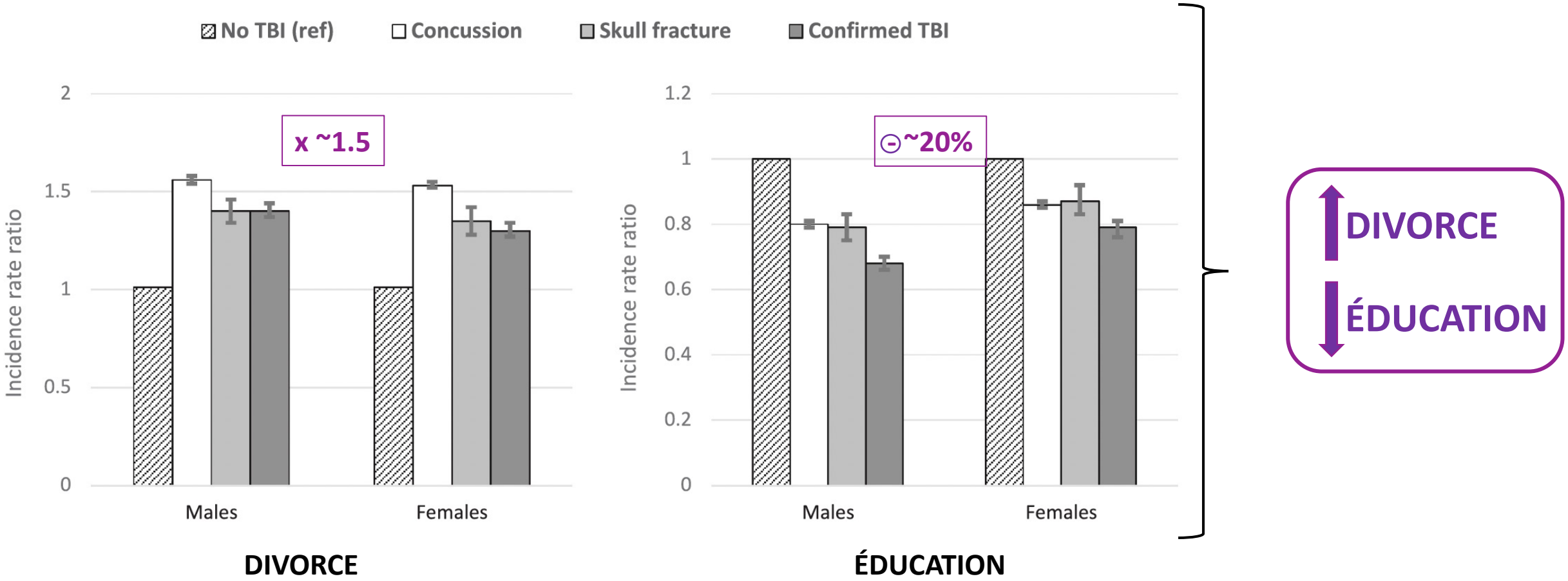
	Pre-injury		Post-injury		
			1 Year*	2 Years*	1 Year
	Head-injured	Friend control	Head-injured		Friend control
Subject earnings	(*n*=24)	(*n*=67)	(*n*=24)		(*n*=55)
$\bar{X}$ Income range last 12 months	$10,000-14,999	$10,000–14,999	<$3,000	$3,000–3,999	$10,000–14,999

Mann-Whitney: $^{*}p < 0{\cdot}0001$; $\bar{X}$: average.

SITUATION FINANCIÈRE

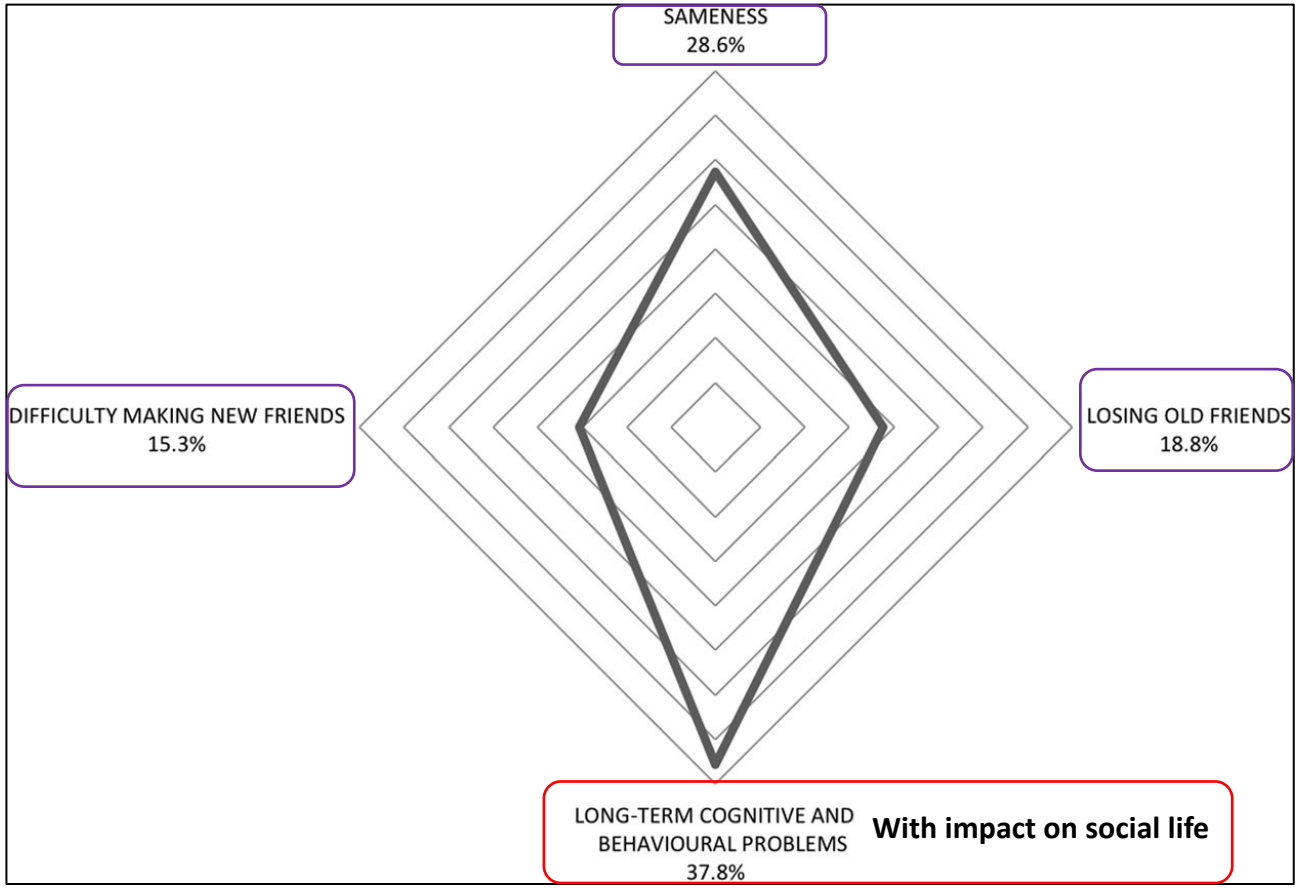
Dikmen, 1993

Divorce et Éducation



Dikmen, 1993

Vie Sociale



VIE SOCIALE

DIVERSITÉ SOCIALE

Salas, Neuropsychological Rehabilitation, 2018

Qualité de Vie

TABLE 1. DESCRIPTION OF QOLIBRI SCALES AND CONTENT

QOLIBRI scale	*Number of items*	*Content*
		"Satisfaction: items:
Cognition	7	Cognitive problems such as memory, attention, expressive speech, and decision making
Self	7	Aspects of self, including energy, motivation, physical appearance, and self-esteem
Daily life and autonomy	7	Independence, activities of daily life, and participation in social roles
Social relationships	6	Relationships with friends, family, and partner
		"Bothered" items
Emotions	5	Feelings of depression, anxiety, loneliness, boredom, and anger
Physical problems	5	Physical problems, such as slowness, pain, sensory impairment, or other consequences of injury

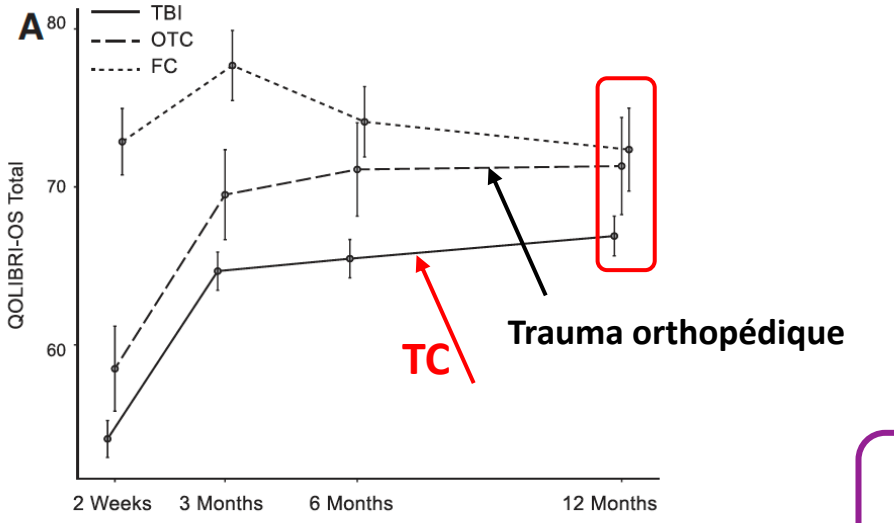
QOLIBRI, Quality of Life after Brain Injury.

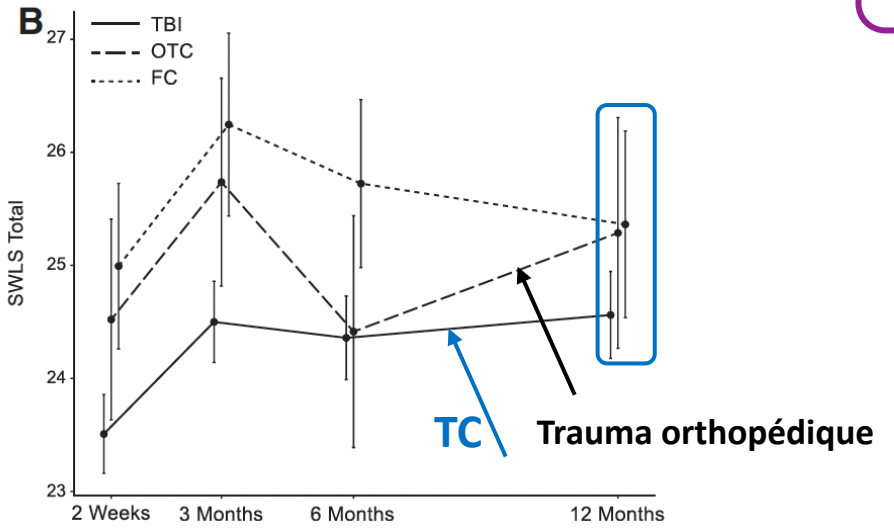
QOLIBRI

		Strongly Disagree	Disagree	Slightly Disagree	Neither Agree nor Disagree	Slightly Agree	Agree	Strongly Agree
1.	In most ways my life is close to my ideal.	1	2	3	4	5	6	7
2.	The conditions of my life are excellent.	1	2	3	4	5	6	7
3.	I am satisfied with my life.	1	2	3	4	5	6	7
4.	So far I have gotten the important things I want in life.	1	2	3	4	5	6	7
5.	If I could live my life over, I would change almost nothing.	1	2	3	4	5	6	7

Score	Level of Satisfaction with Life
31 - 35	Extremely satisfied
26 - 30	Satisfied
21 - 25	Slightly satisfied
20	Neutral
15 - 19	Slightly dissatisfied
10 - 14	Dissatisfied
5 - 9	Extremely dissatisfied

SWLS



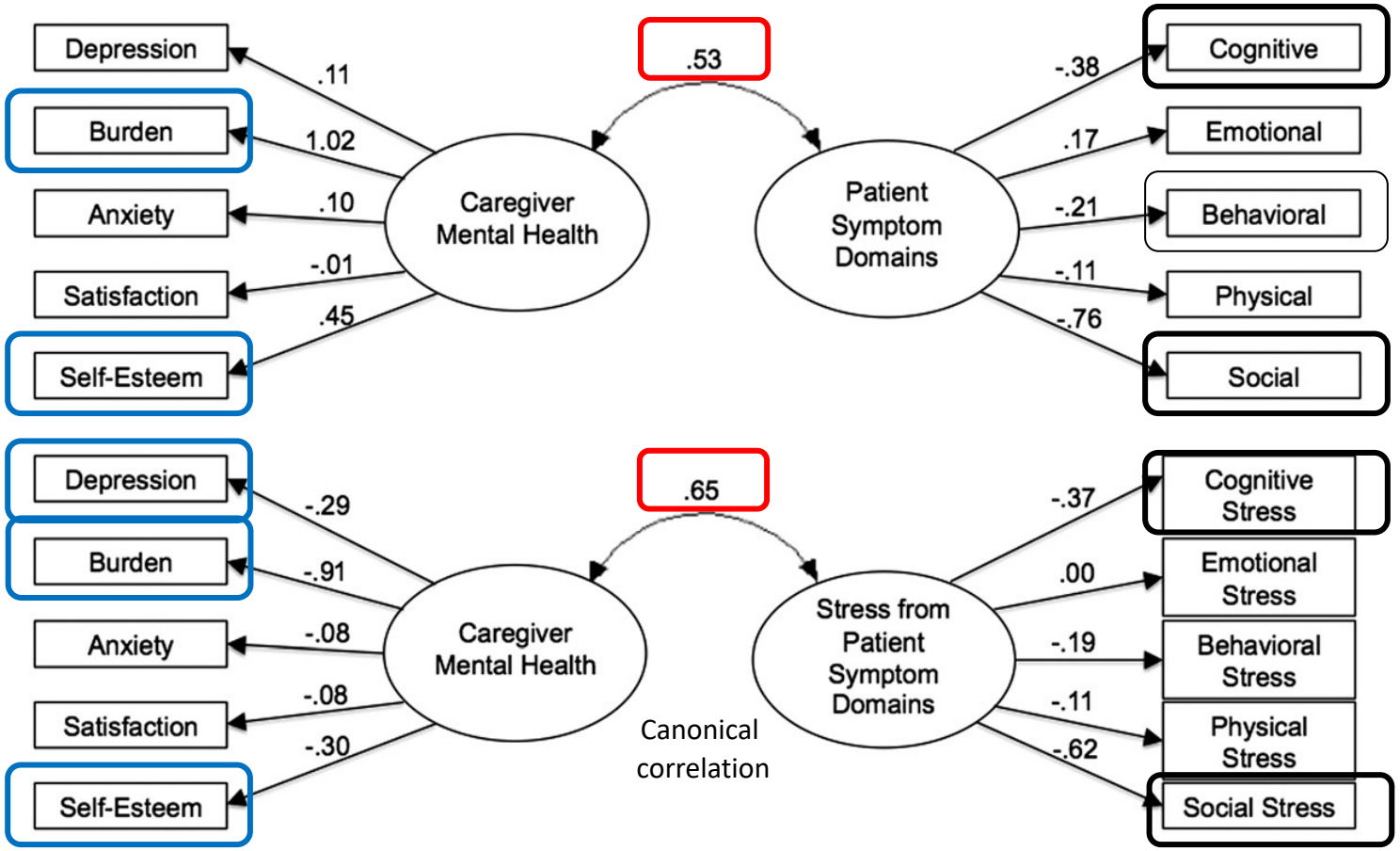


QUALITÉ de VIE

Plus d'impact sur la QdV que les autres traumatismes

Kreitzer et al., J Neurotrauma, 2021

Proche-Aidant



CORRÉLATION SIGNIFICATIVE : Symptomatologie du patient vs Santé mentale du proche-aidant

Nonterah, Brain Inj, 2013

Quel Outcome avec des Symptômes Complexes ?

Symptômes « complexes» :

- Troubles de l'***équilibre***
- Troubles de ***fonctions cognitives*** complexes
- Troubles du ***comportement***
- ***Fatigue***

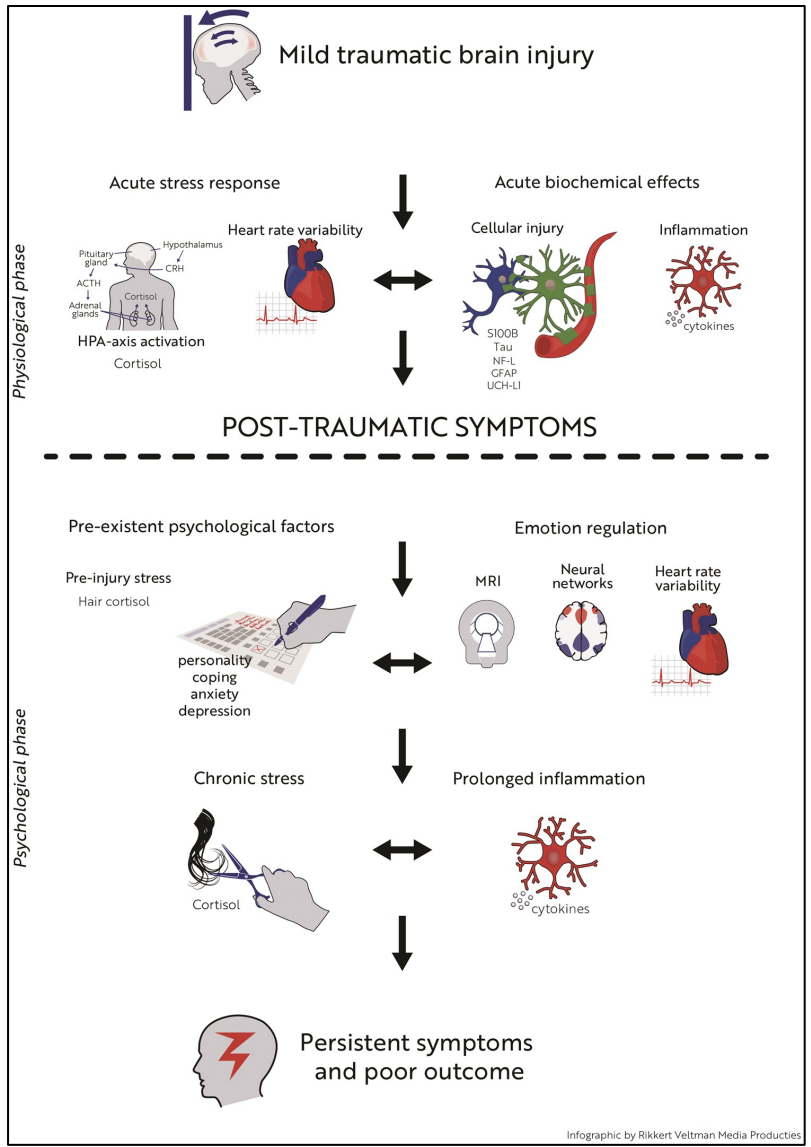
Difficultés -> activités "Complexes" :

- Activités ***"complexes"*** vie quotidienne
- Activités ***sociales***
- ***Reprise professionnelle***
- ***Proche-aidant*** aussi en souffrance

5. OUTCOME

5.2. TC LÉGER

Évolution



PHASE "ORGANIQUE"/CÉRÉBRALE

- **Symptômes expliqués par les micro-lésions**

PHASE "PSYCHIQUE"

- **Symptômes alimentés par des facteurs psychiques**

SYNDROME POST-COMMOTIONNEL PERSISTANT (SPCP)

20% à 12 mois

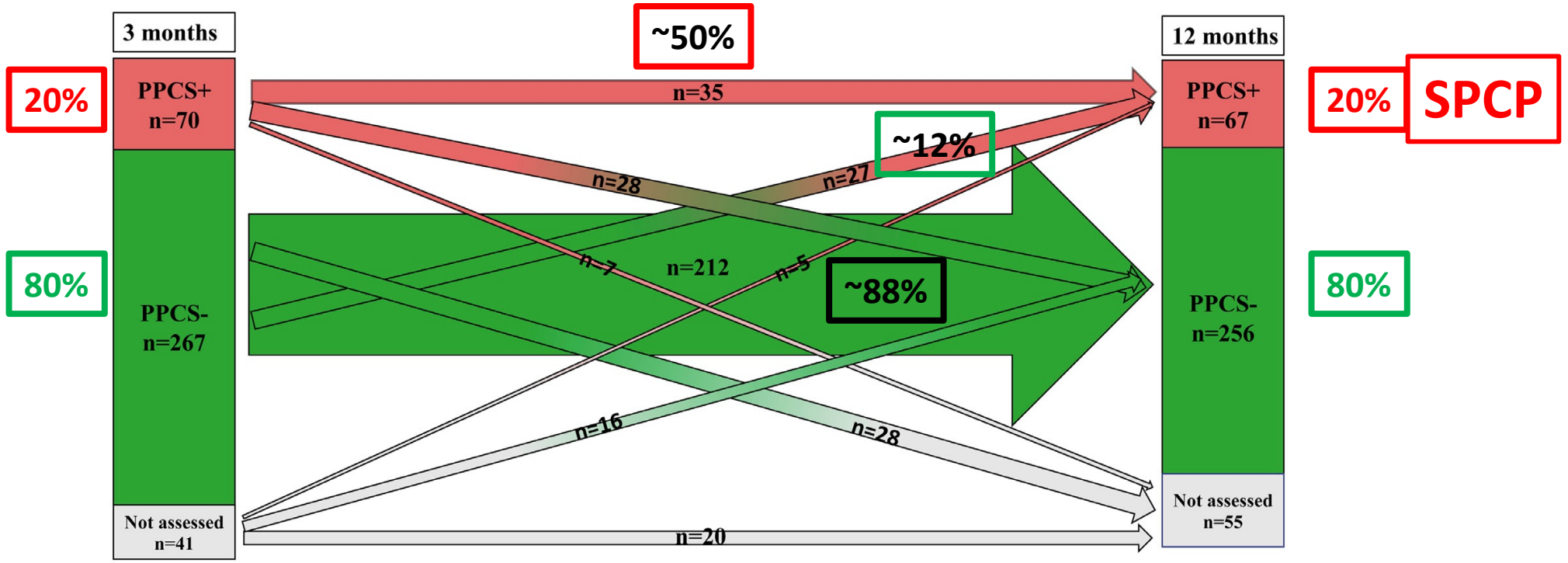
Impact principal: **reprise professionnelle**

Van Der Horn et al., J Neurol, 2020

Évolution

Symptomatique

Récupération complète



PPCS+ : Moderate-severe persistent PCS

Fordal, 2022

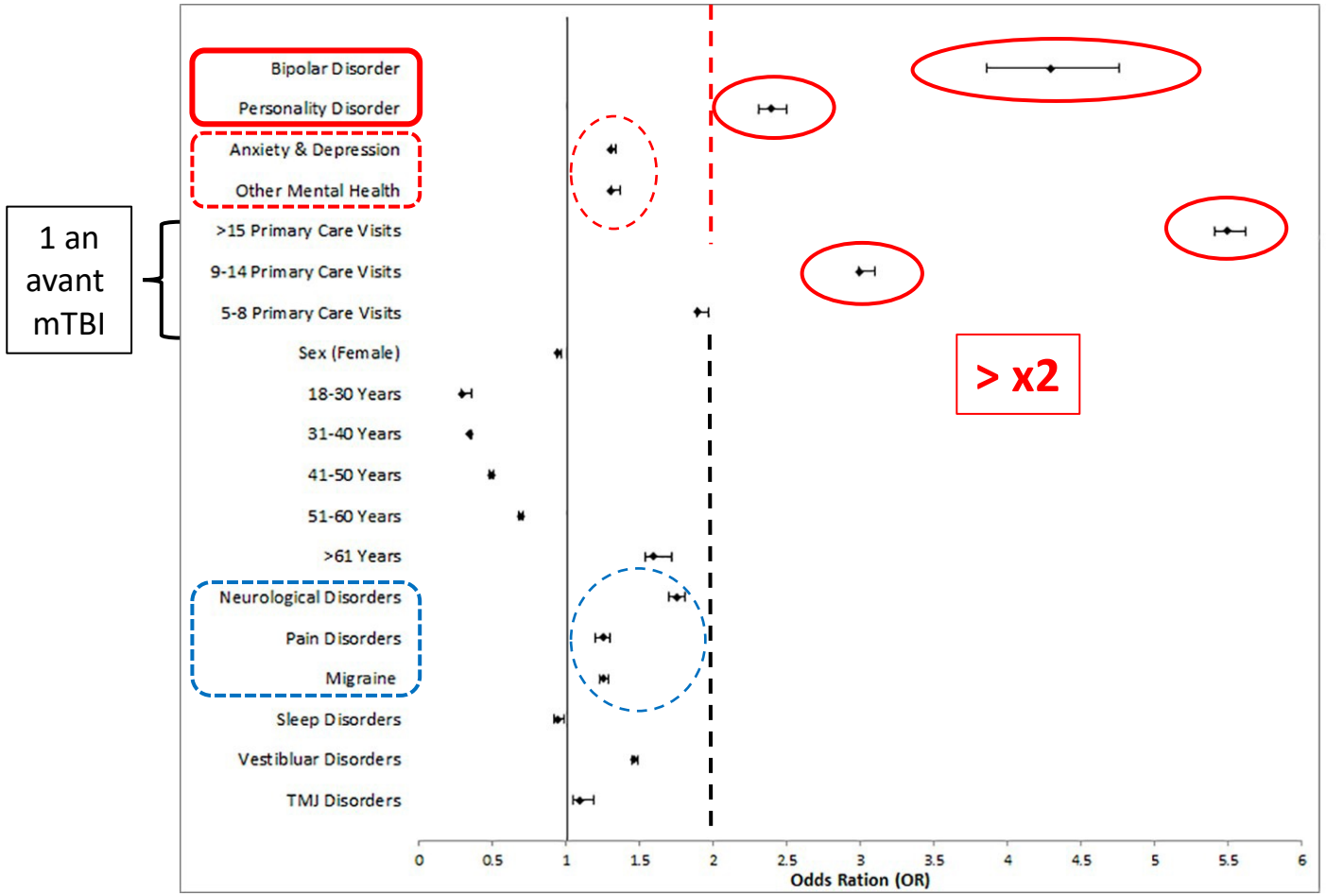
SPCP : Facteurs de Risque

Antécédents:

- ***NEUROLOGIQUES***
- ***PSYCHIATRIQUES***
- ***MÉDICAUX***

=

CHARGE MENTALE



Langer, 2021

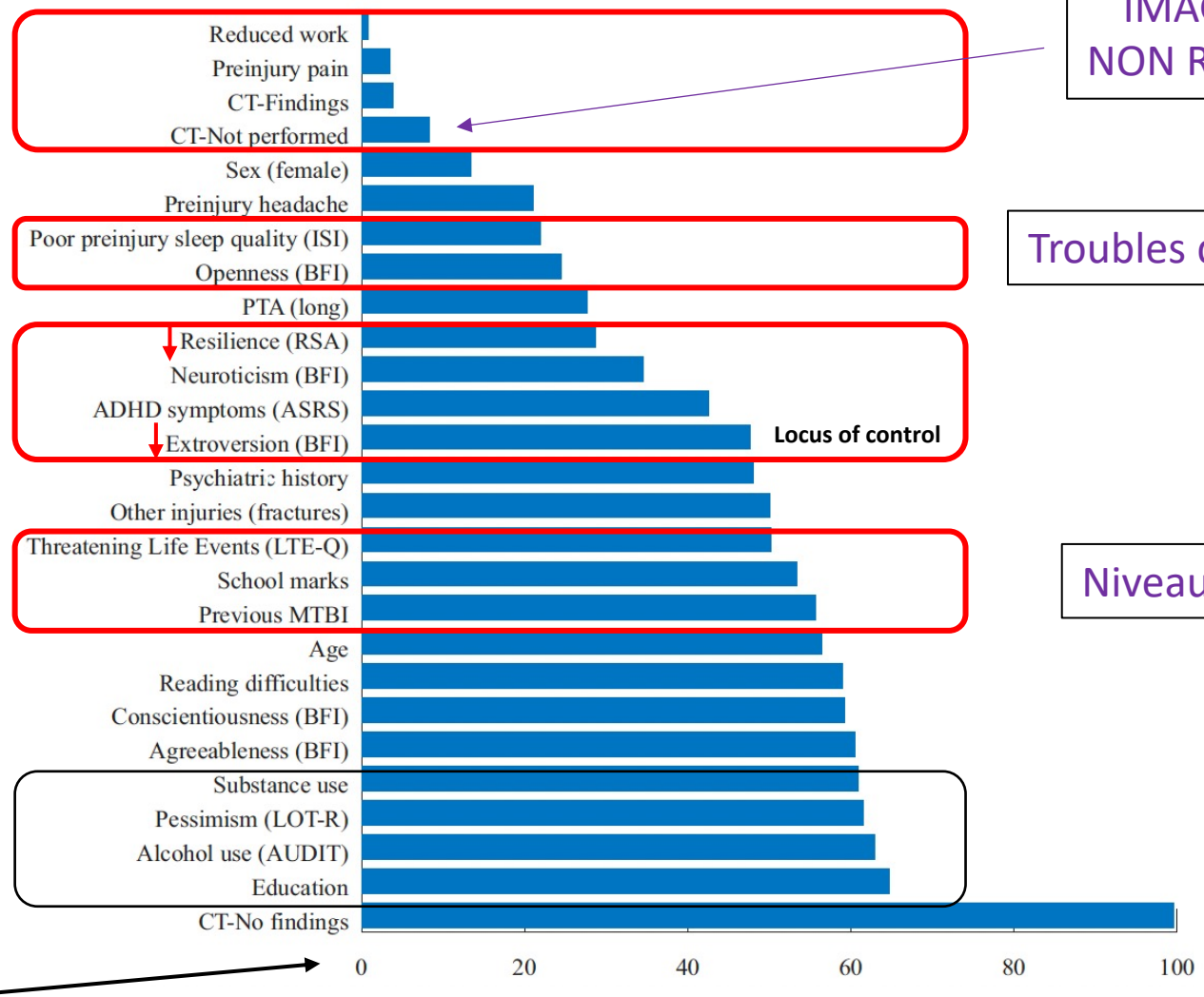
SPCP : Facteurs de Risque

Déterminants psycho-sociaux:

- ***PERSONNALITÉ***
- ***CONDITIONS SOCIALES***
- ***…***

+

Neuro-Imagerie non réalisée



IMAGERIE NON RÉALISÉE

Troubles du sommeil

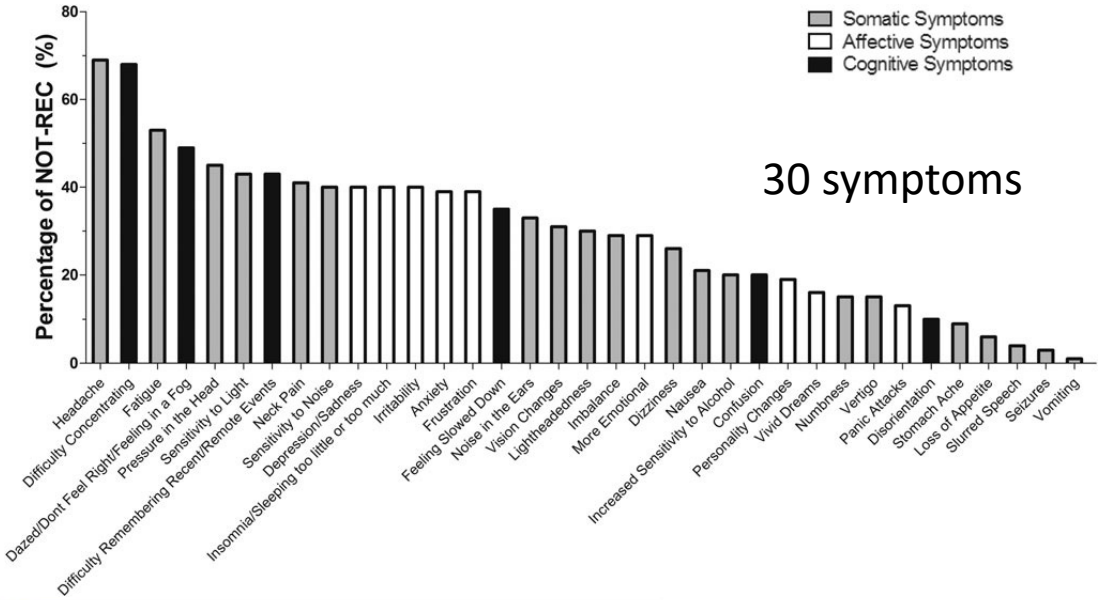
Niveau scolaire

Skandsen, 2021

SPCP : Facteurs de Risque

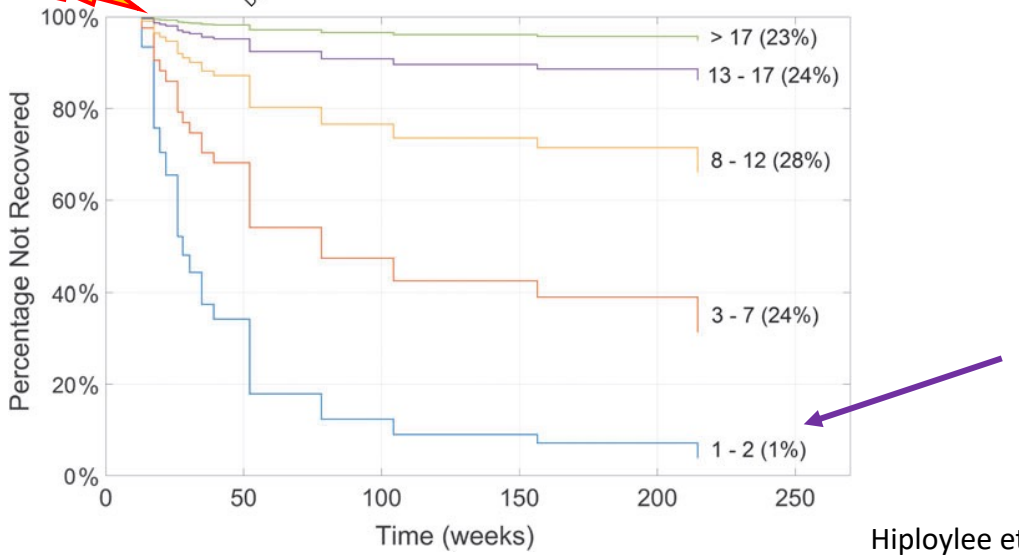
NOMBRE
de
SYMPTÔMES

4 x25%
- 3-7 symptoms
- 8-12 symptoms
- 13-17 symptoms
- >17 symptoms



30 symptoms

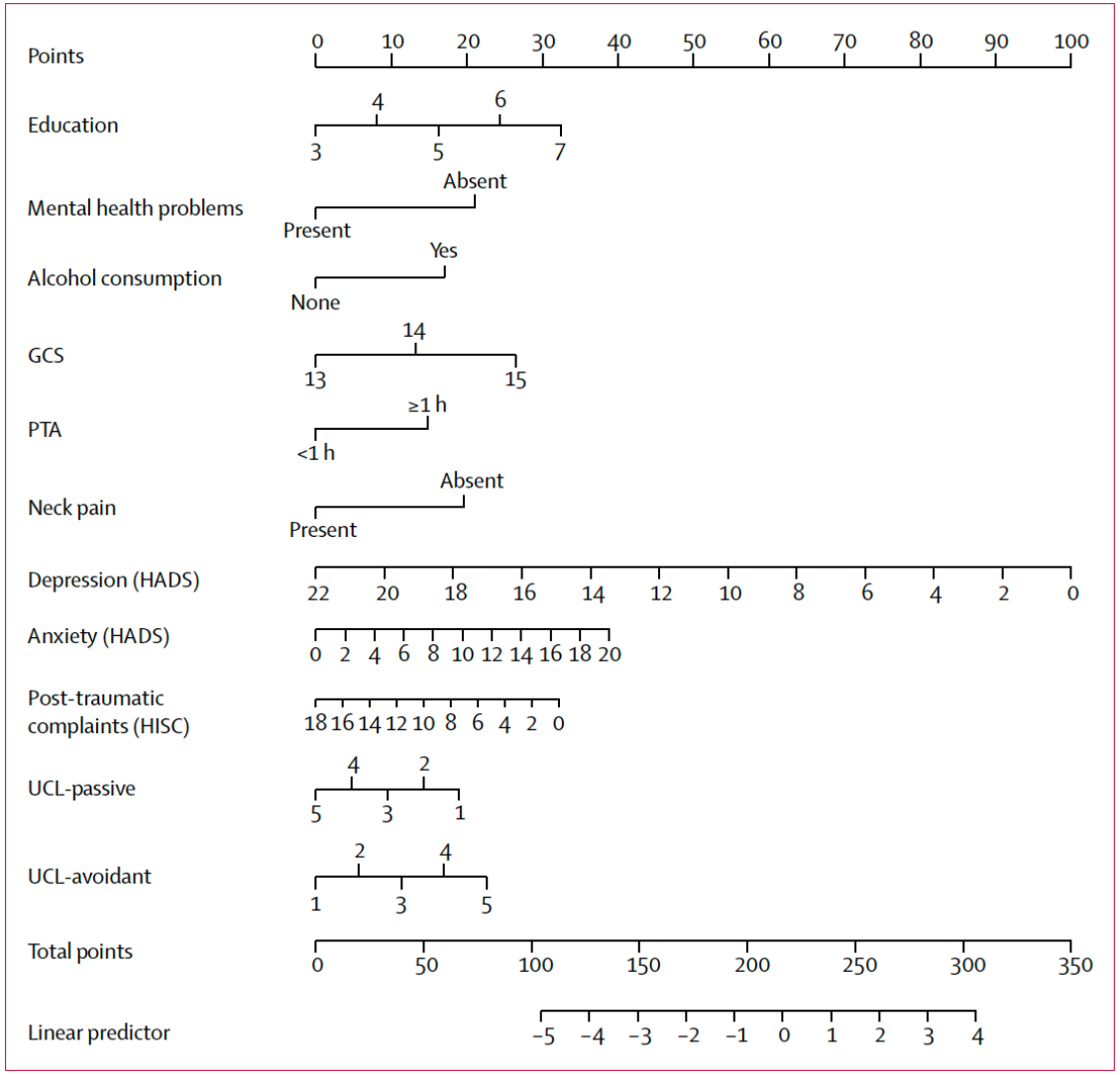
3 moths



Hiploylee et al., J Neurotrauma, 2017

SPCP : Probabilité

probability of outcome (PO)
as
PO = 1 / (1 + exp(–LP))

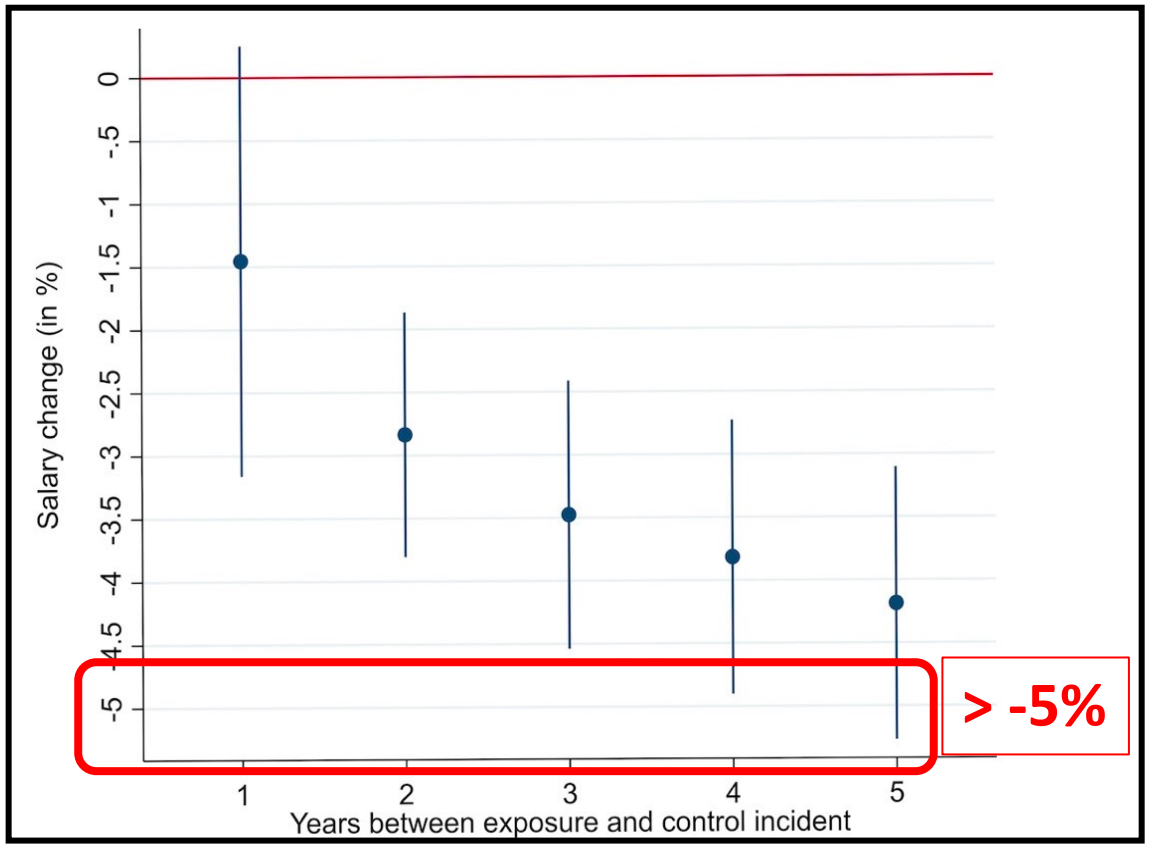


Van der Nalt, Lancet Neurol, 2023

SPCP : Reprise Professionnelle et Salaire



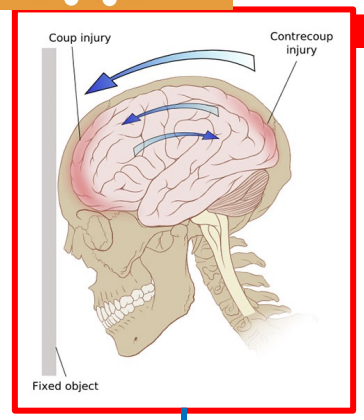
Gaudette, JAMA Netw Open, 2022



Fallesen, 2020

6. TRAITEMENT

Chronologie du Traitement



Head impact

Observable signs
Lying motionless
Motor incoordination
Tonic posturing
Impact convulsion
No protective action
Blank or vacant look

Exclude cervical spine injury

Remove from play and do **SRC assessment**

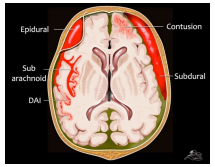
Use CRT5 (lay) or SCAT5 (medical)

Concussion diagnosed

TC léger

No concussion diagnosed
Continue to play but monitor for development of concussion signs or symptoms *

Sans TC



Red flag
Assessment indicates a moderate to severe TBI

TC mod./sév.

SOINS AIGUS

Emergency management and Neurocritical care
ATLS: Airway, breathing, circulation, disability, exposure
Evacuate mass lesions
Adequate intracranial monitoring (ICP, PBtO2 and Microdialysis)
Optimize metabolism and CBF

Remove from play
Follow graduated return to sport/learn paradigm

Initial rest then graduated rehabilitation program

Recovery **<10 days**

Persistant symptoms or signs **> 10 days**

Persistant COMMOTION

NEUROREÉDUCATION*

Rehabilitation
- Assess impairments
- Understand the patients priorities
- Plan and adopt appropriate rehabilitation form and intensity, including cognitive rehabilitation
- Goal management training

?

Recovery

Return to play/learn

CRT-5= Concussion recognition tool v5
SRC= Sports related concussion
SCAT5= Sport concussion assesment tool v5 (note that this includes Glasgow Coma Scale (GCS)
ATLS = Advanced Trauma and Life Support guidelines

ICP = Intracranial pressure
PBtO2= Partial brain tissue oxygen pressure
CBF = Cerebral blood flow
* if symptom free, activity does not elicit symptoms

Marklund et al., J Intern Med, 2020

Principes de la Neuroreéducation

COGNITION

HUMEUR/ COMPORTEMENT



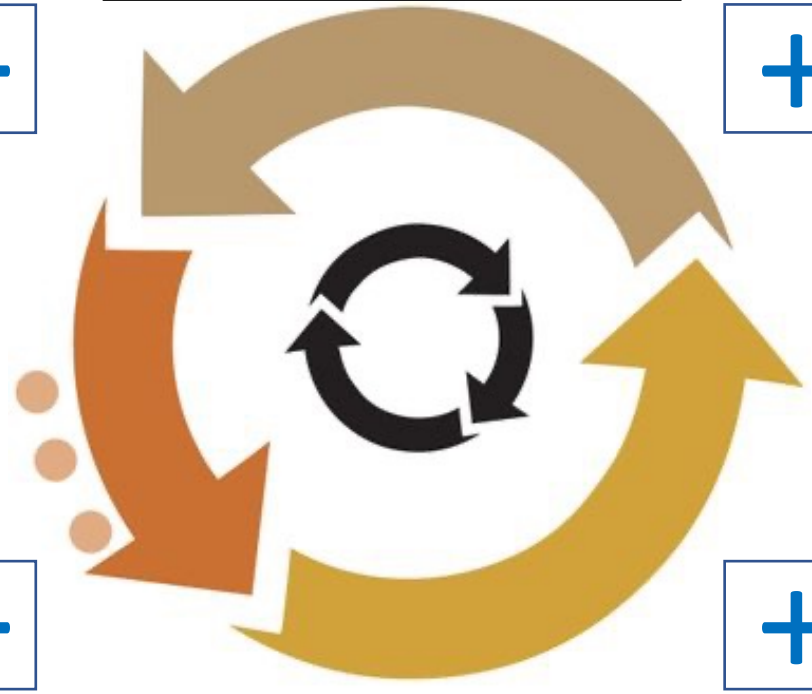
SOMA

FATIGUE

Cercle Vicieux vs Vertueux dans la Récupération

- **ATTENTION**
- **MÉMOIRE**
- **FONCTIONS EXÉCUTIVES**
- **…**

- + **+ -**



- **LABILITÉ ÉMOTIONNELLE**
- **IRRITABILITÉ**
- **PERTURBATION DU SOMMEIL**
- **…**

- **DOULEUR** (Céphalées)
- **VERTIGES/TROUBLES DE L'ÉQUILIBRE**
- **…**

- + **+ -**

FATIGUE

VICIEUX **CERCLE**

Cercle **VERTUEUX**

Traitement Orienté par les Symptômes

- **ATTENTION**
- **MÉMOIRE**
- **FONCTIONS EXÉCUTIVES**
- **…**

TTT : Psychoéducation, Thérapie neuropsychologique (incluant réalité virtuelle, neurotracking)



- **LABILITÉ ÉMOTIONNELLE**
- **IRRITABILITÉ**
- **PERTURBATION DU SOMMEIL**
- **…**

TTT : Psychothérapie+médicaments/ Somnifères

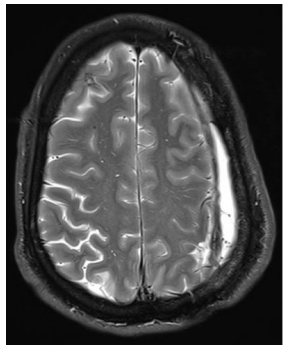
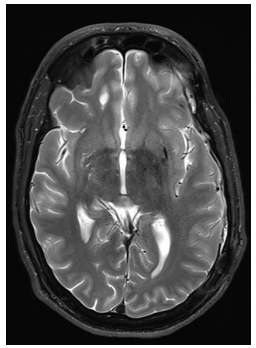
- **DOULEUR** (Céphalées)
- **VERTIGES/TROUBLES DE L'ÉQUILIBRE**
- **…**

TTT : Médicaments/Physiothérapie

FATIGUE

TTT : Sport/Éducation/Médicaments

How to Rehabilitate?

Severe TBI (GSC : 6/15):

- Man
- 40 yo
- Engineer
- Department director
- Divorced, 2 kids

Individual therapies
and
Group therapies
with GAS objectives

PEC **MdT en groupe et individuel EMRV**
1

PEC TCD des **troubles du comportement et de la dysrégulation émotionnelle**
3

Psychoéducation mémoire à long terme
2

PEC **de la gestion de l'énergie en individuel**
4

U

Occupational Therapist
at
the workplace

Courtesy of Dr Peggy d'Honincthun

GAS = Goal Attainment Scaling (method used to evaluate whether a patient achieves individualized rehabilitation goals)



Mon objectif général = reprendre une activité professionnelle et retrouver le sentiment que la vie vaut la peine d'être vécue

Pour cela j'ai pour sous-objectif de mieux me souvenir des choses à faire

Pourquoi? Afin de suivre les informations lors des réunions professionnelles, de ne pas faire d'erreurs dans la comparaison de tableau excel complexes

Comment?

- Thérapie cognitive et écologique de la MdT en groupe (d'Honincthun et al. 2018 ; d'Honincthun et Vallat-Azouvi 2025)
- Entraînement en séance et à la maison

- **Progressive**
- **Practical**
- **Patient-oriented**

OBJECTIVES

OBJECTIF (XXX) :

OBJECTIF (décembre 2023) : Je parviens à mener une réunion professionnelle et prendre des notes

OBJECTIF (30 avril 2023) : j'arrive à comparer des données chiffrées, je suis le fil des conversations simples et complexes, je gère les interférences lors des réunions professionnelles ou lors d'un souper entre amis

OBJECTIF (16.03.2023) : Je suis une conversation à plusieurs sans difficulté

Actuellement (12.1.2023) : je n'arrive pas à comparer des données chiffrées, je perds le fil des conversations, je n'arrive pas à gérer les interférences lors des réunions professionnelles ou lors d'un souper entre amis

Courtesy of Dr Peggy d'Honincthun

Adapté de Krasny Pacini et al. (2023), Willems (2025)

“Take home messages”

- Pathologie **“fréquente”** et -> toute la population (dont en âge de travail)
- Particularités:
  - **Méchanismes biophysiques** spécifiques (lésions mutliples, diffuses, visibles et invisibles)
  - **Symptomatologie** spécifique (troubles cognitifs/comportementaux, fatigue, troubles de l’équilibre)
  - **Effets** spécifiques (difficultés -> : tâches cognitives “complexes”, interactions sociales, reprise du travail)
  - Prise en charge/traitement **multidisciplinaire**
- Traumatisme cérébral **léger** => **potentiellement mêmes particularités** ⚠ Ne pas sous-estimer
- ⚠ Symptomatologie non reconnue => source de souffrance



FIN

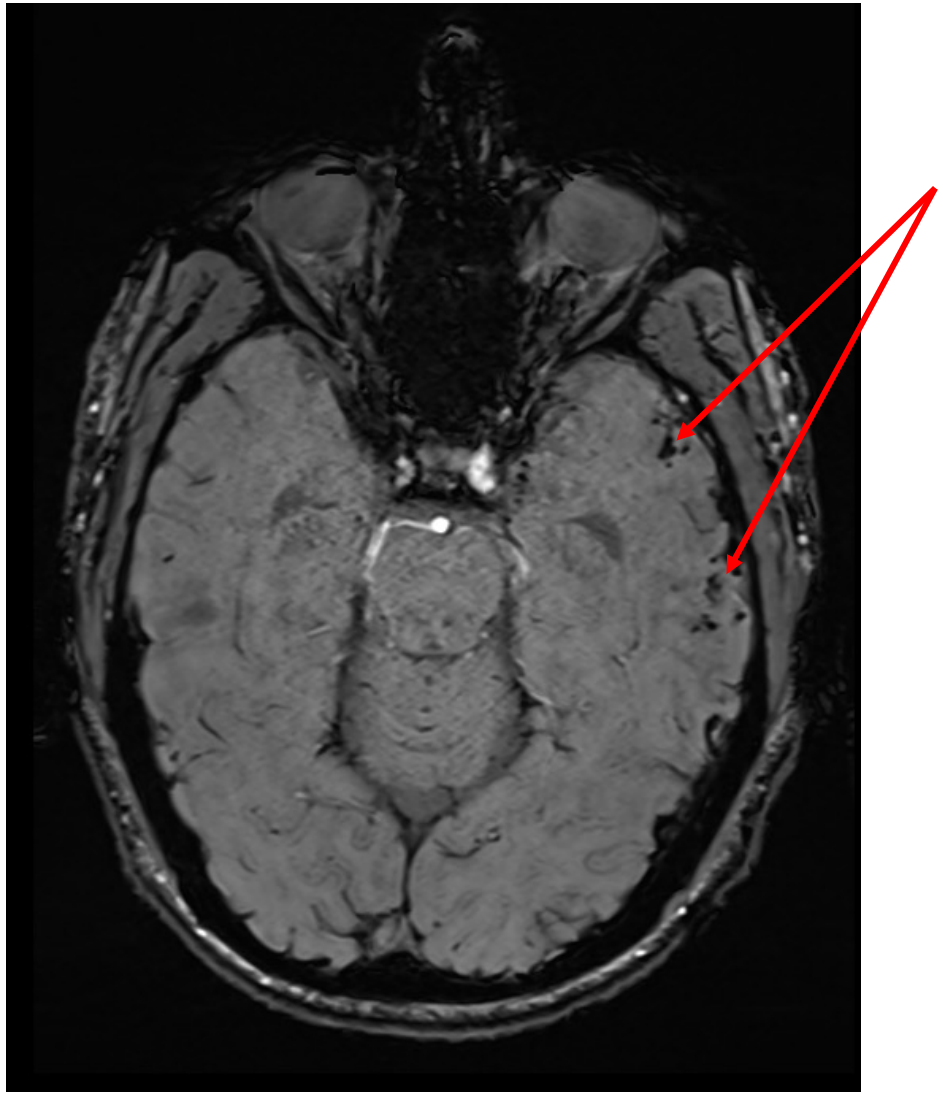
7. CAS CLINIQUES

Cas Clinique 1

- Patient
  - 46 ans
  - BSH et Sportif
  - Enseignant spécialisé 100%

- Polytraumatisme
  - Fractures costales
  - Traumatisme cérébral -> ***GCS = 12***

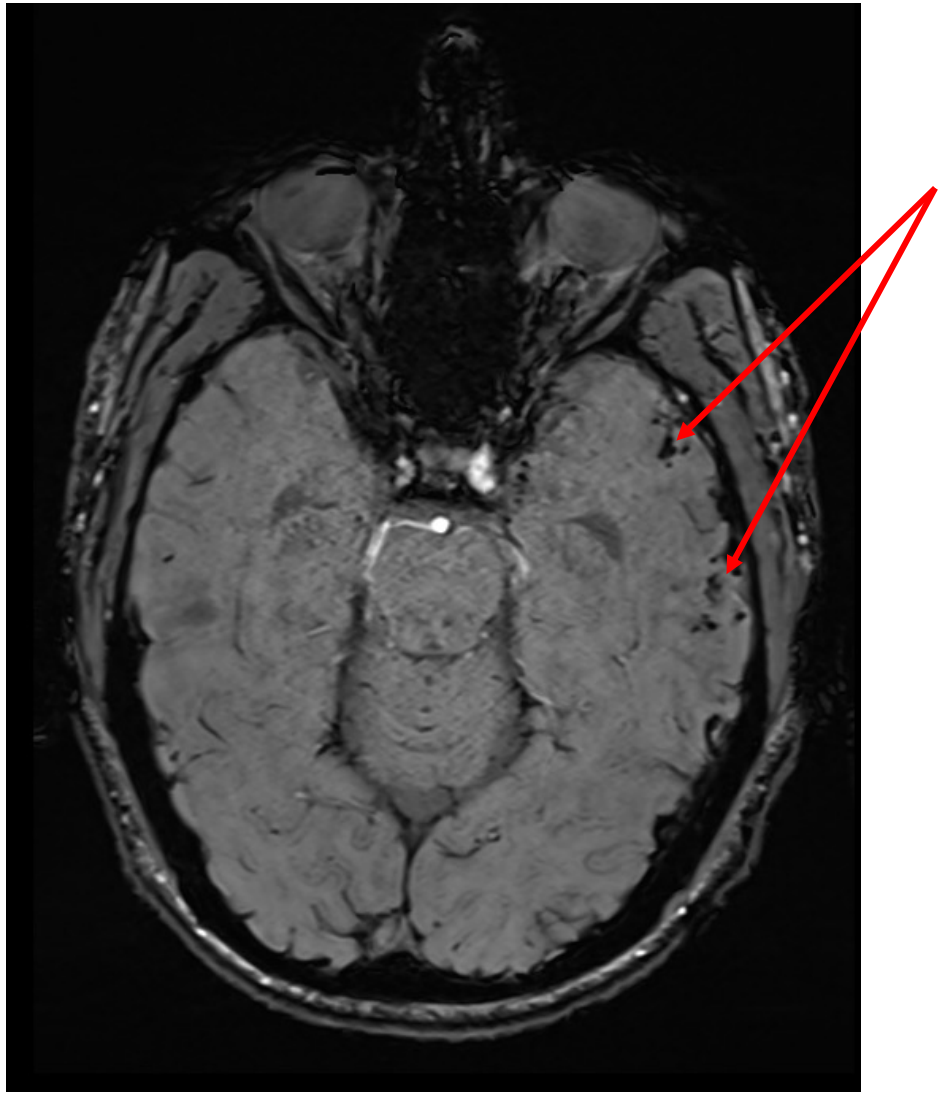
Lésions axonales diffuses: frontales et temporales



Cas Clinique 1

- Symptomatologie aigue
  - Crise d'épilepsie unique
  - Troubles neuropsychologiques
    - Troubles de la mémoire anterograde
    - Troubles de la mémoire de travail
    - Troubles exécutif
    - Troubles de l'attention
  - Pas de troubles moteurs/neurosomatiques

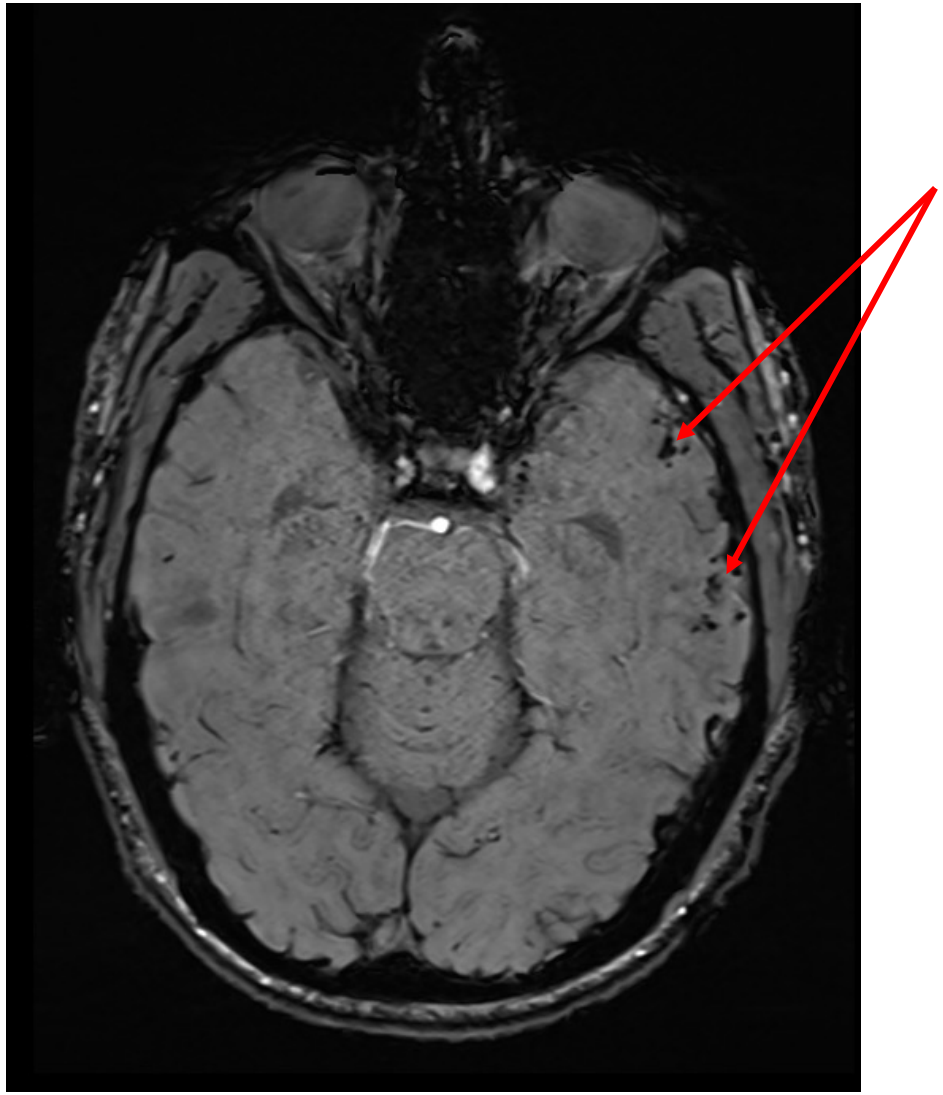
Neuro-Réhabilitation
Stationnaire et ambulatoire



Cas Clinique 1

- Symptomatologie post-aigue (Réhab)
  - Troubles neuropsychologiques
    - Troubles de la mémoire de travail ↓
    - Troubles de l'attention ↓
  - **Fatigue primaire**
  - **Troubles émotionnels**(/comportementaux)

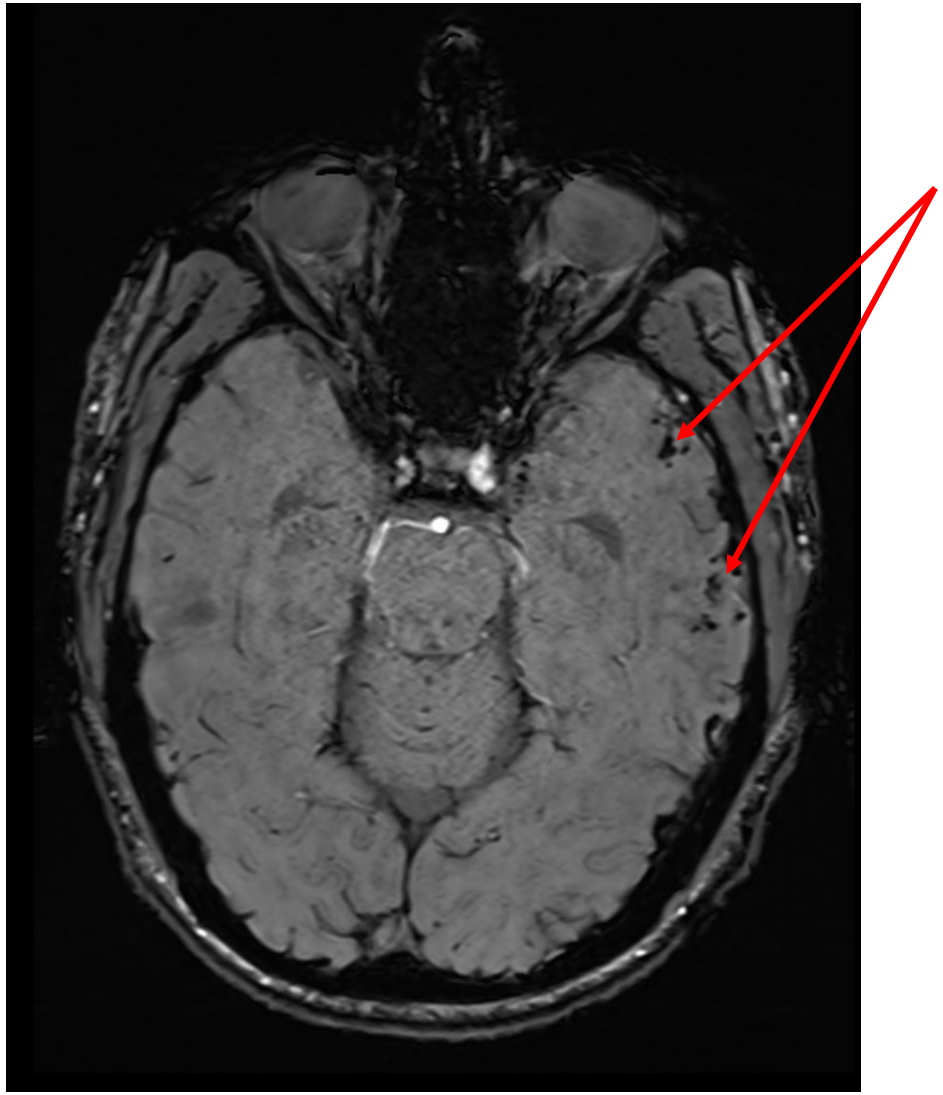
4'27''
5'34''



Cas Clinique 1

- Symptomatologie à distance (>1 an)
  - **Fatigue primaire**
  - **Troubles émotionnels**

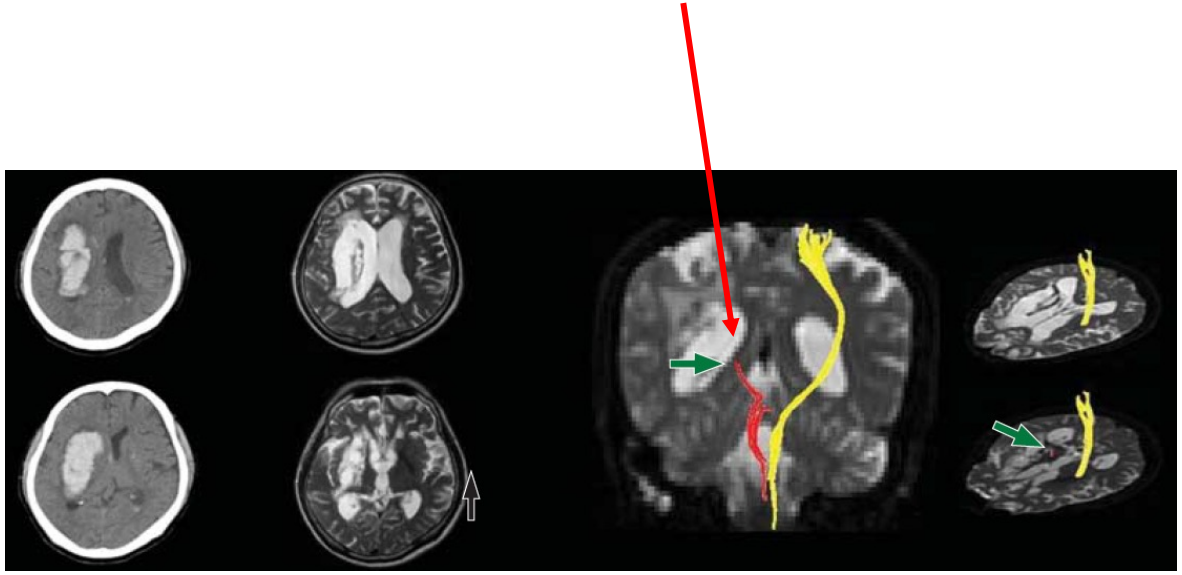
Retour au travail (->100%)



Cas Clinique 2

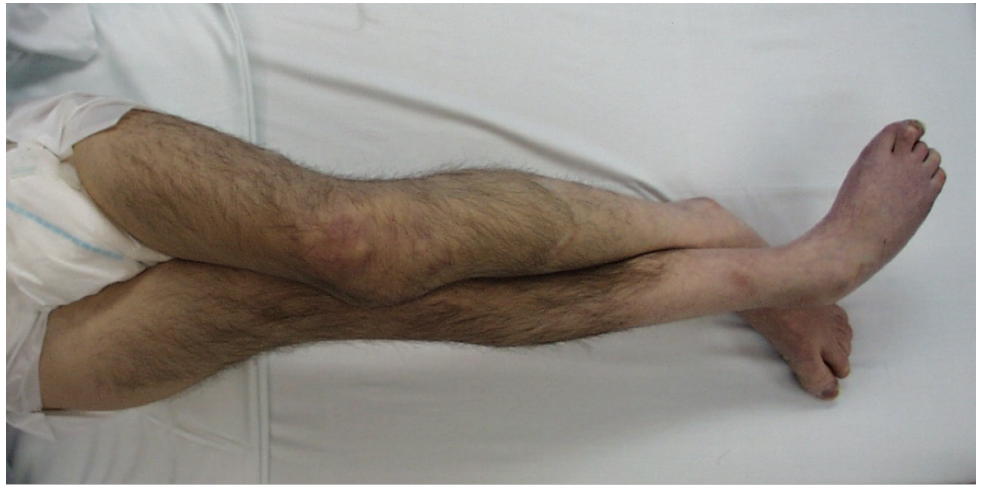
- Troubles moteurs





Cas Clinique 1

- Complications motrices
  - Spasticité
  - Retractions myo-tendineuses
  - Para-Ostéo-Arthropathies Neurogènes (POAN)
  - Sarcopénie
  - Etc.





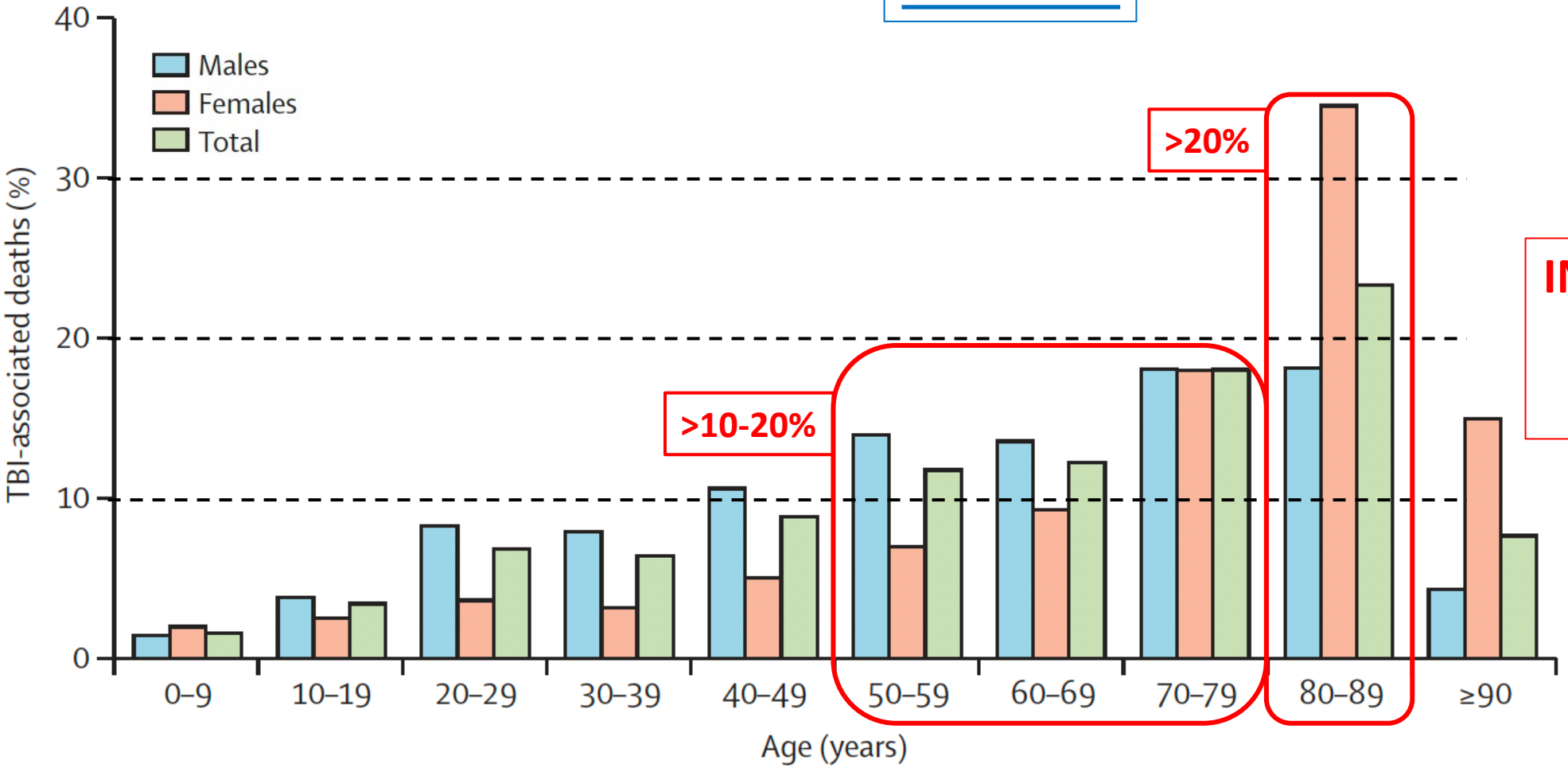
Fin du cours

Annexes

Pour information uniquement

TRAUMATIC BRAIN INJURY : *Epidemiology*

TBI DEATH



INCIDENCE of DEATH
=
AGE-DEPENDENT

Majdan, 2016

TRAUMATIC BRAIN INJURY : *Epidemiology VD*

Traumatic ***BRAIN*** injury: VD

STATISTIQUE VAUD
Département des finances et de l'agriculture (DFA)

Population résidante permanente par classe d'âges, sexe et état civil, Vaud, 2023

Classe d'âges	Total (1)
Effectif	
Population totale	846 303
0 à 24 ans	236 799
25 à 39 ans	181 118
40 à 49 ans	120 669
50 à 69 ans	202 771
70 ans et +	104 946
Hommes	415 802
0 à 24 ans	121 835
25 à 39 ans	91 251
40 à 49 ans	59 382
50 à 69 ans	99 387
70 ans et +	43 947
Femmes	430 501
0 à 24 ans	114 964
25 à 39 ans	89 867
40 à 49 ans	61 287
50 à 69 ans	103 384
70 ans et +	60 999

ANNUAL INCIDENCE (16-59) NORWAY

MALE 0,357%

FEMALE 0,242%

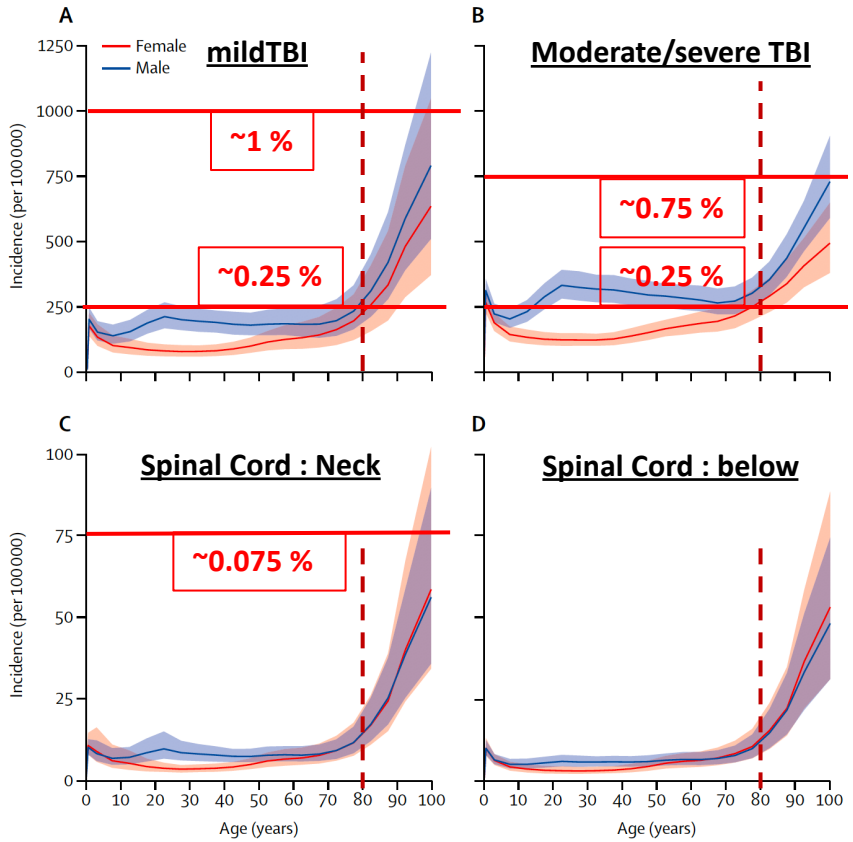
TOTAL 0,302%

16-24: ~*75766*
25-39: 181118
40-49: 120669
50-69: 202771
70-75: ~~*35000*

TOTAL: 615324

0.3%: 1846 mTBI
0.026%: 160 msTBI

INCIDENCE = AGE-DEPENDENT



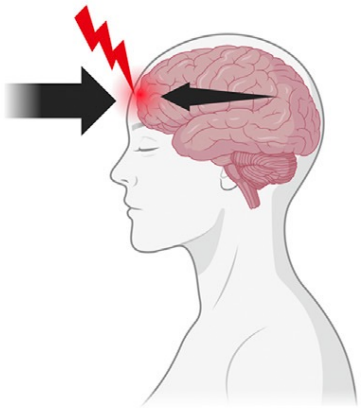
Skandsen et al., Front Neurol, 2019

GBD, Lancet Neurol, 2019

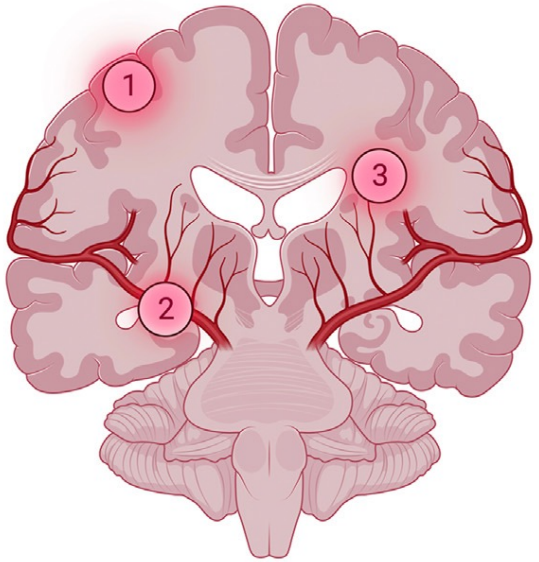
TRAUMATIC BRAIN INJURY : *Semiology (severe TBI)*

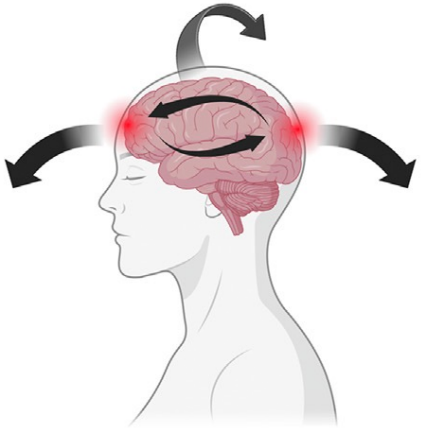
1. SUMMARY

c. Synthesis

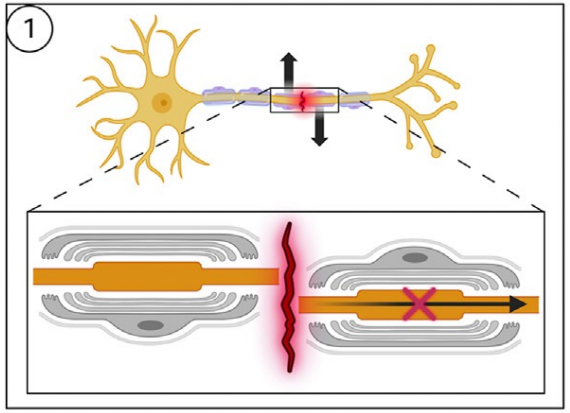


Direct Impact Loading

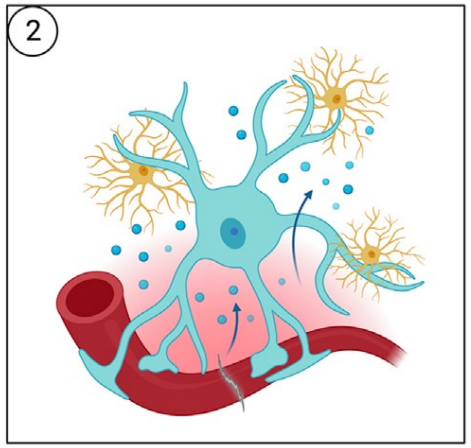




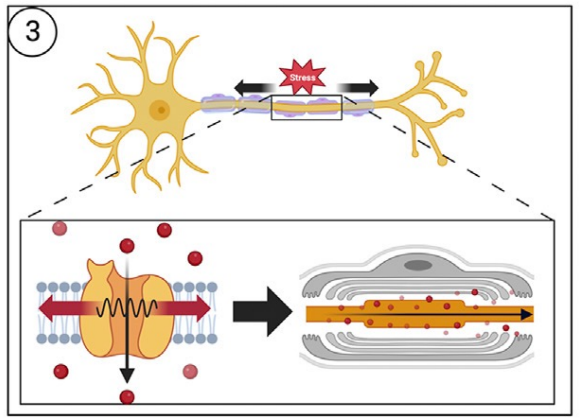
Rotational/Angular Inertia



Gray-White Matter Junction
Shearing Forces - Differences in stiffness leading to diffuse axonal injury



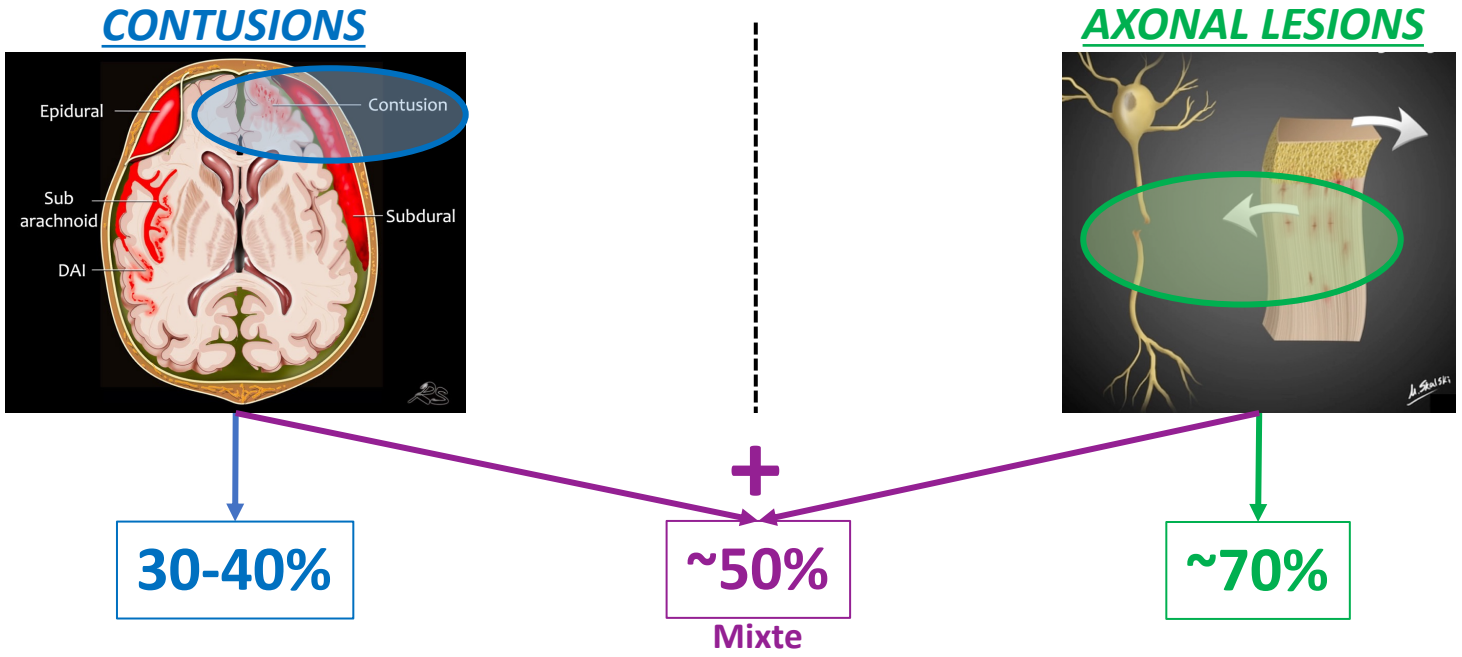
Cerebrovasculature
Shearing & Tensile Forces - Leads to BBB damage & neuroinflammation



White Matter Axonal Tracts
Tensile Forces - Mechanotransduction leading to aberrant signaling & excitotoxicity

T. J. Orr, World Neurosurg, 2024

TRAUMATIC BRAIN INJURY : *Lesion Distribution*



Lesion distribution in moderate/severe TBI

Khoshyomn et al., Semin Pediatr Surg, 2004

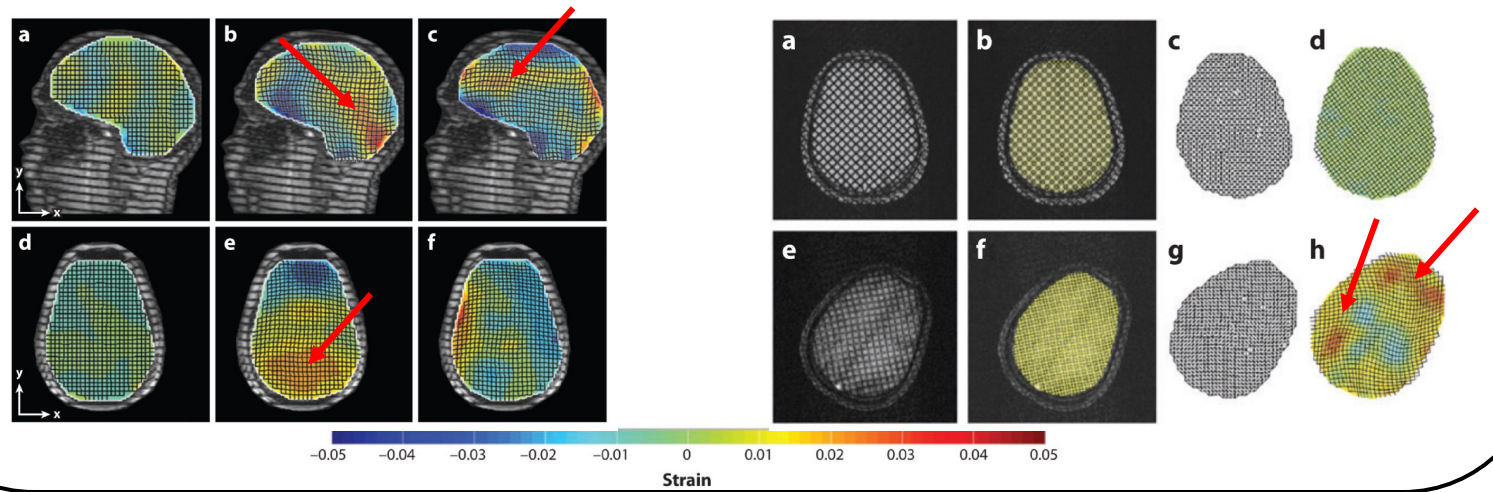
Skandsen et al., J Neurosurg, 2010

TRAUMATIC BRAIN INJURY : *Lesions (mild TBI)*

2. MICROSTRUCTURE ALTERATIONS

DIFFUSE SHEAR FORCES

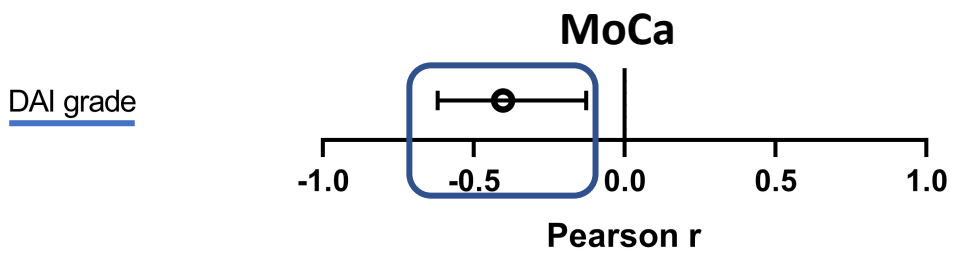
DIFFUSE "MICROSCOPIC" LESIONS



TRAUMATIC BRAIN INJURY : *Lesions and Semiology*

Diffuse axonal injury

Grade of DAI	Outcome			Total	*P*-value
	Satisfactory		Unsatisfactory		
Grade I	32	>	23	55	0.020
Grade II	24	=	24	48	
Grade III	8	<<	22	30	
Total	64		69	133	



LINK
between
LESIONS
&
SYMPTOMS

NUMBER
of the
the lesions

Javeed et al., Surg Neurol Int, 2021
Chen et al., Front Neurosci, 2023

TRAUMATIC BRAIN INJURY : *Lesions and Semiology*

RED FLAGS

↓

LONG-TERM NEUROPSYCHOLOGICAL IMPAIRMENTS

Table 2 Red flags for the risk of traumatic brain injury resulting in long-term neuropsychological impairments with an organic basis

Clinical feature	Risk of developing long-term neuropsychological sequelae	Comments
Intraventricular haemorrhage	🚩🚩🚩	
Prolonged post-traumatic amnesia	🚩🚩🚩	High risk associated with PTA >1 week determined by prospective assessment*.
Surgical intervention required	🚩🚩🚩	
Presence of ischaemic brain injury	🚩🚩🚩	
Anoxia	🚩🚩🚩	Neuropsychological risk depends on the period and severity of anoxia.
Evidence of diffuse axonal injury on MRI	🚩🚩🚩	The more widespread the injury, the more widespread the associated cognitive deficit is likely to be.
Elevated ICP	🚩🚩	The more elevated and longer the duration, the higher the risk.
Presence of midline shift	🚩🚩	
Evidence of inflammatory response	🚩🚩	
Evidence of sulcal effacement	🚩	Duration and extent is an important determinant of associated deficit.
Evidence of contusions	🚩	May result in focal deficits, particularly if damage remains evident on later neuroradiology (MRI).
Abnormalities suggestive of traumatic axonal injuries evident on DTI	🚩	May be associated with reduced processing speed or focal deficits. These abnormalities can also be present with no neuropsychological correlates.

🚩🚩🚩 Incomplete neuropsychological recovery likely.

🚩🚩 Some long-term neuropsychological sequelae likely.

🚩 Possibility of some long.

Flags are cumulative.

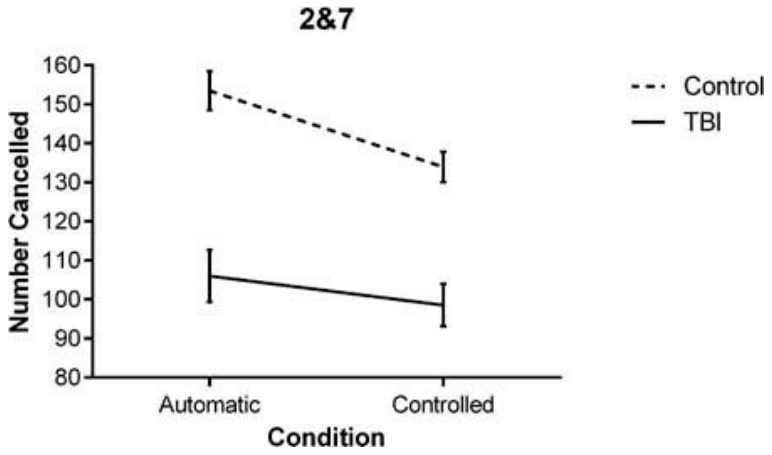
*Reports of prolonged post-traumatic amnesia gained retrospectively must be carefully evaluated. If indicating significant brain trauma, there should also be an evident corroborative sign and symptoms.

DTI, diffusion tensor imaging; ICP, intracranial pressure; PTA, post-traumatic amnesia.

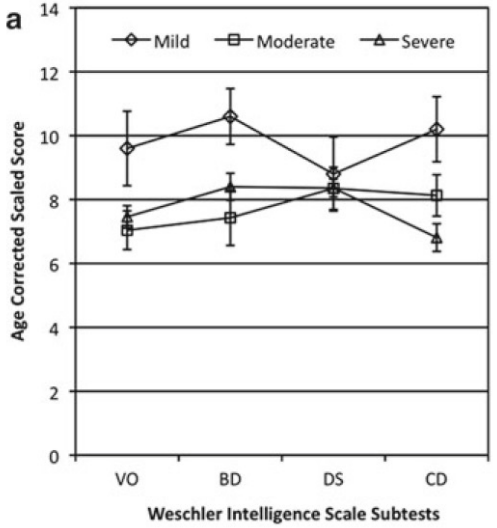
Baxendale et al., Pract Neurol, 2019

TRAUMATIC BRAIN INJURY : *Semiology (severe TBI)*

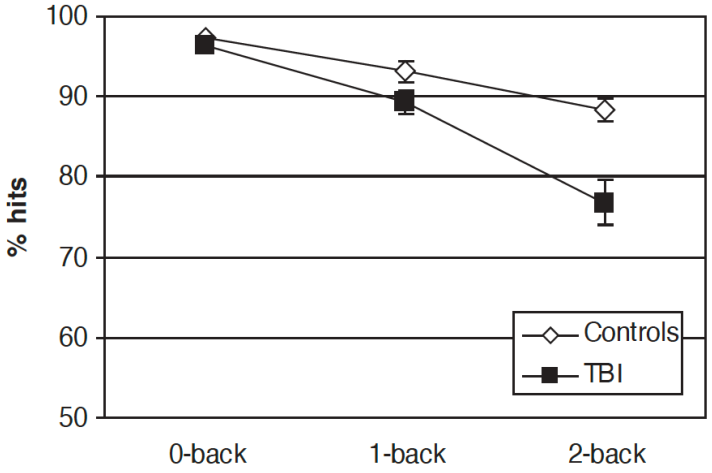
3. NEUROPSYCHOLOGICAL SEQUELAE



Attention



Executive functions



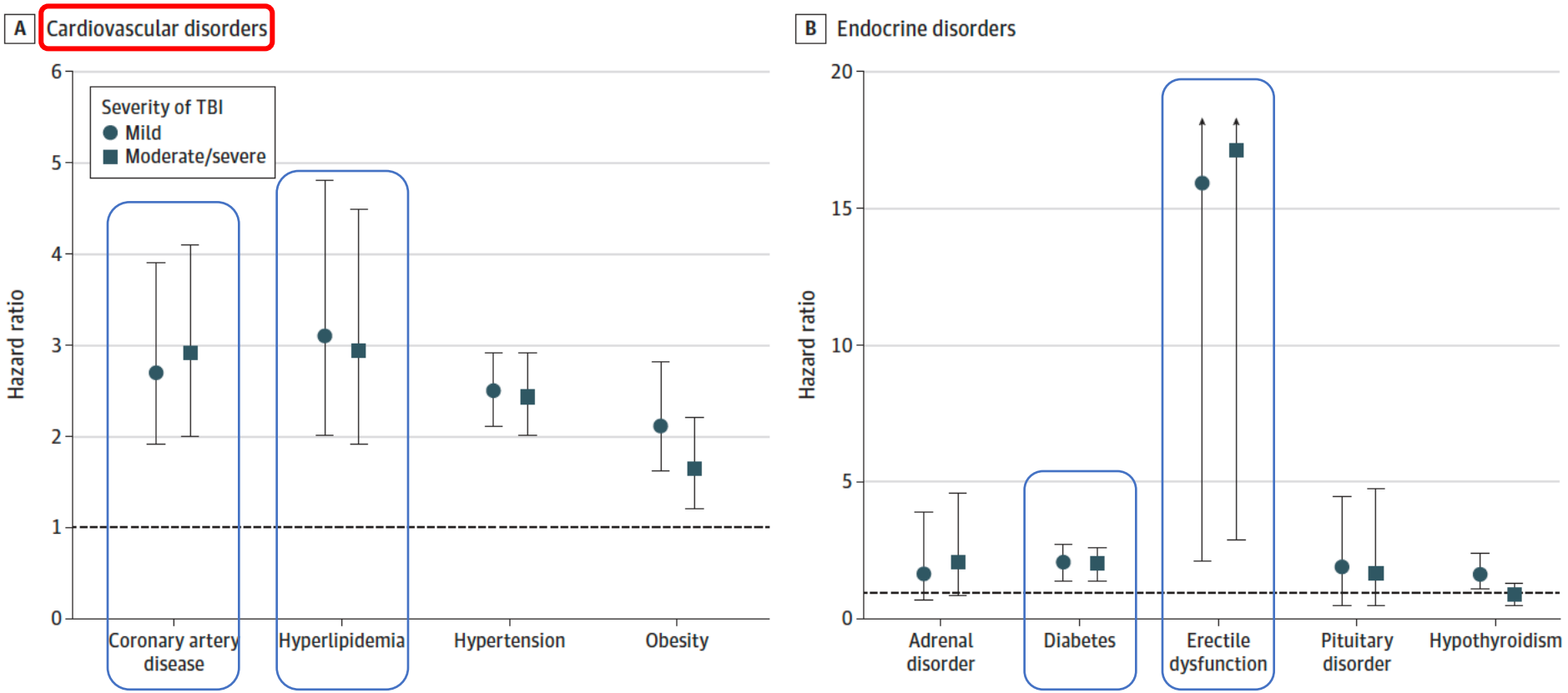
Working Memory

For detailed results, see Sternberg 2015 and Stalnacke 2019

Allen, 2013
Dymowski, 2015
Azouvi, 2009

TRAUMATIC BRAIN INJURY : *Semiology (severe TBI)*

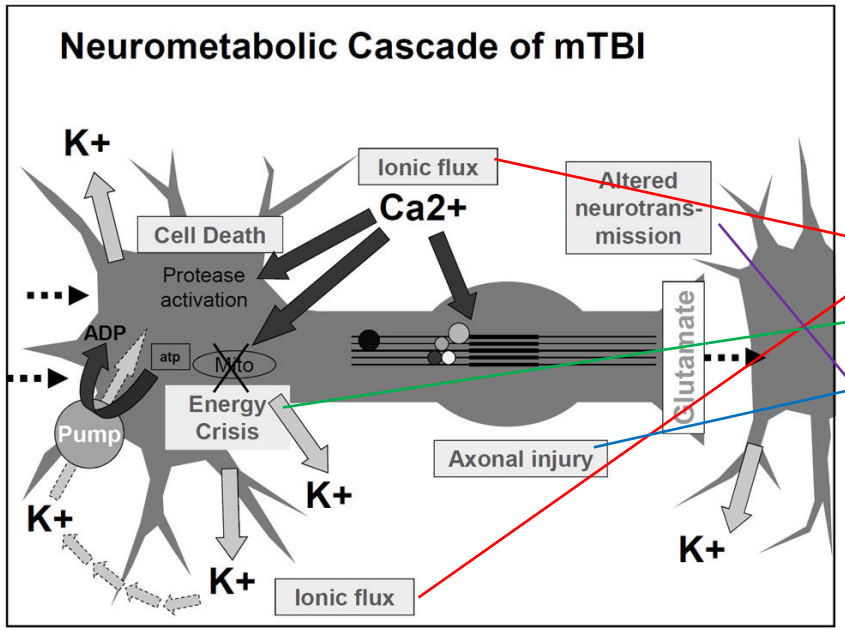
6. MULTISYSTEMIC COMORBIDITIES



Izzy, JAMA Netw Open, 2022

TRAUMATIC BRAIN INJURY : *Semiology (mild TBI)*

4. MICROSTRUCTURE ALTERATIONS and SEMIOLOGY !?



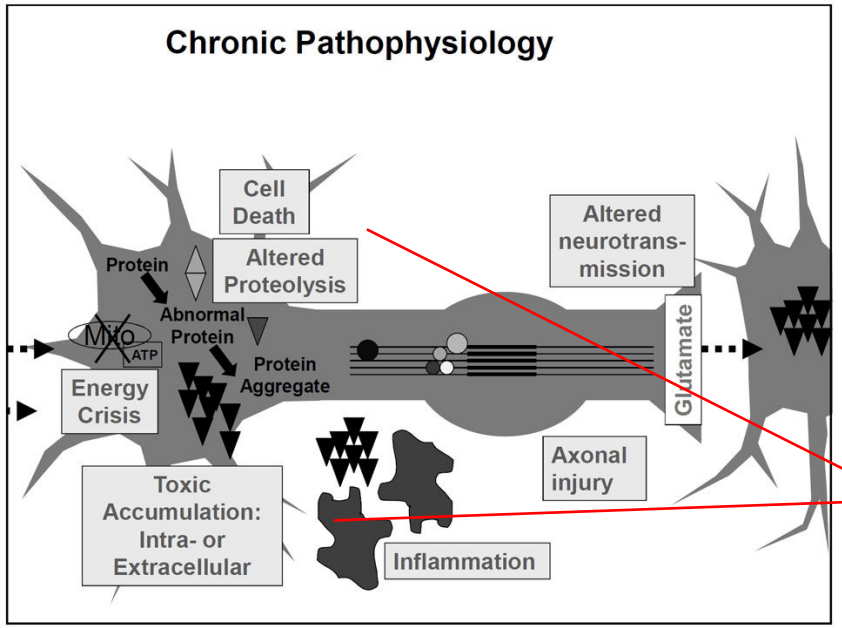
Physiological perturbations after concussion and proposed clinical correlates.

Post-TBI pathophysiology	Acute symptom / clinical correlate
Ionic flux	Migraine headache, photophobia, phonophobia
Energy crisis	Vulnerability to second injury
Axonal injury	Impaired cognition, slowed processing, slowed reaction time
Impaired neurotransmission	Impaired cognition, slowed processing, slowed reaction time
Protease activation, altered cytoskeletal proteins, cell death	Chronic atrophy, development of persistent impairments

Giza et al., Neurosurg, 2014

TRAUMATIC BRAIN INJURY : *Semiology (mild TBI)*

4. MICROSTRUCTURE ALTERATIONS and SEMIOLOGY !?



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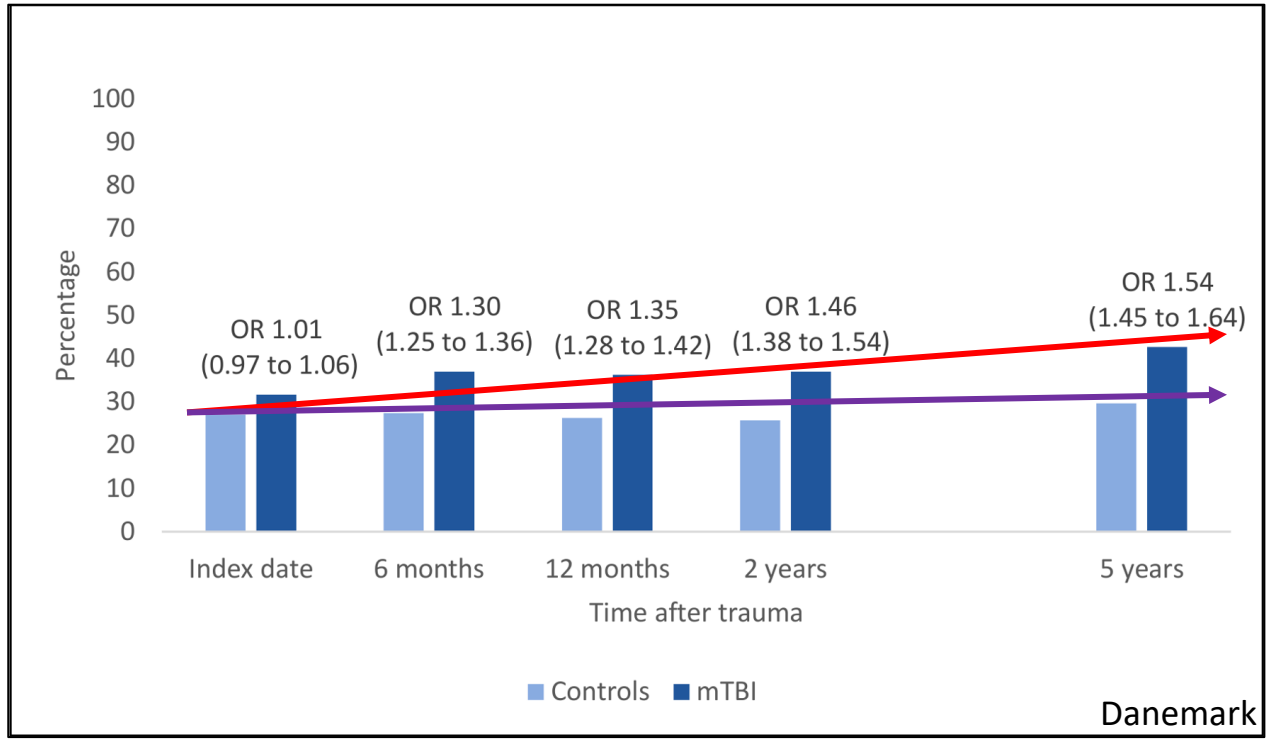
Giza et al., Neurosurg, 2014

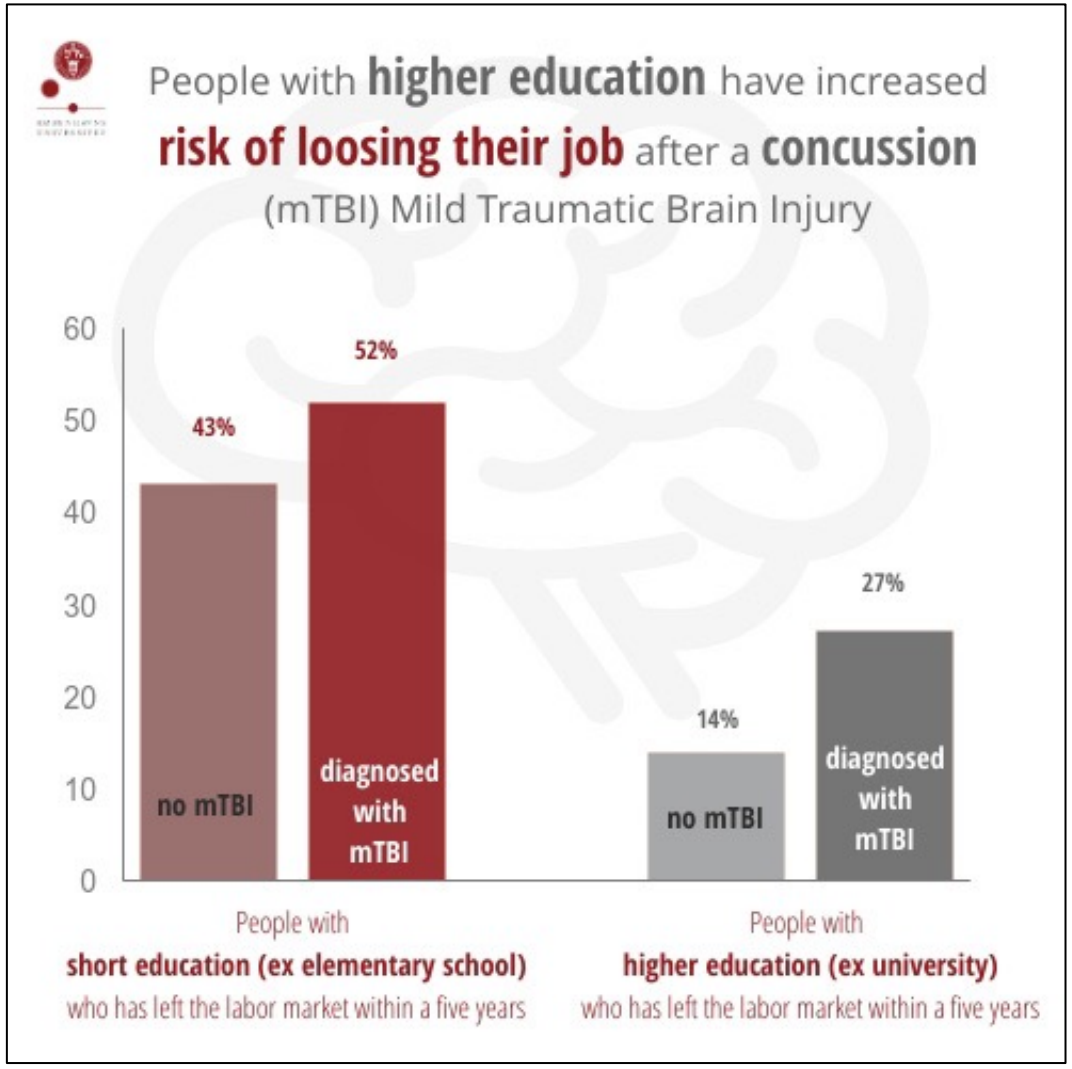
TRAUMATIC BRAIN INJURY : *Return to work (mTBI)*

5. RETURN to WORK



Danemark

Graff, 2019



TRAUMATIC BRAIN INJURY : *Treatment (mTBI)*

A. NON PHARMALOGICAL TREATMENTS

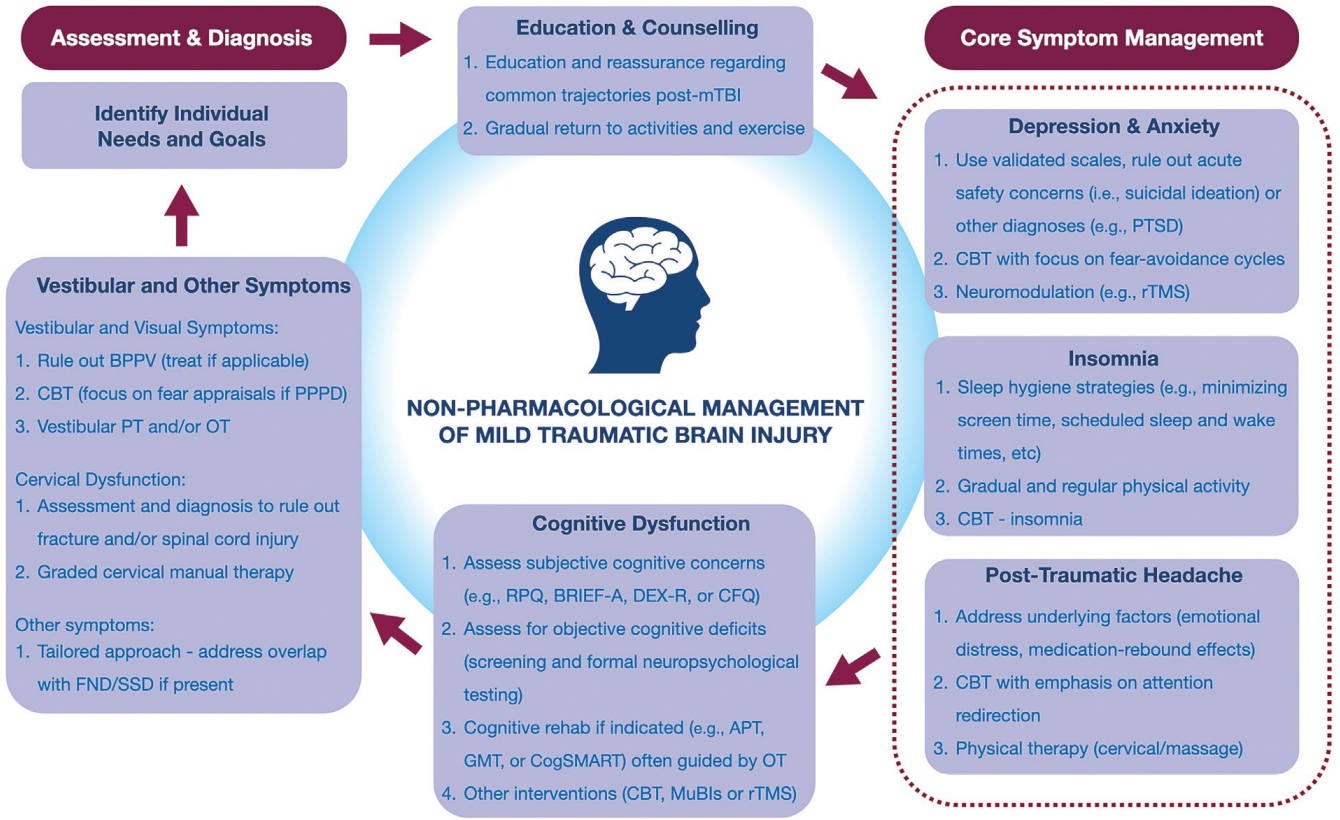


Fig. 1 Non-pharmacological approaches for the management mild traumatic brain injury. APT, attention process training; BPPV, benign paroxysmal positional vertigo; BRIEF-A, Behavior Rating Inventory of Executive Functions for Adults; CBT, cognitive behavioural therapy; CFQ, cognitive failures questionnaire; DEX-R, dysexecutive questionnaire revised; dlPFC, dorsolateral pre-frontal cortex; FND, functional neurological disorder; GMT, goal management training; MuBIs, music-based interventions; OT, occupational therapy; PPPD, persistent postural perceptual dizziness; PTSD, post-traumatic stress disorder; PT, physiotherapy; RPQ, Rivermead Post Concussion Questionnaire; rTMS, repetitive transcranial magnetic stimulation; SSD, somatic symptom disorder.

Mollica, 2022