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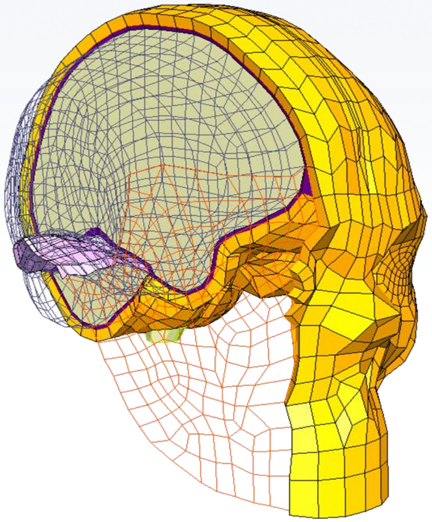

63rd GRSP Meeting – R22
Geneva, May 14th 2018

French considerations on R22

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INTRODUCTION

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- **The needs of R22- improvements**
- **Head impact conditions**
- **Critical issue with current head injury criteria**
- **State of the Art head FE modelling and validation**
- **Focus on head trauma database and accident reconstruction**
- **Model based head injury criteria**
- **Head injury prediction tool for end user**
- **Towards advanced experimental vs numerical helmet test methods**
- **Conclusions**

NEEDS OF R22 IMPROVEMENTS

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- **More realistic head impact conditions : Consideration of Oblique impacts**
- **Consideration of advanced head injury criteria**
- **Proposal of an experimental versus numerical helmet test method**

More general Context:

- **Similar progress exist within CEN TC158-WG11 (bycicle and equestrian helmets.**
- **Progress also exist within FIM**
- **Similar approach under progress within EuroNcap for car environment**
- **Existing Helmet rating**

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TOWARDS NEW HELMET STANDARDS

CONTEXT

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It is **well known** that brain is sensitive to rotational acceleration

since Holbourn (1943)

This phenomenon has essentially been addressed qualitatively with animal or physical models.

Ommaya et al. (1967, 1968), Unterharnscheidt (1971), Ono et al. (1980), Gennarelli et al. (1982), Newman et al. (1999,2000).....

By using **Finite Element Head Models** it was demonstrated and expressed quantitatively the dramatic influence of the rotational acceleration on intra-cerebral loading.

Deck et al. (2007), Kleiven et al. (2007), Zhang et al. (2001)...

THE NEED OF OBLIQUE IMPACT TEST

A number of studies focussed on the victim kinematics in **real world accident** and demonstrated the effectiveness of oblique head impact conditions

Mills et al. (1996), Bourdet et al. (2011, 2012, 2015)...

.

Despite this consolidated knowledge **no head protection standard are currently considering head rotational acceleration**.

The reason may be that there is no accepted brain injury criteria for 6D head kinematic

EXISTING ATTEMPTS FOR OBLIQUE IMPACT TESTS

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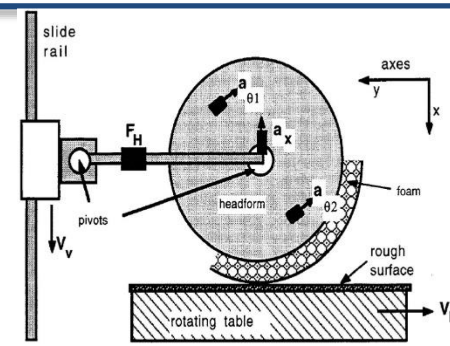
Existing test procedures

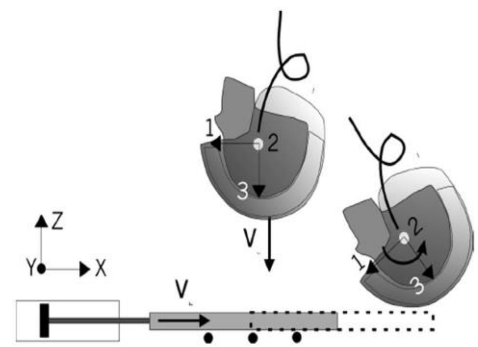
Authors	Helmet	Headform	V_N (m/s)	V_T (m/s)	$\ddot{\alpha}$ (krad/s²)
Aldman et al., 1976	Motorcycle	Ogle-Opat + neck	5.2	8.3	[4.5 ; 14.5]
Aldman et al., 1978	Motorcycle	Ogle-Opat full dummy	4.4	8.3	[4.8 ; 19]
			5.2		
Mills & Gilchrist, 1996	Motorcycle	Spherical	2.4	8.0	[10.4 ; 16.0]
			3.1		
			4.0		

Authors	Helmet	Headform	V_N (m/s)	V_T (m/s)	$\ddot{\alpha}$ (krad/s²)
Halldin et al., 2001	Motorcycle	Ogle	5.0	5.0	[6.0 ; 14.0]
Mills & Gilchrist, 2007	Bicycle	Ogle	4.5	3.6	[2.8 ; 6.2]
Pang et al., 2011	Motorcycle	Hybrid III + neck	6.26	3.13	[1.3 ; 10.9]
			7.67	5.42	

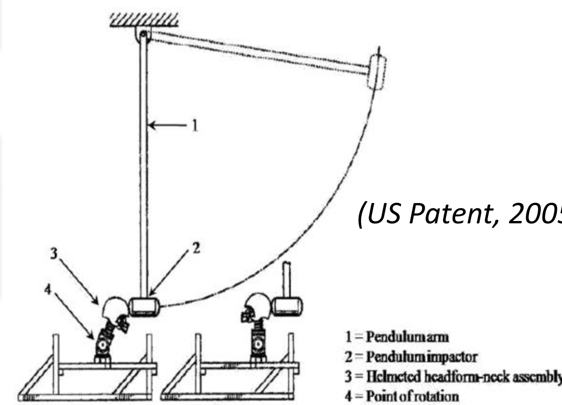
Authors	Helmet	Headform	V_N (m/s)	V_T (m/s)	$\ddot{\alpha}$ (krad/s²)
Withnall & Bayne, 2005	Football	Hybrid III + neck	5.4	0	Non precised



(Mills & Gilchrist, 1996)



(Harrison et al., 1996)



(US Patent, 2005)

THRE KEY ASPECTS TO BE CONSIDERED

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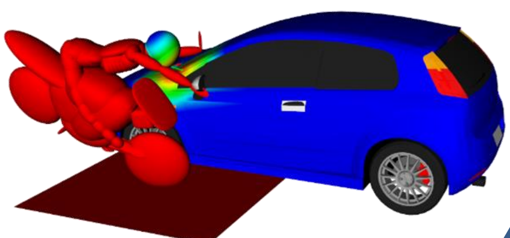
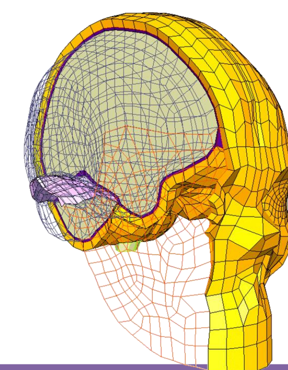
A more realistic 6D instrumented headform

New Test Method





More realistic impact conditions

More Biofidelic Injury criteria

HEAD IMPACT CONDITION VIA ACCIDENT SIMULATION

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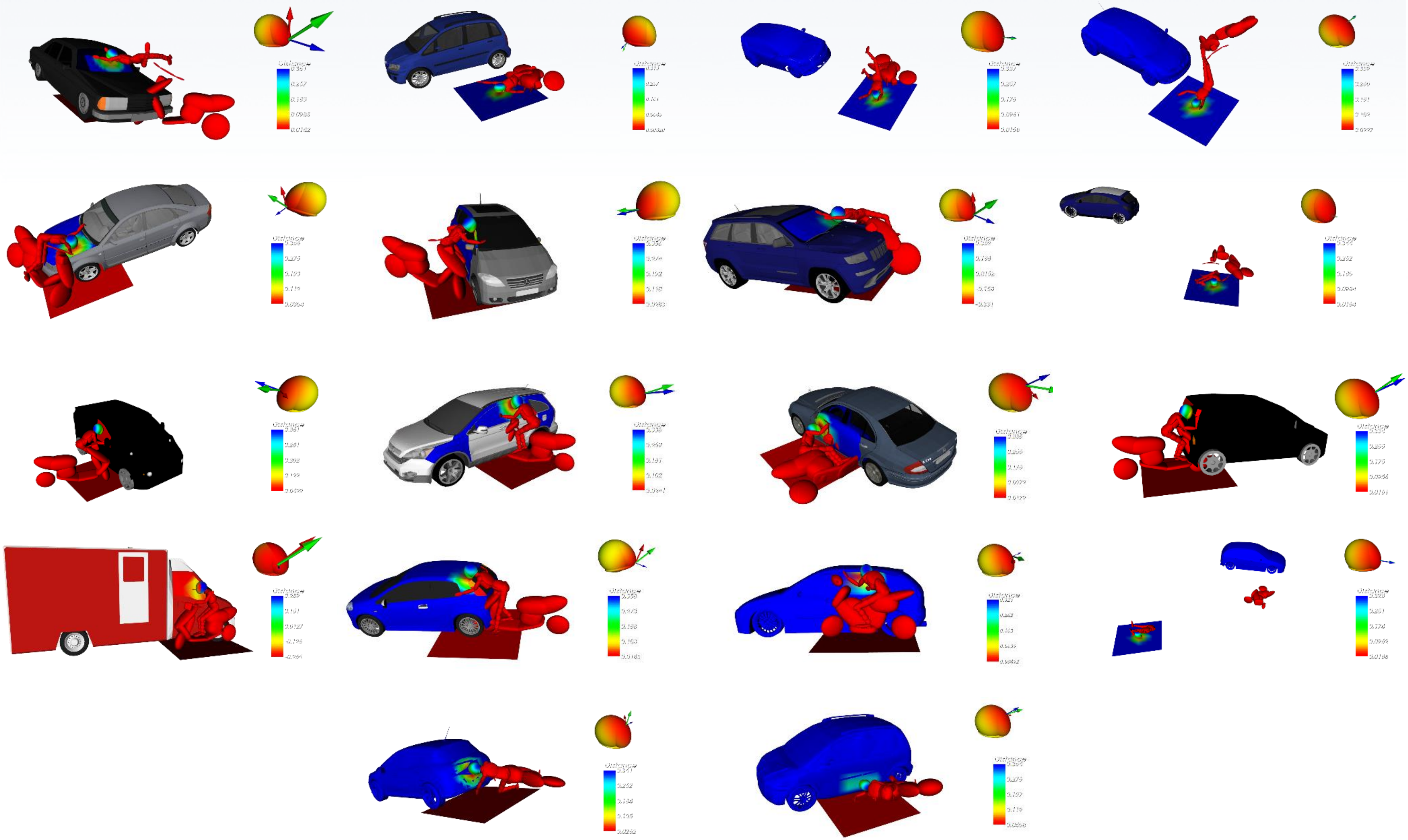

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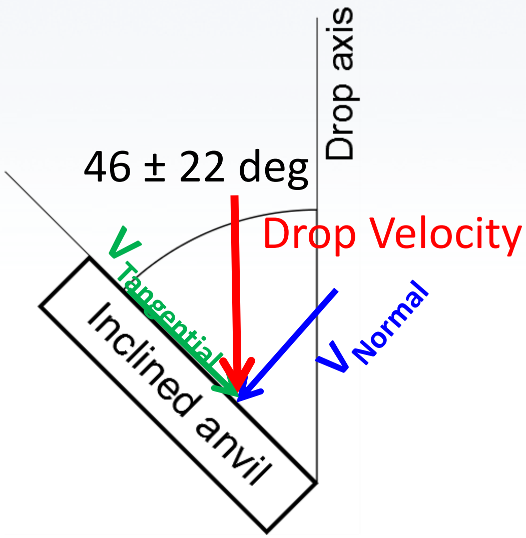
Additional head impact condition

IFSTTAR, CEESAR (Centre Européen d'Etudes de Sécurité et d'Analyse des Risques), bast, In-SAFE, VOIESUR

A total of 78 real world motorcycle accidents

$V_{Resultant}$ = 13 ± 7.2 m/s
V_{Normal} = 7.4 ± 4.5 m/s
$V_{Tangential}$ = 9.7 ± 7.3 m/s



Comparison with drop velocity and angle from real accident cases gathered from literature

Helmet	References	Drop velocity [m/s]	Anvil / Drop axis[deg]	Surface
Motorcycle	Otte et al. 1999	12	<30	Side of car or road
Equestrian	Mellor and Chinn 2006	9	37	Hard grass
Bike	Vershueren 2009	5.3	40	Road
	Bourdet et al. 2013	6.8	60	Car
	Bourdet et al. 2012	6.7 10.2	55 33	Road
Motorcycle	Real-world cases	11.1	44	Road and car

CONCLUSION

- The simulations of the victim kinematics in real world accident demonstrated the effectiveness of oblique head impact conditions.

- The human head is very sensitive to the rotational acceleration induced by this tangential component

- It is important that the helmet presents protection capabilities against this loading

Despite this consolidated knowledge
no head protection standard are currently considering head rotational acceleration.

From ISO EN960 to Hybrid III headform

ISO headform complying EN 960 requirements

EN 960 headform size	Head circumference [mm]	Dummy model	Head circumference [mm]
A	500	Hybrid III 3 Year Old	508
C	520	Hybrid III 6 Year Old	520.7
E	540	Hybrid III 10 Year or 5th Female	538.5
J	570	Hybrid III 95th Large Male	584
M	600	Hybrid III 50th Male	597
O	620		

Hybrid III head

- Mass in accordance with a the average adult head
- More realistic inertial properties
- Deformable skin : soft contact between headform/helmet
- Further discussions undert progress within CEN TC158-WG11

DROP TEST DEVICE

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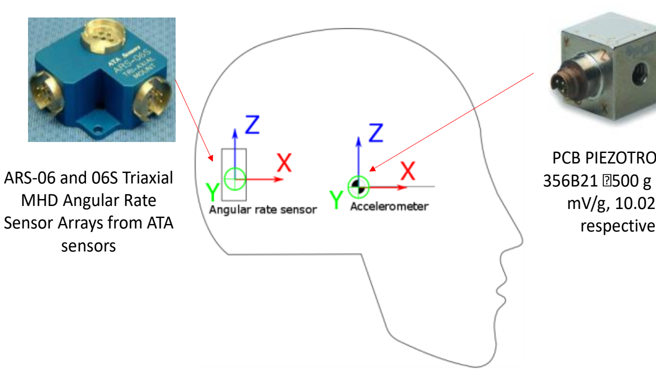
In collaboration with AD Engineering this test method is now operational

Certificated drop test device helmet testing
absorption test

Anvil with a
45° inclined



ARS-06 and 06S Triaxial MHD Angular Rate Sensor Arrays from ATA sensors

PCB PIEZOTRONICSinc. accelerometers 356B21 □500 g with a sensitivity of 10.00 mV/g, 10.02 mV/g and 10.05 mV/g respectively for x, y and z axes.

ad ENGINEERING srl
DEVICES AND EQUIPMENTS FOR TESTING - INDUSTRIAL PRODUCTION PLANT & PROTOTYPES

Instrumentation used for the 6D measurement of the headform

MOTORCYCLE HELMET TEST METHOD

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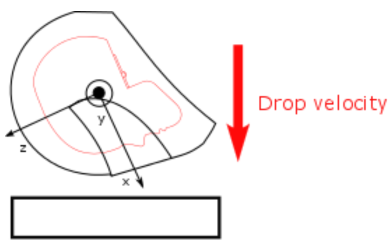
Submitted by the expert from France

- Hybrid III 50% head
- Number of repetitions: 3 tests

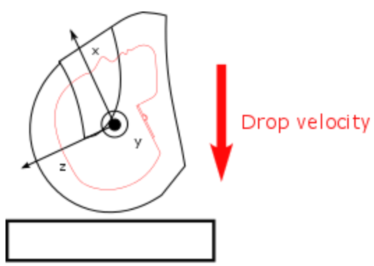
Linear Impacts

Drop velocity = 7.5 m/s

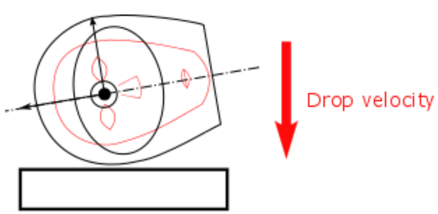
B



R



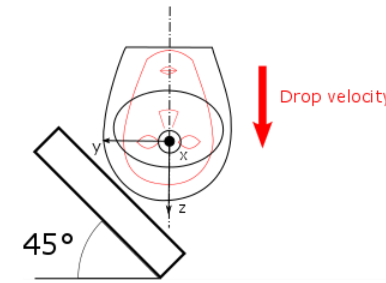
X



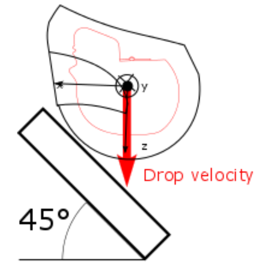
Oblique Impacts

Drop velocity = 8.5 m/s

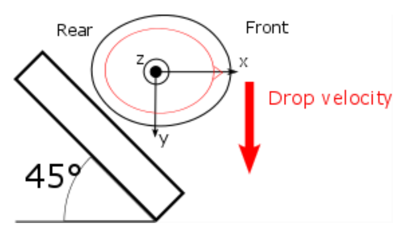
LX



FY



LZ



BICYCLE HELMET TEST METHOD (WITHIN CEN)

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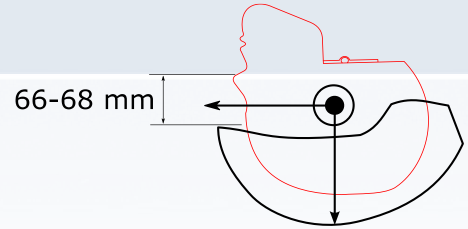
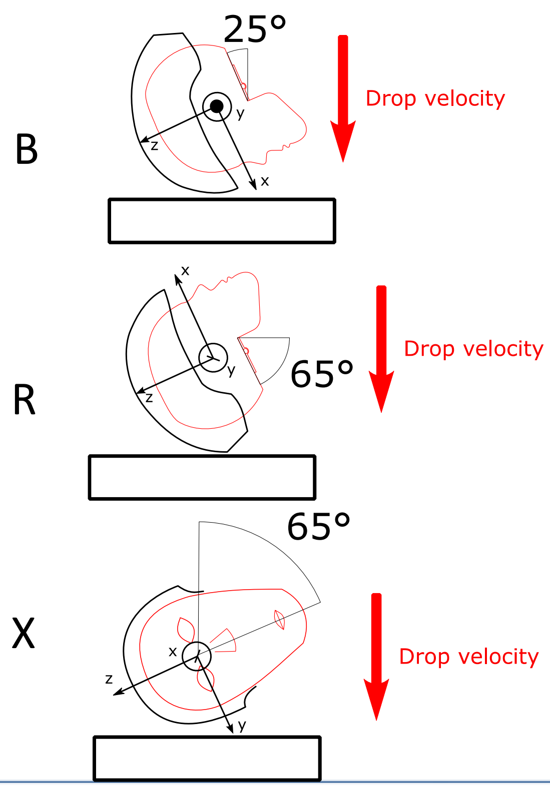
Submitted by the expert from France

- Hybrid III 50% head
- Number of repetitions: 3 tests



Linear Impacts

Drop velocity = 5.5 m/s



Oblique Impacts

Drop velocity = 6.0 m/s (V_N = 4.2 m/s)

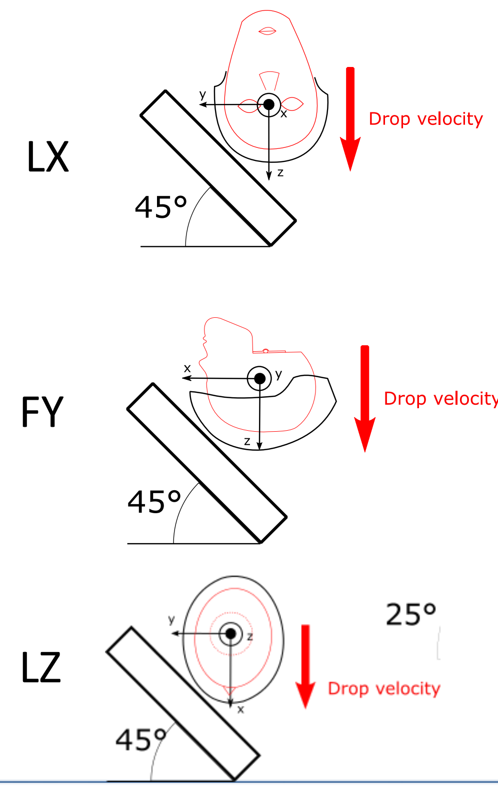


ILLUSTRATION OF OBLIQUE IMPACT

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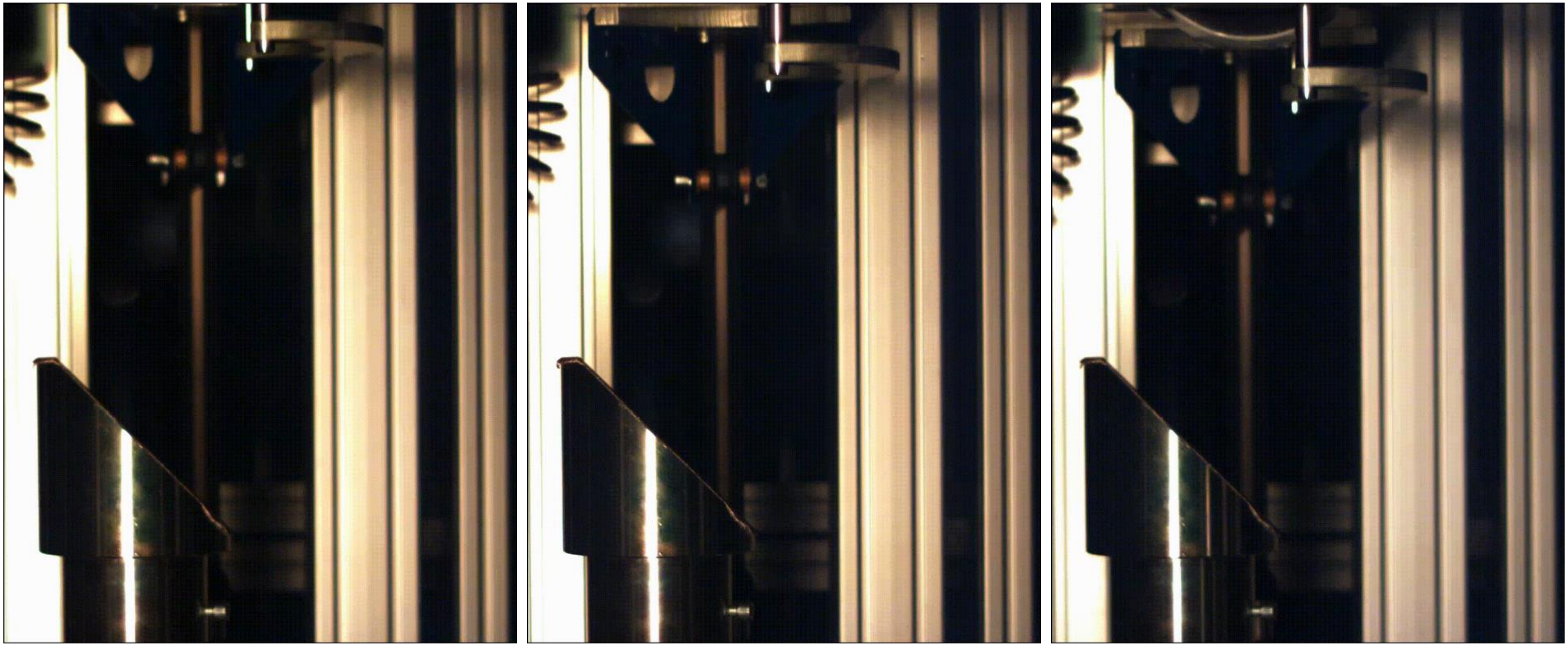

LX Point FY Point LZ Point

16

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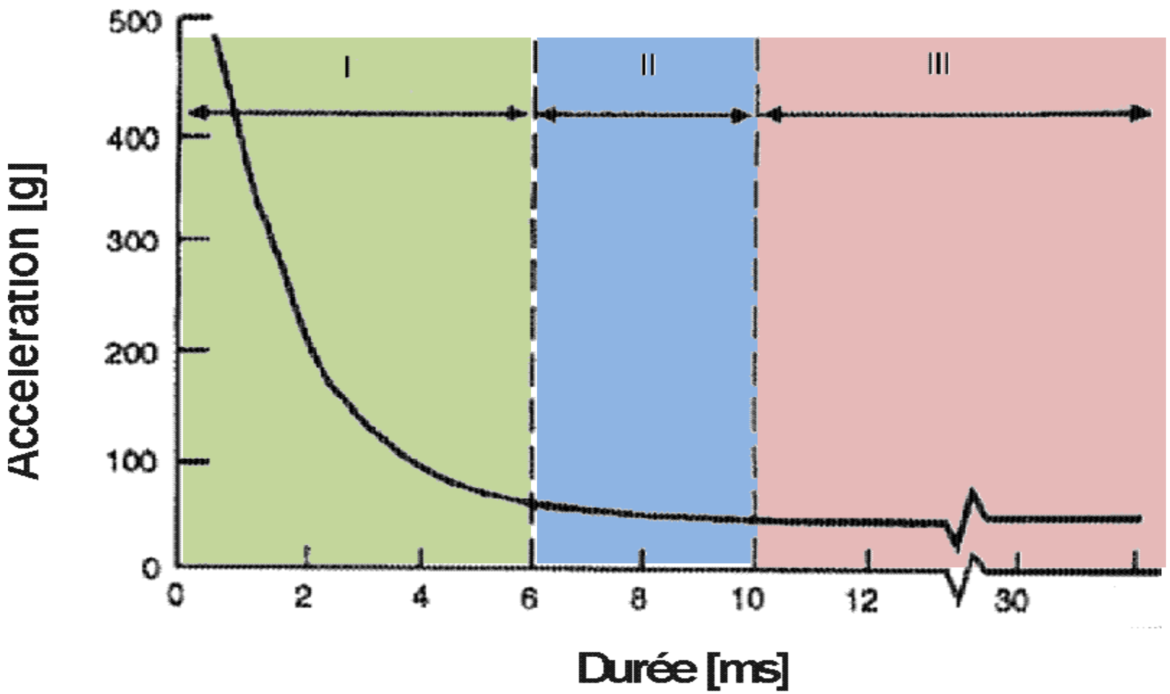
PASS/FAIL CRITERIA FOR COMPLEX LOADING

HEAD TOLERANCE LIMITS AND HEAD INJURY CRITERIA

Head tolerance curve proposed by Wayne State University given linear head accelerations versus time : WSUTC (1966).
Head injuries occur in the part upper the curve.

Part I : tests on cadavers, skull failure considered as head injury.

Part II : intracranial pressure recorded on anatomical subjects and animals, head injury : commotion.



Part III : tests on human volunteers, no head impact, head kinematics recorded during sled tests.

HEAD INJURY CRITERION (1972) : HIC DEFINITION

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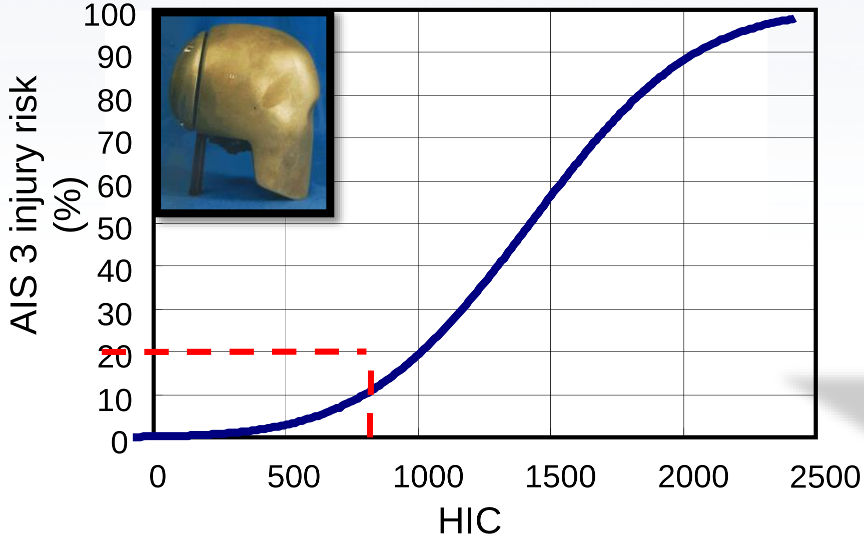
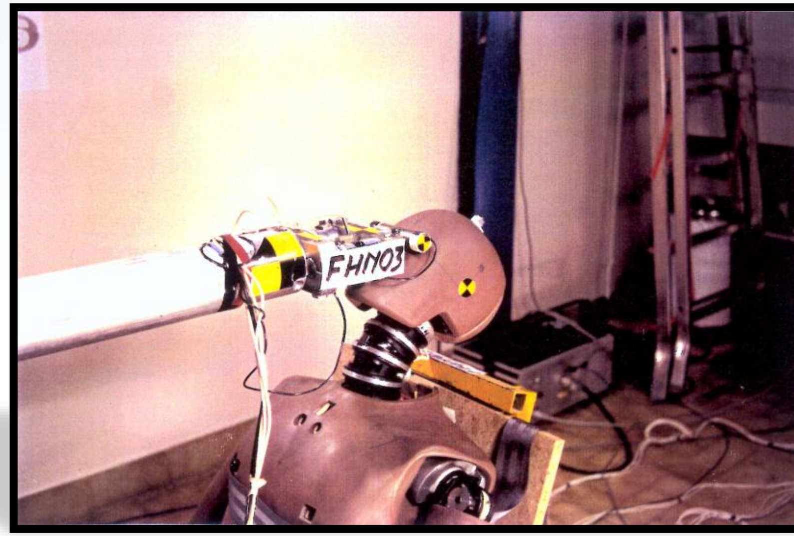
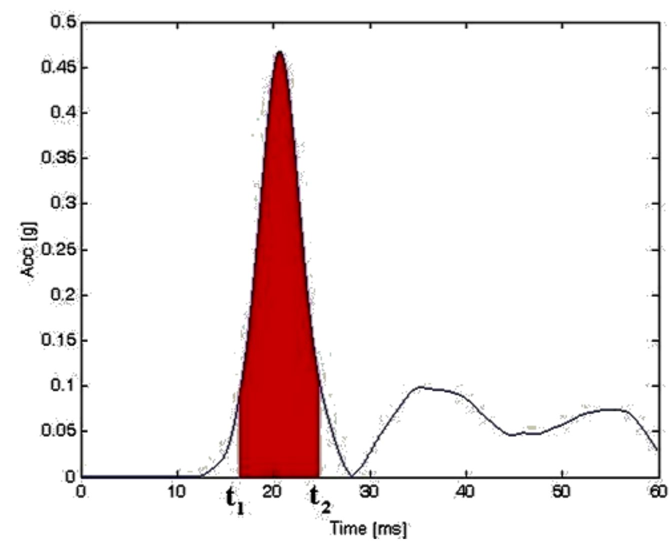




Head mass = 4.58 kg; HIC = 1000

$$HIC = \max_{(t_1,t_2)} \left\{ (t_2 - t_1) \left[\frac{1}{t_2 - t_1} \int_{t_1}^{t_2} a(t)dt \right]^{2.5} \right\}$$



CONTEXT OF HEAD PROTECTION STANDARDS

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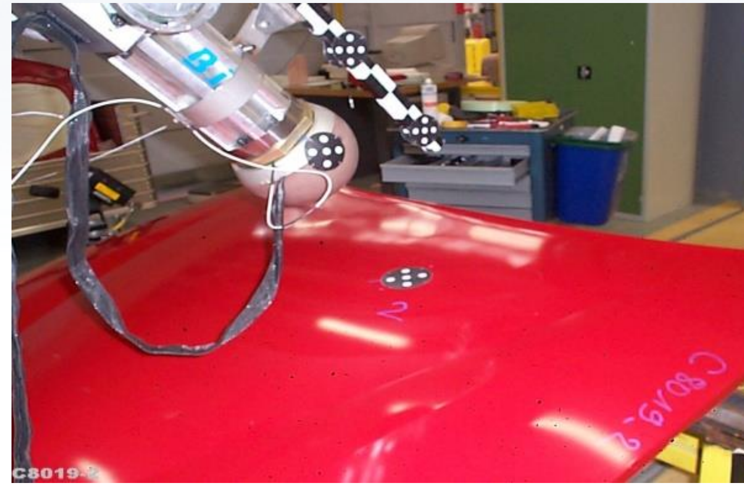
- Inside a car (1970)
  - Dummy head; **HIC 1000**

- Outside – pedestrian (2005)
  - Headform; V=11 m/s ;
    e = 7 cm ; **HIC 1000 à 1700**

- Motorcyclist (2002)
  - Headform; V = 7.5 m/s ;
    e = 5 cm ; **HIC 2400** ; **Γ= 275G**

- Cyclist
  - Headform; V = 5.42 m/s ;
    e = 2.5 cm ; **Γ= 250G**



… for a same human head !

LIMITATIONS OF EXISTING STANDARDS

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- Poor correlation with real world observation
- HIC was defined for a frontal impact…and is not direction dependent
- Not injury mechanism related
- No consideration of rotational acceleration
- No criteria for children (6 YOC, 3 YOC…)

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ADVANCED TISSU LEVEL INJURY CRITERIA

STATE OF THE ART HEAD FE MODEL AND VALIDATION

23

STRASBOURG UNIVERSITY FE HEAD MODEL

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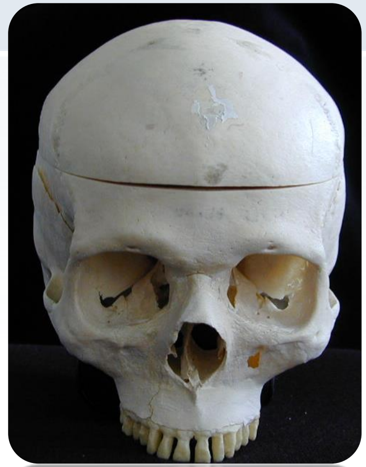


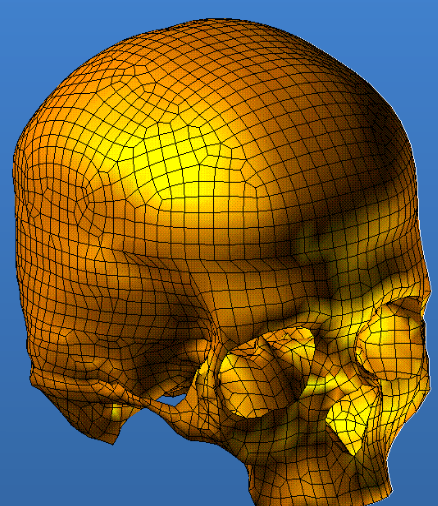
50th percentile adult skull

[Kang, 1997]

SUFEHM 98

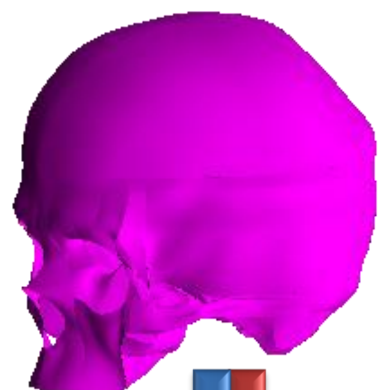
Accident reconstructions

Tolerance limits



Digitalisation

[Deck, 2004]



Skull Model Improvement

- Refined meshing
- Skull thickness variation
- Inclusion of reinforced beams
- Improvement of non-linear material characteristics

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cnrs

SUFEHM PRESENTATION

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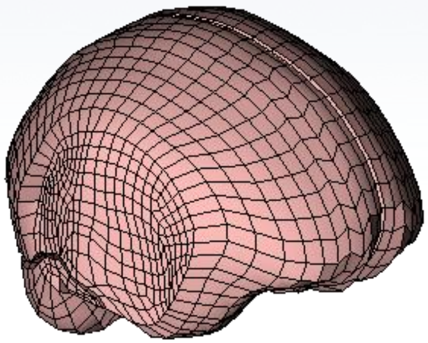
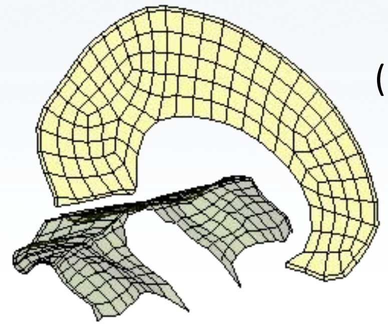
Brain

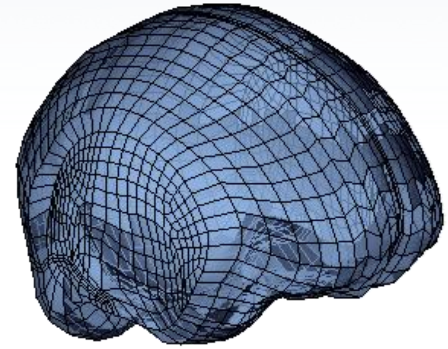
(Viscoelastic G_0=49kPa, G_∞=16.7kPa, β=145s^{-1})





Membranes

(Elastic E=31.5MPa, γ=0.23)

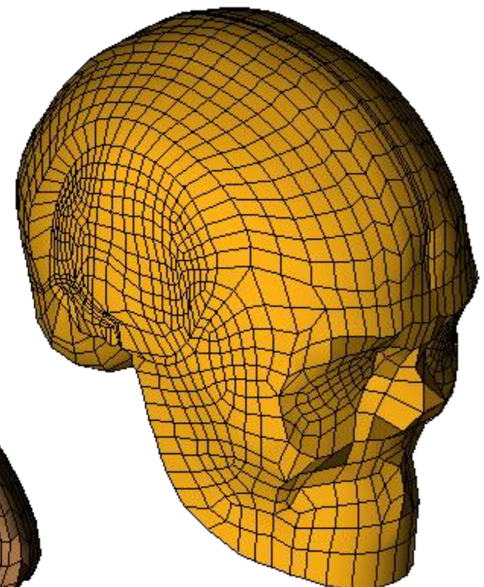


CSF

(Elastic E=12kPa, γ=0.49)

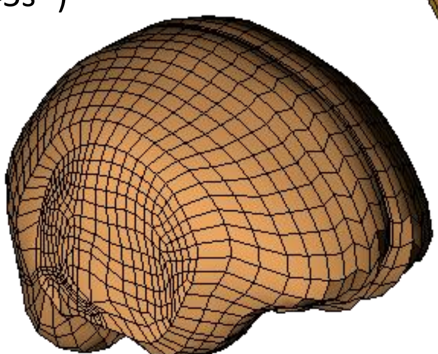
Brainstem

(Viscoelastic G_0=49kPa, G_∞=16.7kPa, β=145s^{-1})



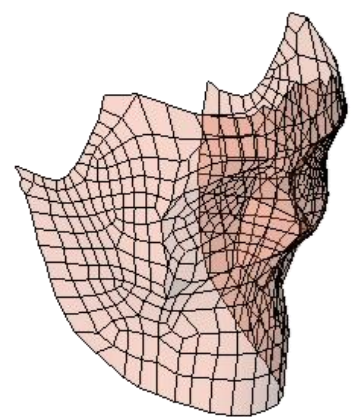
Scalp

(Elastic E=16.7MPa, γ=0.42)



Skull

(Shell elements, composite law with failure criterion)



Face

(rigid)

HEAD FE MODELS AROUND THE WORLD

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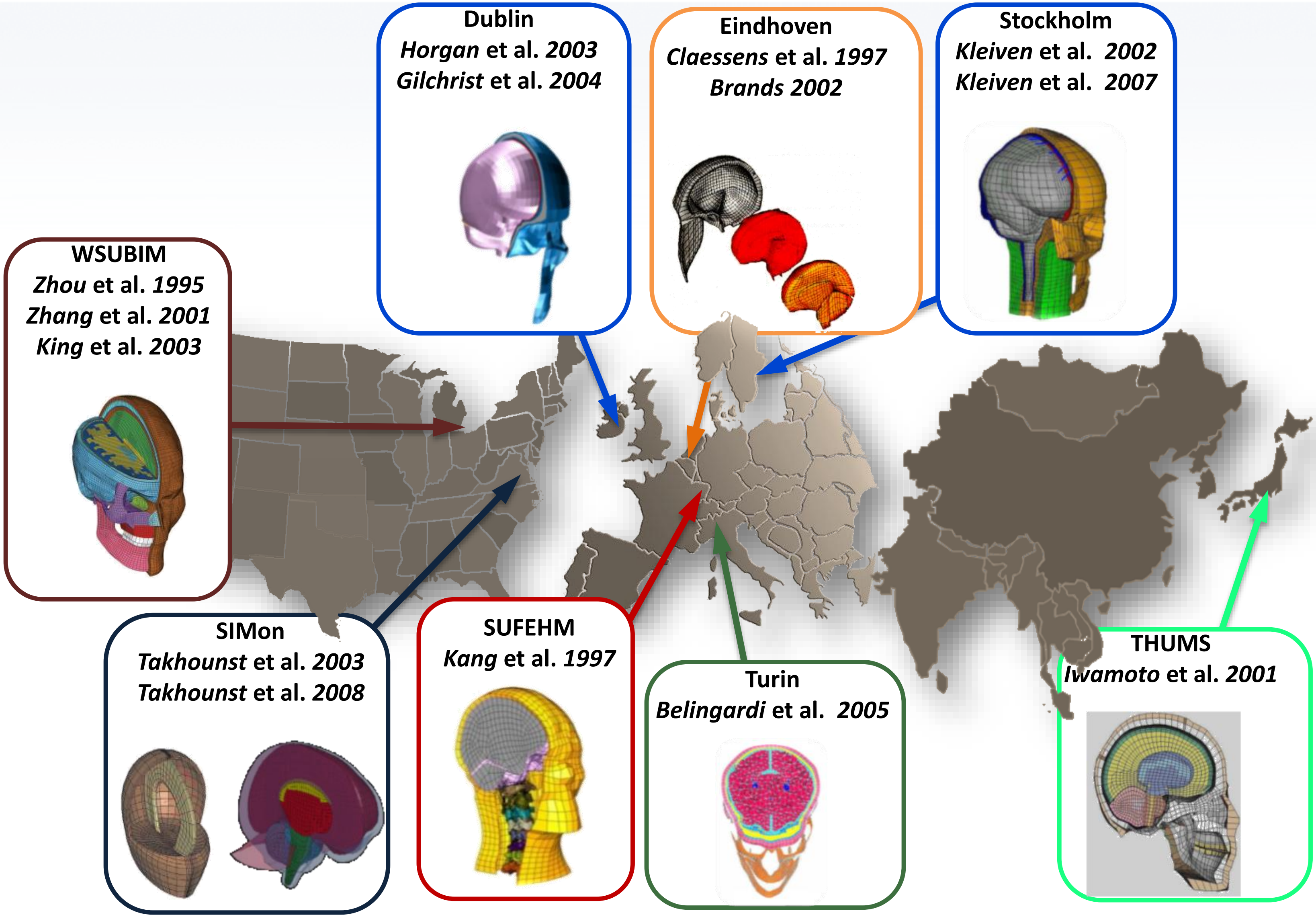

Validation Data

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Nahum & Trosseille
(1977) (1992)
Impact area : front
Impactor : Cylinder with padding
Impact velocity : 6.3 m/s
Duration : 6.2 ms

Intra-cranial behaviour validation

Hardy
(2001)
Impact area : occipital
Impactor : Cylinder
Impact velocity : 2 m/s
Duration : 20 ms

Yoganandan
(1994)
Impact area : vertex
Impactor : Rigid sphere
Impact velocity : 7.3 m/s
Duration : 2 ms

Skull validation

Sarron
(1999)
Back face effect
Under Balistic conditions

BENCHMARK PROCEDURE AND MODELS EVALUATION

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Intra-cranial behaviour validation

PRESSURE

1. Nahum (1977)
2. Trosseille (1992)

BRAIN MOTION

Hardy et al. (2001)

1. Frontal impact (Test C383-T1)
2. Occipital impact (Test C755-T2
3. Right lateral impact (Test C383-T1)

Skull validation

Yoganandan et al. (1994)

BENCHMARK PROCEDURE : NAHUM INPUT

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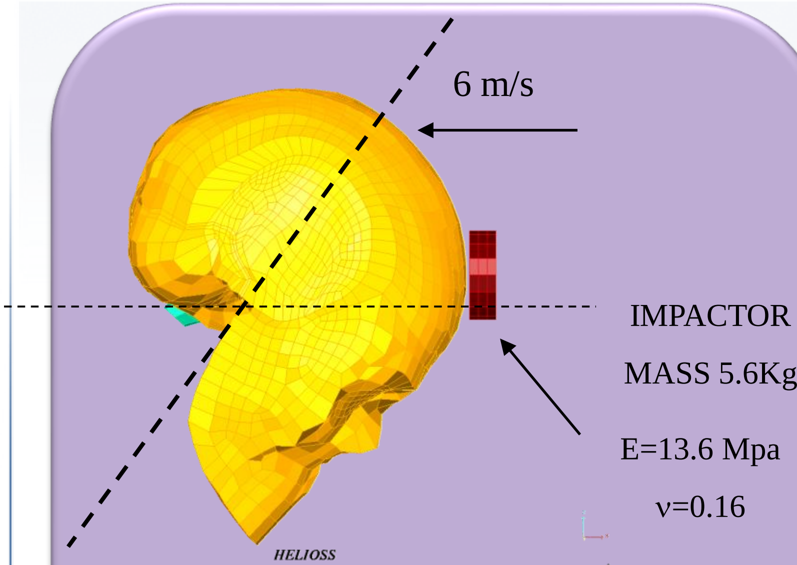
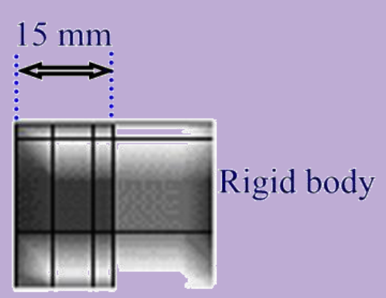


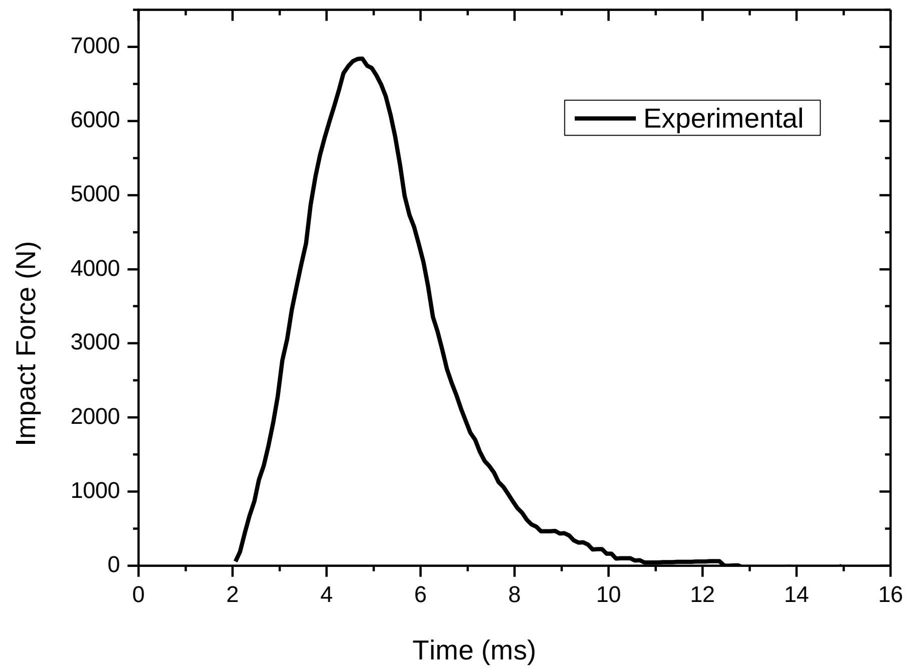


Padding
E = 13.6 MPa
Poisson ratio = 0.16

[Nahum et al., 1977]

Input :

- A 5.6 kg cylindrical impactor (with padding).
- An initial velocity about 6.3 m/s
- Boundary conditions : Head free



Interaction force between the head and the impactor

NAHUM IMPACT NUMERICAL RESULTS

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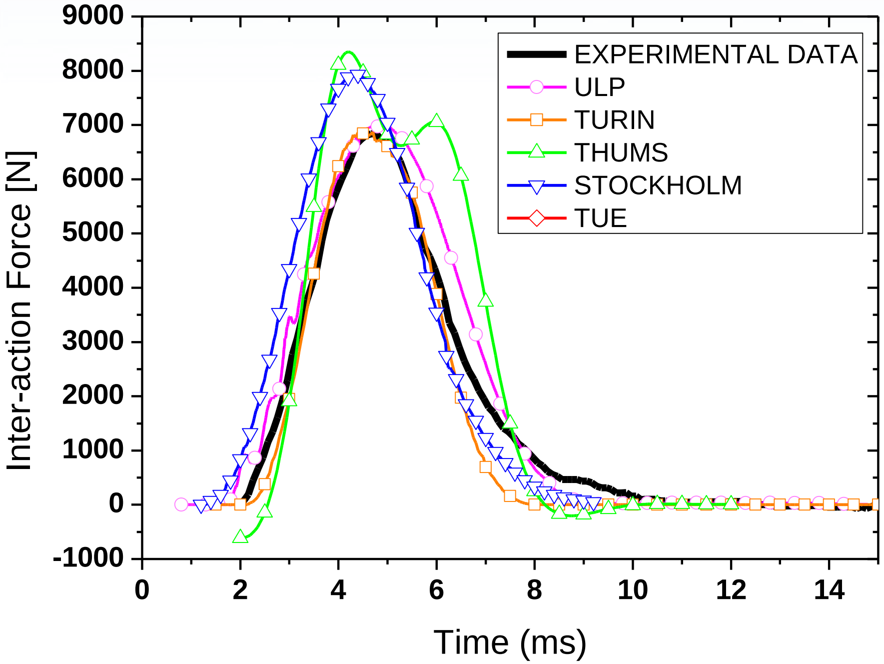
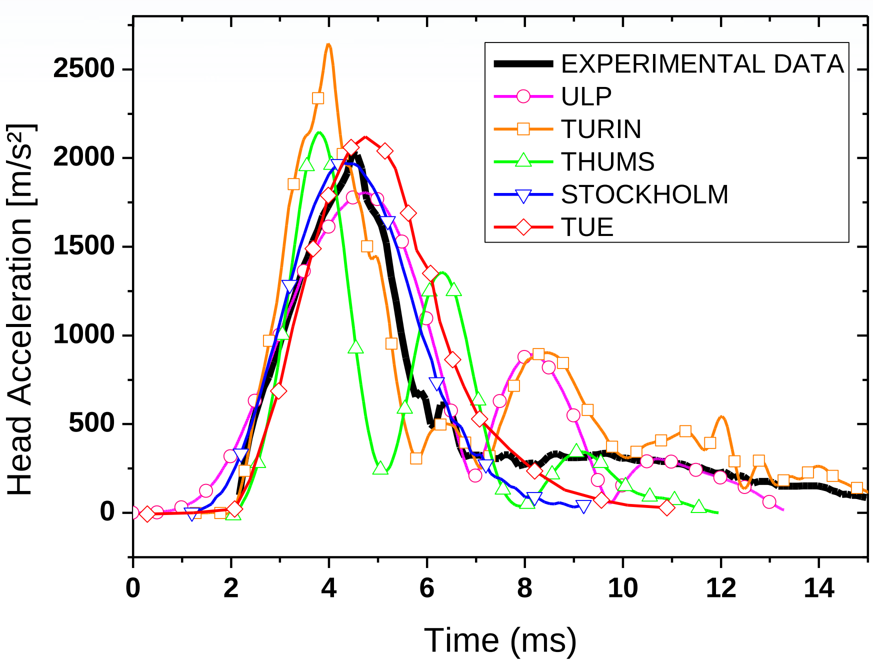
- Impact force, head acceleration





Some oscillations can appear in head acceleration results

STATE OF THE ART NUMERICAL HEAD MODEL

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- Brain acceleration and pressure

  - THUMS, SUFEHM and KTH models provided a comparable level of accuracy for brain acceleration

  - Pressure prediction was at similar level of accuracy for all models

- Brain displacement

  - THUMS, SUFEHM and KTH presented best accuracy

  - NHTSA and TUE were less accurate

- Skull deflection

  - Only THUMS and SUFEHM models predicted an accurate skull deflection as well as skull rupture

Model Based Brain Injury Criteria
Real World Head Trauma Simulation

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ACCIDENTS RECONSTRUCTIONS

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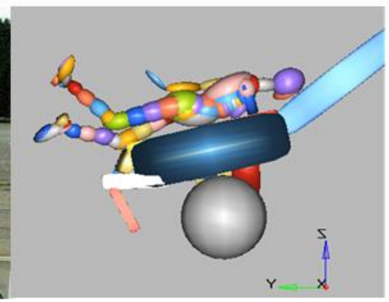
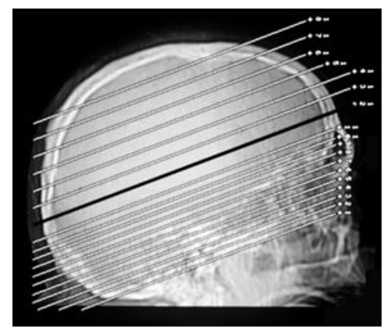
- METHODOLOGY

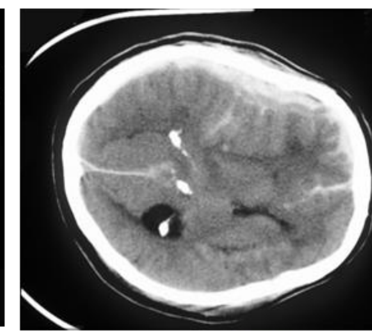
Experimental or analytical replication



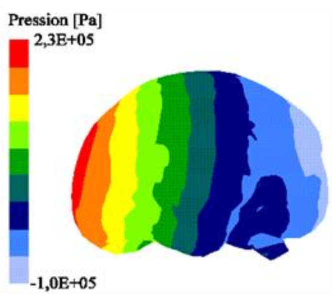
Real accidents

Detailed medical report





Numerical reconstruction



Injury mechanisms and tolerance limits

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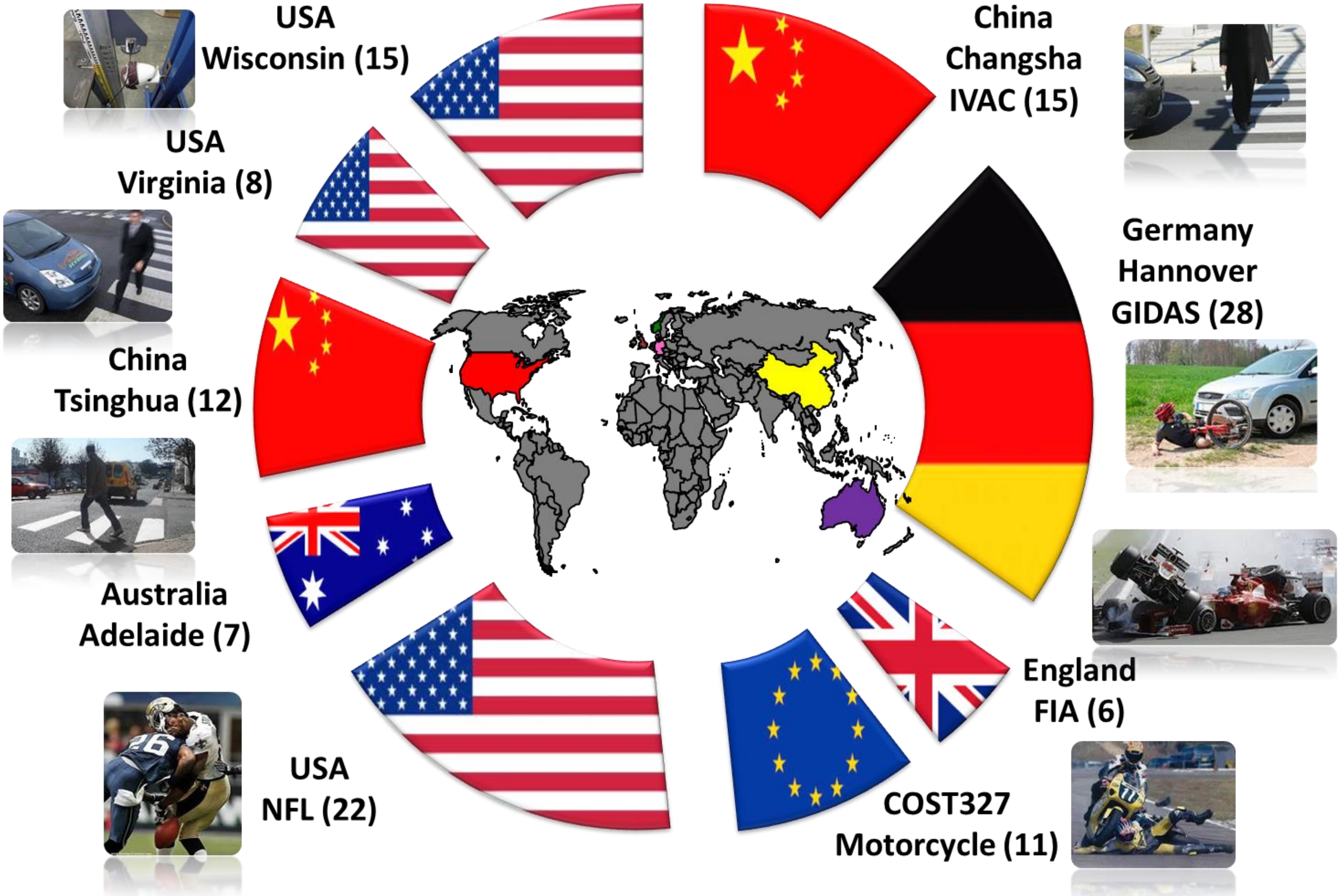
Database (125 cases)

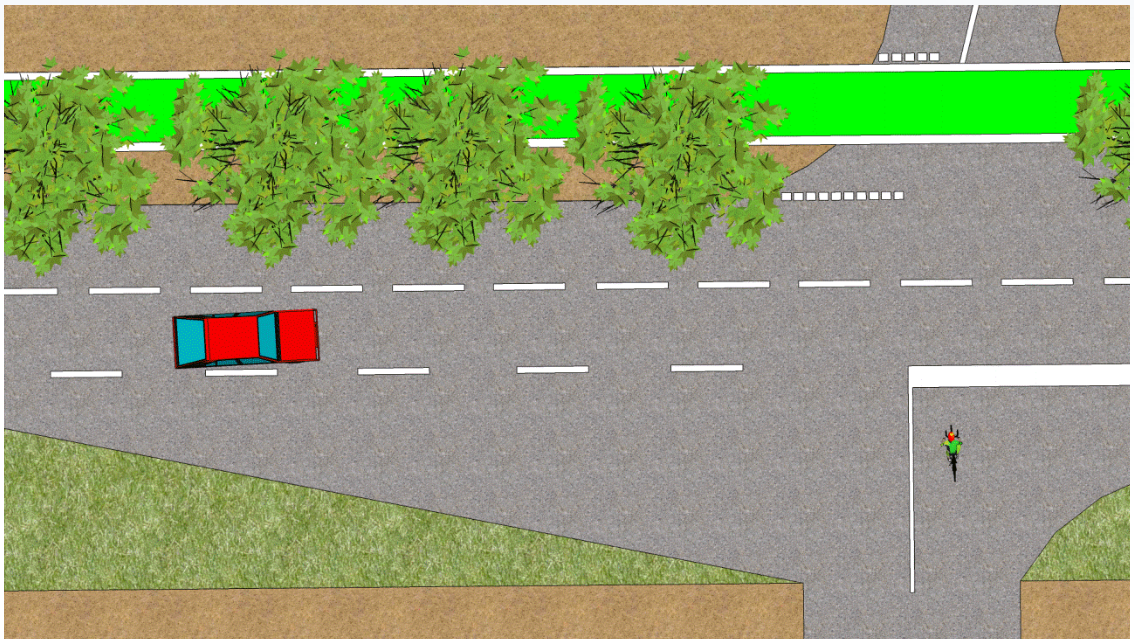


DETAILED ACCIDENT RECONSTRUCTION

EXAMPLE : DESCRIPTION OF ACCIDENT CASE

Submitted by the expert from France

Unistra modeling



Impact Conditions

Car velocity ~ 45 km/h
Cycle Velocity ~ 5.5 km/h
Cycle/Car angle ~ 6°
Vehicle deceleration ~ 6,5 m/s²

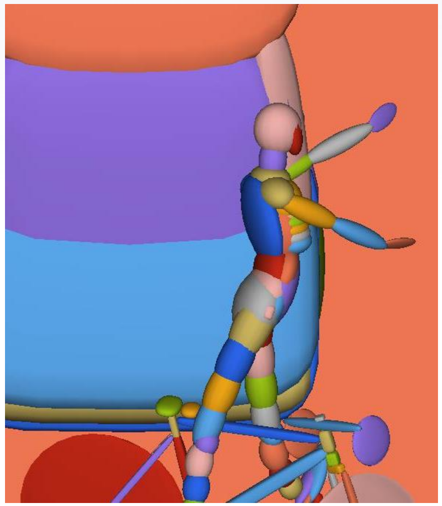
Victim

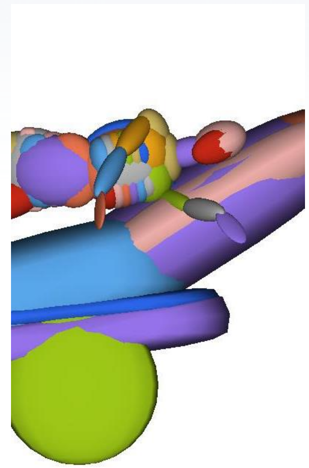
Man, 91 years old,
Failure parieto-occipito-temporal
Coma with a Glasgow score of 5

EXAMPLE : KINEMATICS RECONSTRUCTION

Submitted by the expert from France

Unistra modeling





$V_{resultant}$ = 10.9 m/s

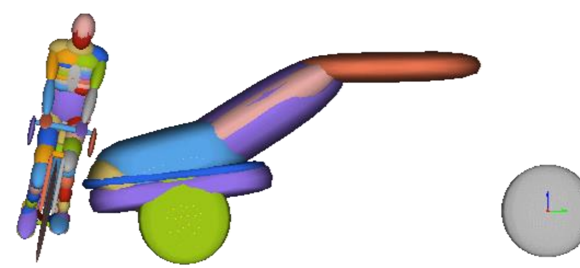
V_{normal} = 10.0 m/s

$V_{tangential}$ = 4.4 m/s

Two impacts
• on windshield with the left shoulder,
• on pillar with head area occipito-parieto-temporal.

Projection distance of 16.3 m

WAD of 2.10 m



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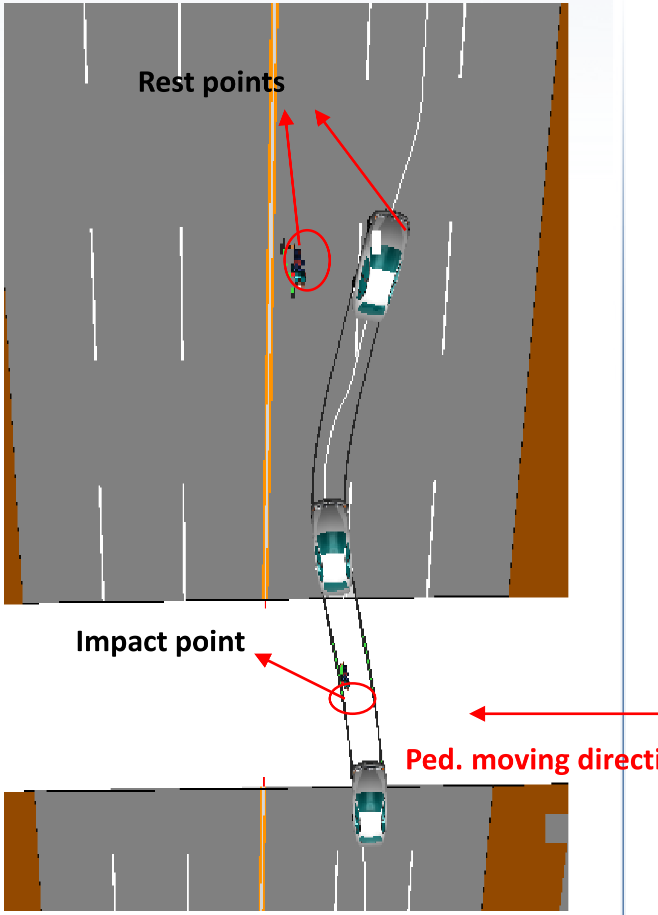
➢ *Exemple pedestrian case (2)*

From IVAC database

- Victim information: 49-year-old female, 158cm and 58kg
- Vehicle information: BMW 318
- Impact speed: about 62.9 km/h



Injury details:

- Cerebral contusion (AIS3), Hematoma (AIS2), Fatal head injuries (AIS6)
- Right tibia (AIS3) and fibula (AIS3) fracture

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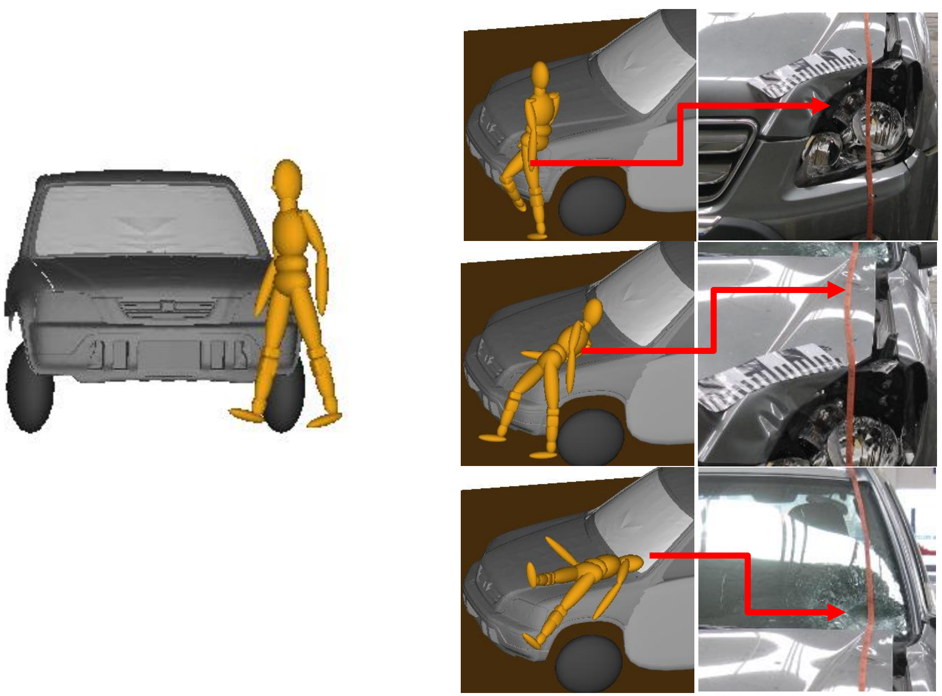
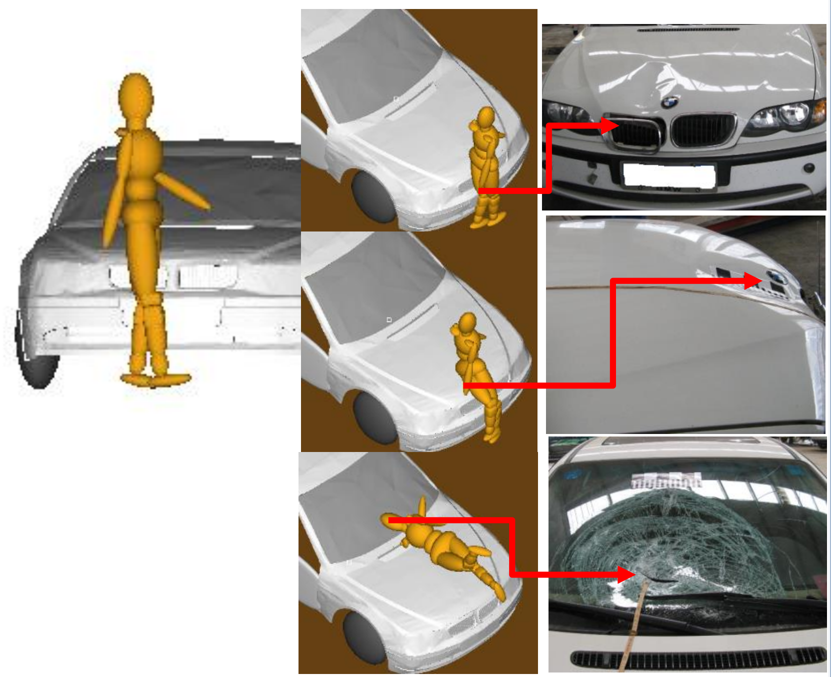
➢ *Reconstruction results*

	Example 1		Example 2	
	Accident	Simulation	Accident	Simulation
Throw distance (m)	12.4	11.3	18	17.5
WAD (mm)	2000	2030	1980	1940
Velocity (km/h)	60	54	60	62.9



Example 1



Example 2

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MODEL BASED HEAD INJURY CRITERIA

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HEAD TRAUMA SIMULATIONS

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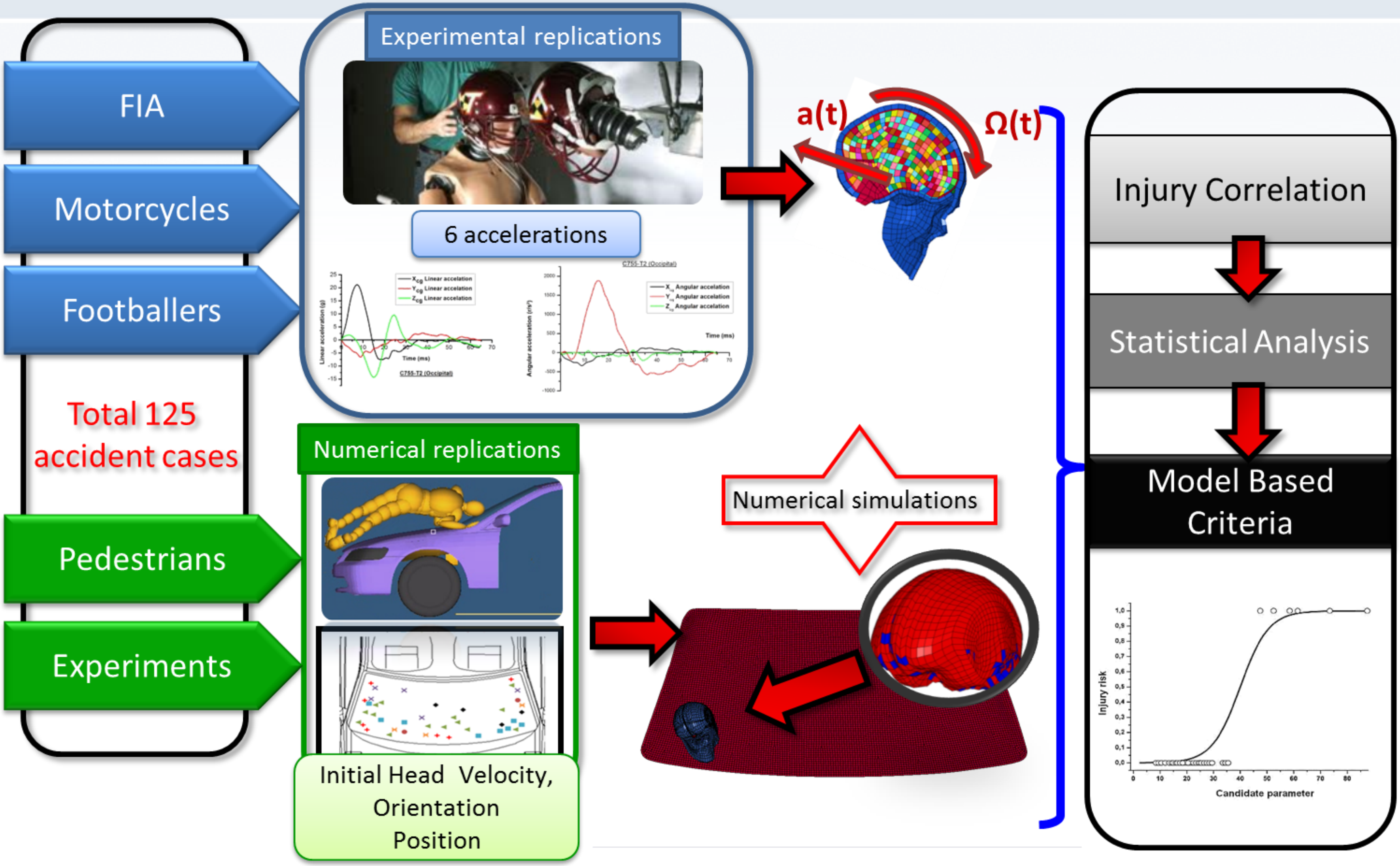

EXTRACTION OF CRITERIA

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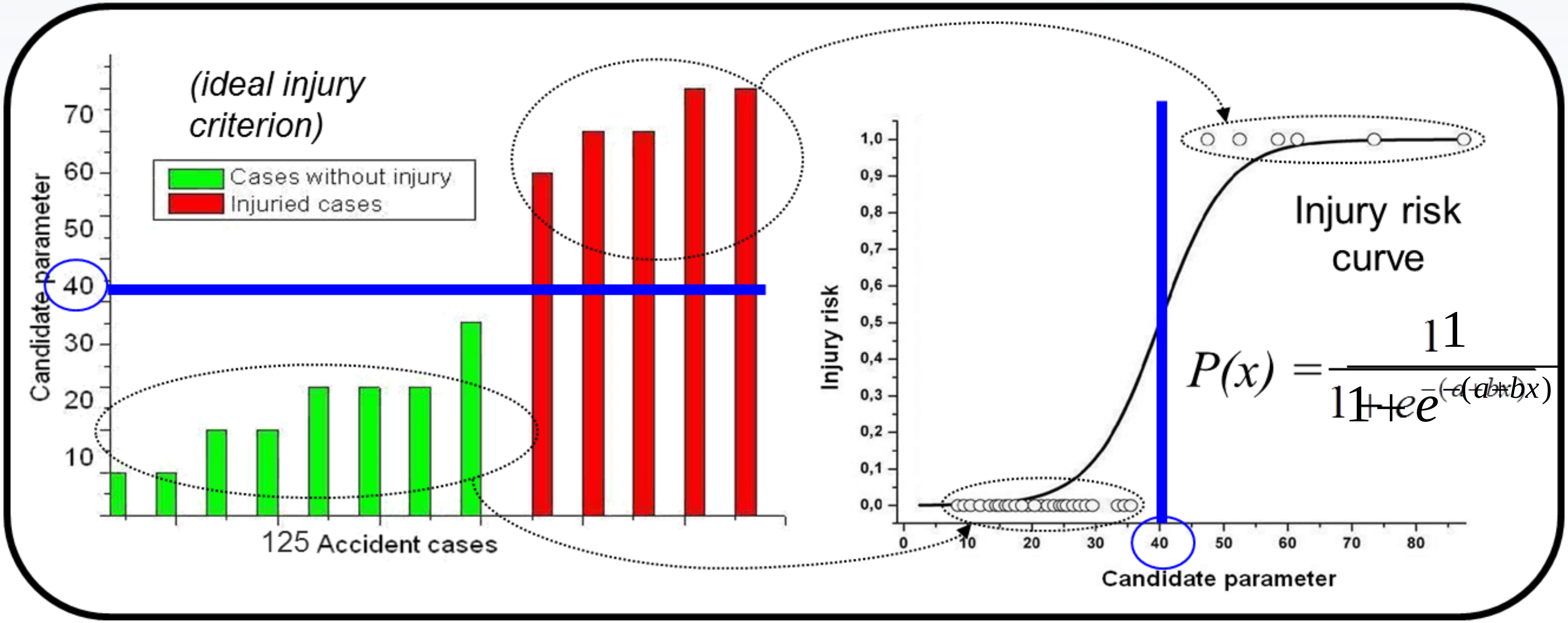

<u>Binary logistic regression *(SPSS v14.0)*</u>

we compared
the Nagelkerke R-sq statistics

Brain injury Criteria : AIS 2+

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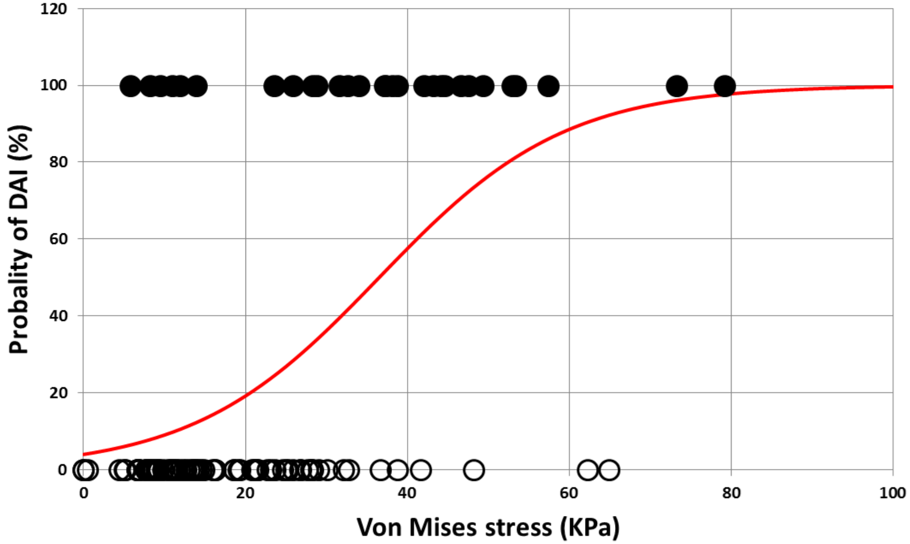
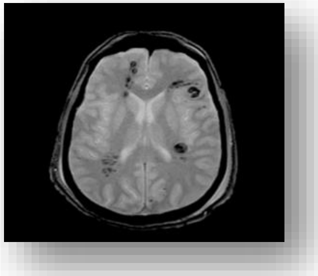
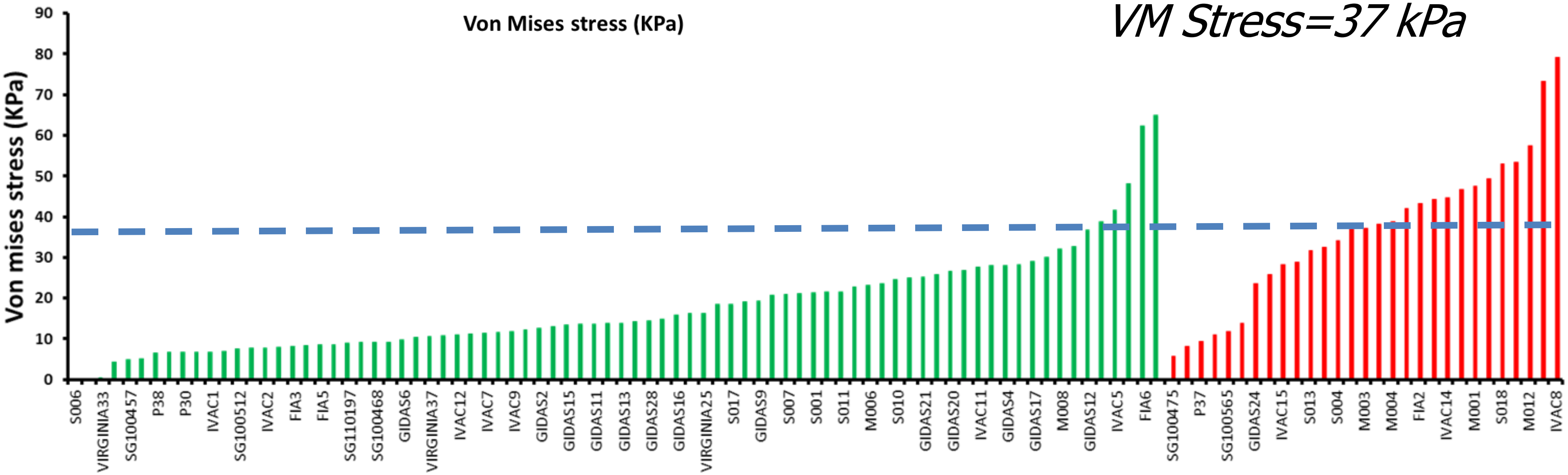




50% risk of DAI (AIS 2+):

VM Stress=37 kPa



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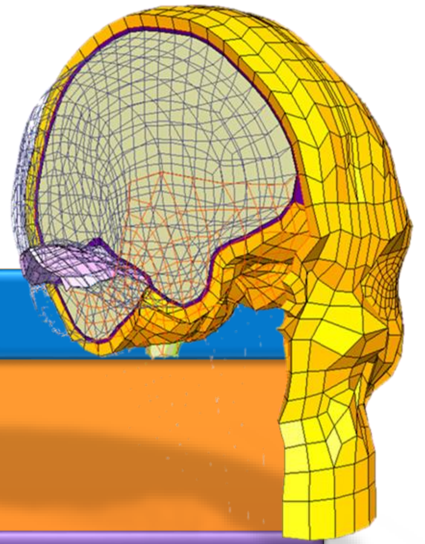
SUFEHM Head injury Criteria



Sub-arachnoidal haematoma (50% Risk)

- ✓ CSF Internal Energy : -135 kPa

DAI (50% Risk) of AIS 2+

- ✓ Intra-cerebral Von Mises stress : 37 kPa

Skull fracture injuries (50% Risk) of AIS 2+

- ✓ Skull strain Energy : 439 mJ

HEAD INJURY PREDICTION TOOL FOR END USERS

FROM RESEARCH TO END USERS

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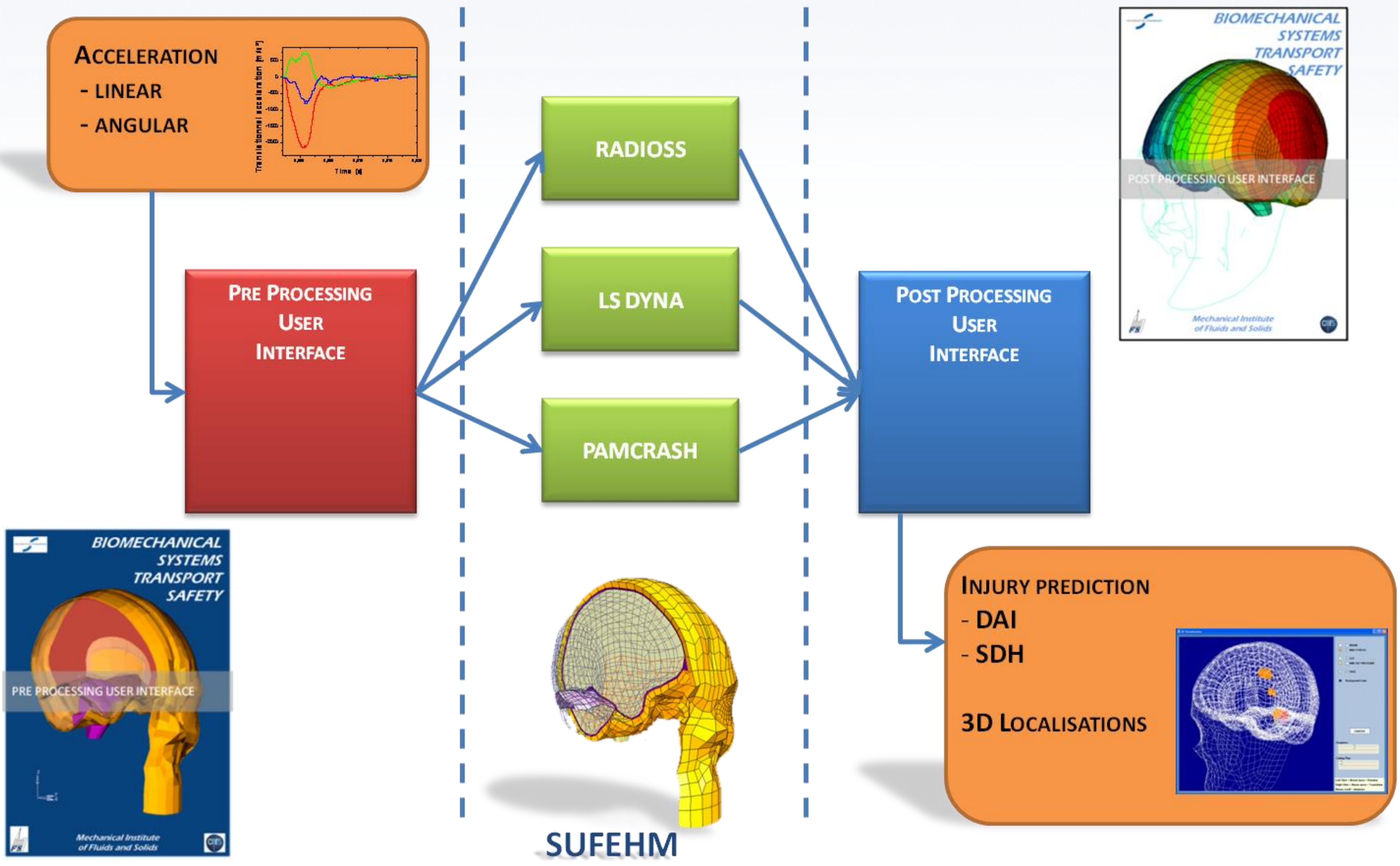
- **PRE-POST-PROCESSING USER INTERFACES :**



EXPERIMENTAL VS NUMERICAL TEST METHOD

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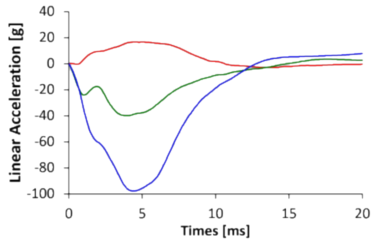
Submitted by the expert from France

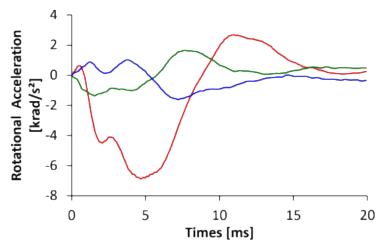
Experimental Test

The 18 impact tests are simulated using SUFEHM

Linear Accelerations



Rotational Accelerations

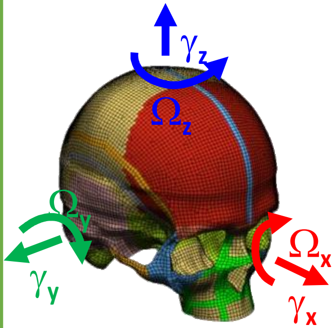


Standard Parameters

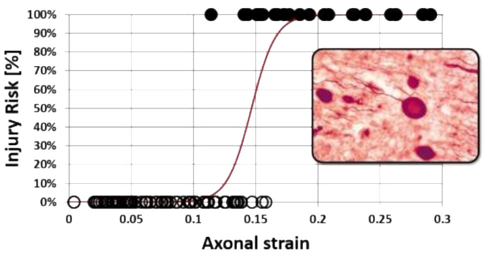
$$HIC = max_{t1,t2}\left\{(t_2 - t_1)\left[\frac{1}{t_2 - t_1}\int_{t_1}^{t_2} a(t)dt\right]^{2.5}\right\}$$

Improved Model Based Head Injury Criteria

SUFEHM



Assessment of Brain Injury Risk



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Injury Risk Assessment

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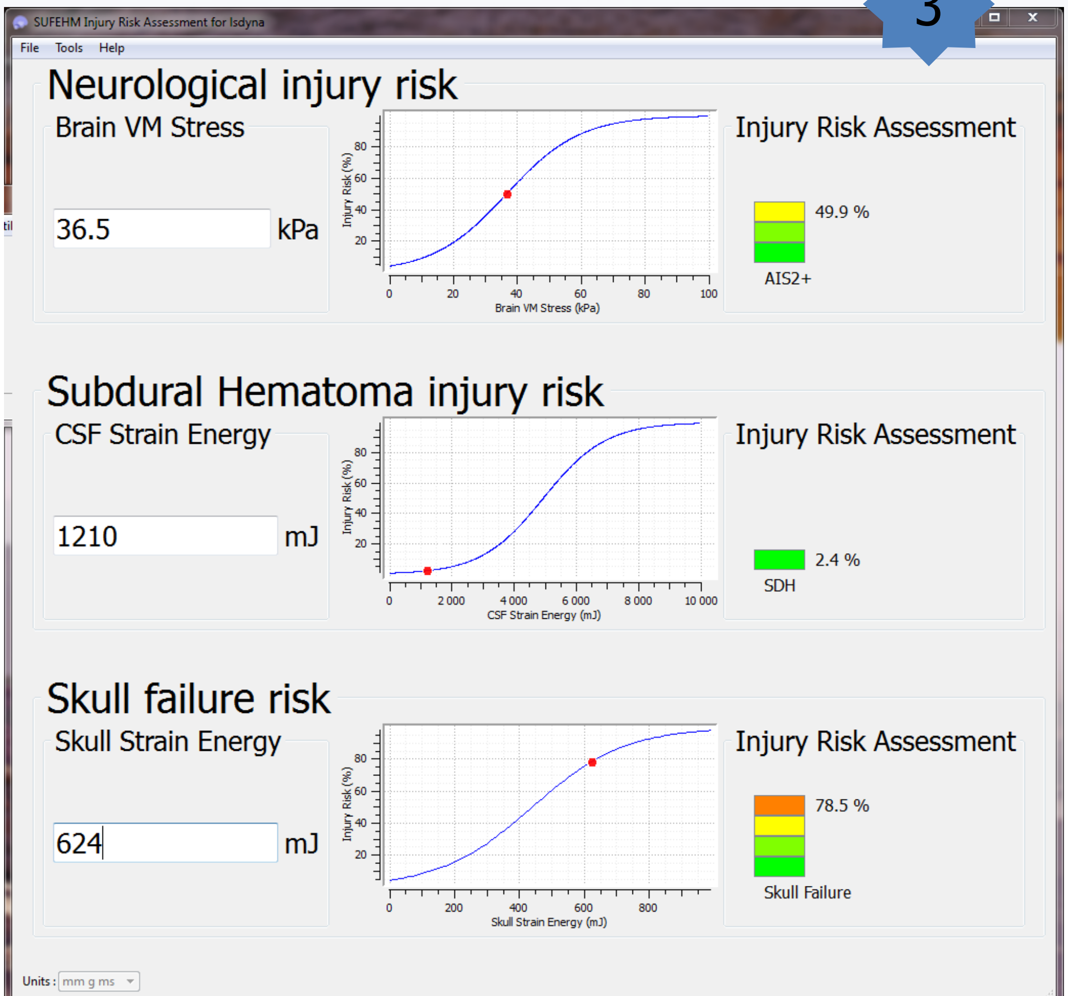

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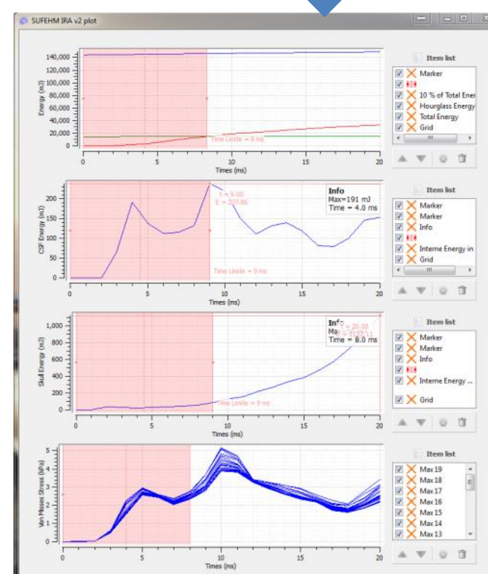

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HELMET RATING

Rating Based on Brain Injury Risk

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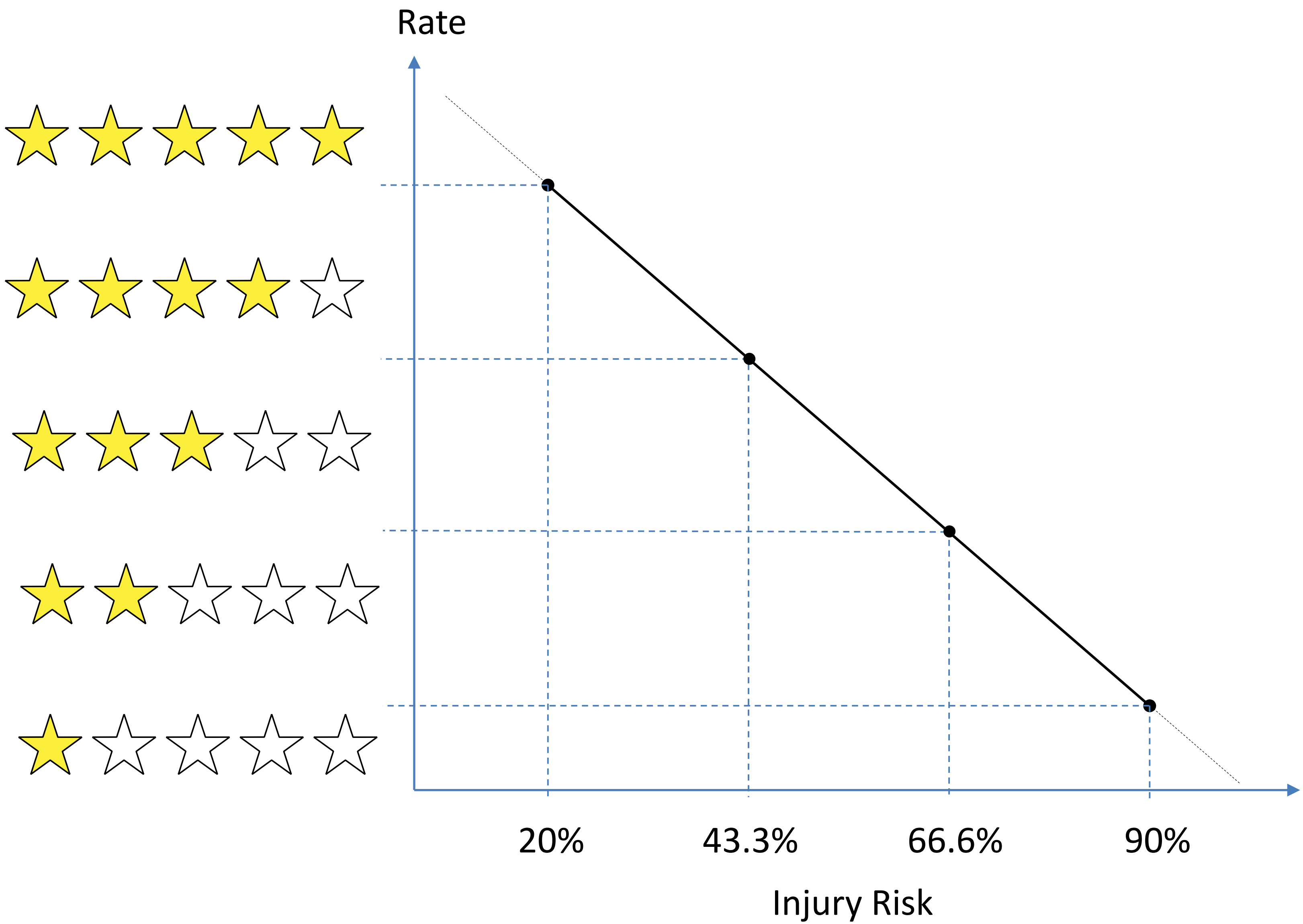

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HELMET RATING : STIFTUNGWAHRENTEST 2017

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CRATONI | CASCO | LAZER | ALPINA | ONEAL

LIMAR | PROPHETE | GIRO | BELL | B'TWIN

ABUS | UVEX | KED | POC | OVERADE

HELMET RATING : QUE CHOISIR, SEPT 2017

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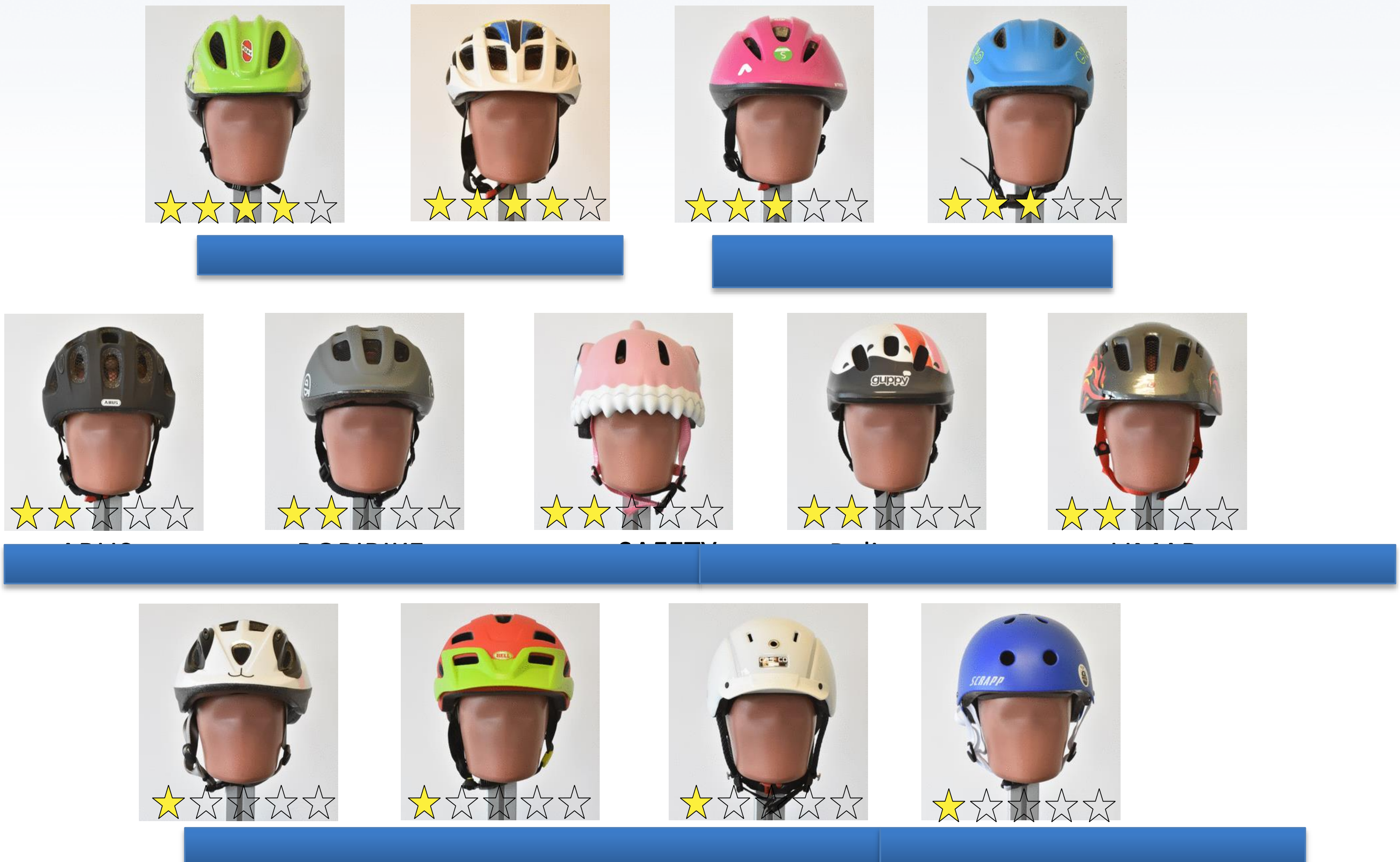
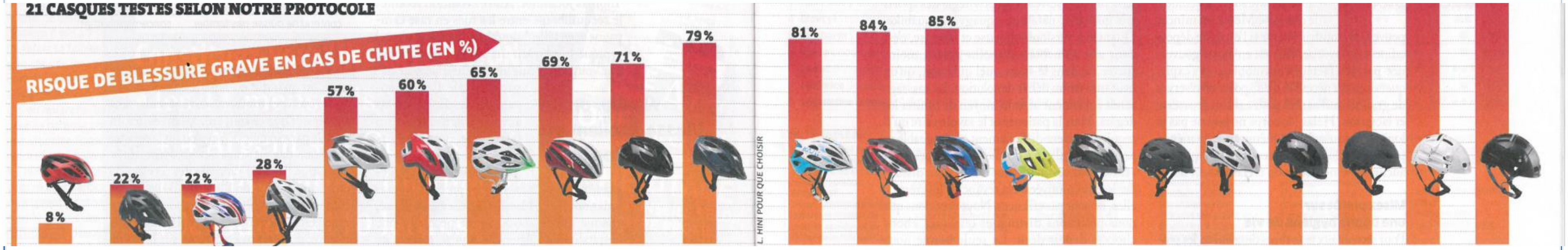


HELMET RATING : QUE CHOISIR, MAY 2018

Submitted by the expert from France

Rating of 21 bycicle helmets



60 Millions de Consommateurs, August 2015

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+++ Très bon 20 à 17
++ Bon 16,5 à 13
+ Acceptable 12,5 à 10
− Insuffisant 9,5 à 7
−− Très insuffisant 6,5 à 0

Les pourcentages entre parenthèses expriment le poids de chaque critère dans la note finale.

	SHOEI GT-AIR	HJC FG-17	ARAI AXCES II	SCHUBERTH S2	CABERG EGO
Prix indicatif	465 €	190 €	380 à 430 €	400 à 450 €	180 à 200 €
Prix écran seul	59 €	49 €	60 €	72 €	31 €
Matériau de la coque	Fibre de verre	Fibre de verre	Fibres composites	Fibre de verre	Polycarbonate
Poids mesuré, taille M	1,45 kg	1,40 kg	1,55 kg	1,45 kg	1,55 kg
Poids mesuré, taille XL	1,50 kg	1,50 kg	1,65 kg	1,55 kg	1,60 kg
Nombre de calottes externes	3	2	1	2	1
Jugulaire	Crémaillère	Double anneaux	Double anneaux	Crémaillère	Crémaillère
Pare-soleil	Oui	Non	Non	Oui	Oui
Antibuée Pinlock	Oui	Oui	Non[1]	Oui	Oui
Absorption des chocs (40 %)	+++	+++	+++	++	++
Aptitudes routières (36 %)	+++	++	++	+++	++
Confort	+++	+++	+++	+++	++
Maintien	+++	+++	++	+++	+
Champ de vision	++	+++	+++	++	+++
Manipulation écran/pare-soleil	+++	+	−	+++	+++
Efficacité de la ventilation	++	+++	+++	+++	++
Étanchéité du casque	++	+	+	+	++
Isolation phonique (18 %)	++	+	−	++	+
Pressions acoustiques à 90/130 km/h	90/98 dB(A)	93/100 dB(A)	95/102 dB(A)	89/98 dB(A)	92/100 dB(A)
Entretien (6 %)	+++	+++	+	+++	++
Dépose écran	+++	+++	++	+++	+++
Dépose pare-soleil	+++		–	+++	++
Dépose garniture intérieure	+++	+++	+	++	+++
Documentation	+++	+++	−	+++	+
Note globale (100 %)[3]	**17/20**	**16,5/20**	**15,5/20**	**13/20**	**13/20**

(1) Pas de Pinlock fourni, alors que l'on note la présence de trous de fixation. (2) Traitement de l'écran antibuée. (3) La note globale ne peut pas être supérieure à la note donnée sur sécurité.

Le critère de la sécurité avant tout

Nous avons sélectionné douze références de casques intégraux. Les prix annoncés correspondent à des casques de couleur noire, la moins chère avec le blanc. Les habillages sont susceptibles de faire grimper l'addition.

Le matériau de la coque est mentionné, mais on ne peut pas en faire un critère de choix. Les fibres de verre ou composites sont plutôt dans le haut du tableau. Mais cette constatation ne vaut pas généralité en matière de résistance au choc. Celle-ci dépend de l'ensemble de la construction du casque, avec tous ses composants. Le matériau de la coque a sans doute son importance mais il n'est pas suffisant aujourd'hui pour choisir un casque qui protégerait mieux.

Des poids et volumes très variables

Il faut rappeler que rien ne remplace un essayage pour faire son choix. Mieux vaut donc se rendre en magasin pour acheter son casque.

→ **Les poids annoncés** sont parfois éloignés du résultat de la pesée. On constate par ailleurs qu'il peut y avoir facilement 100 g d'écart entre deux casques de même taille. Mais en pratique, il n'est pas sûr que l'utilisateur perçoive la différence lorsqu'il les essaie.

→ **Le nombre de calottes externes** correspond au nombre de moules utilisés par le fabricant pour proposer des tailles différentes. S'il ne dispose que d'une calotte externe, il va jouer sur le remplissage pour faire varier la taille. Cela ne sera pas neutre en termes de volume et de poids. S'il en possède plusieurs, le casque de petite taille pourra être moins volumineux.

→ **Le traitement antibuée mérite une attention particulière.** De multiples traitements ou systèmes existent, parmi lesquels la lentille Pinlock qui se distingue aujourd'hui. Cette lentille en plastique souple s'applique à l'intérieur de l'écran et parvient à drainer les

20 MOTORCYCLE HELMETS

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Under progress …

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CONCLUSION

- Needs of R22 improvements
- Importance of oblique impact conditions and need of protection against rotational acceleration.
- Advanced Brain injury prediction tool for end user are available
- Proposal of a novel test method
- Consumer tests & Helmet rating

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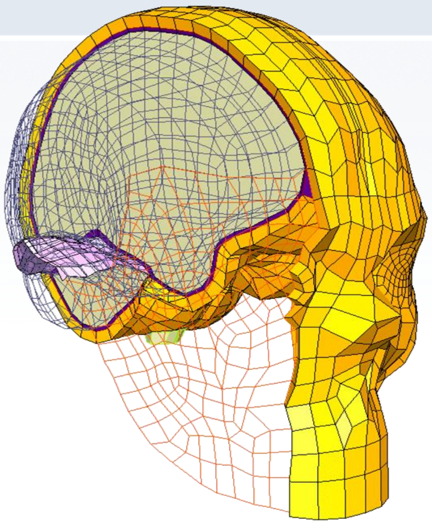

GRSP 63rd, Geneva May 2018

Remerciements :

MAIF FONDATION

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Equipe Matériaux multi-échelles et Biomécanique (MMB)

PRESENTATIONS AT STANDARD BODIES

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- Strasbourg University Head Injury Criteria , *San Diego, October 2003 (ISO-doc N° 594)*
- HIC injury prediction capability versus Strasbourg criteria, *Nashville, October 2004 (Idoc N° 611)*
- HIC injury prediction capability vs Strasbourg criteria and SIMON, *Paris, June 2005 (doc N° 620)*
- State of the art head FE models and guidelines for validation, *Seoul, May 2007 (doc N° 680 & 681)*
- Improved Model Based Head Injury Criteria, *Madrid, January 2008 , EEVC WG 12 meeting*
- Improved Model Based Head Injury Criteria, ISO, WG6 ,*Paris, May 2009*
- Code and Model dependence of model based head injury criteria, *Stuttgart, June 2009 (EEVC-WG 12)*
- Towards new head protection standards, *Saint Louis, MO, USA, May 2010 (ASTM meeting)*
- *Model based Head Injury Criteria : Code, Model and Age Dependence, Paris June 2011, ISO WG6*
- New bicycle helmets test procedure, Milan October 2012, CEN TC158 WG11
- Brain injury criteria based on axon strain, Strasbourg, March 2015, CEN TC158 WG11
- Model based head injury criteria , Sept 2015 NTSEL, Tokyo
- New helmet test methode, Tampa, November 2015 (ASTM meeting)

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- Marjoux, D., Bourdet, N., and Willinger, R. . Computation of axonal elongations: towards a new brain injury criterion. International Journal of Vehicle Safety, 2009, Vol.4 No 4, pp.271-284.
- Chatelin S., Deck C., Renard F., Kremer S., Heinrich C., Armspach JP, Willinger R : Computation of axonal elongation in head trauma finite element simulation. J of Mech. Behavior of Biomed Material, V4, 2011, 1905-1919.
- Sahoo D., Deck C., Yoganandan N., Willinger R : Anisotropic composite human skull model and skull fracture validation against temporo-parietal skull fracture. Journal of the Mechanical Behavior of Biomedical Materials, 2013, vol 28, 340-353.
- Sahoo D., Deck C., Willinger R.: Development and validation of an advanced anisotropic visco-hyperelastic human brain FE model. Journal of the Mechanical Behavior of Biomedical Materials, 2014, vol.33, 24-42

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- Deck C., Willinger R. : Pass-fail criteria for helmet standard tests : CEN TC158-WG11 meeting, Strasbourg, March 2015.
- Deck C., Willinger R. : Head Injury Criteria : Consolidation of head trauma database and model based head injury criteria: ISO document SC36-WG6, Paris, June 2015.
- Sahoo D., Deck C., Willinger R. : Axonal strain as brain injury predictor, based on real world head trauma simulations. IRCOBI Conference, Lyon, Sept. 2015.
- Sahoo D., Deck C., Willinger R : Brain injury criteria expressed in terms of axon strains : Asian-Pacific Conf. on Biomech, Sapporo, Sept 2015.

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