Digital Human Body Modeling: A Priority to Address Future Vehicle Safety Challenges

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Outlines

- Motor Vehicle Crashes Statistics and Fatality Trends
  - Demographic and Physiology Trend
    - » Aging and Elderly Population Growth
    - » Obesity Growth
- Safety Regulatory and NCAP Ratings Trends
- Emerging Technologies Trends and User Experience Challenges
- Human Body Modeling Motivation
- Examples of Automotive Application and Potential Use (Elderly, Obesity, Brain Injury Criteria, Risk Curves Development, AV etc.)
-

Leading Causes of Death, All Age Groups in 2016

- The World Health Organization (WHO) reported 1.25M traffic fatalities in 2013, it was estimated the **Ninth** leading cause of death across all age groups globally.
- Traffic fatalities have increased to 1.35 million in 2106. Estimated the **Eights** leading cause of death across all age groups globally.

Rank	Cause	% of total deaths
	All Causes	
1	Ischaemic heart disease	16.6
2	Stroke	10.2
3	Chronic obstructive pulmonary disease	5.4
4	Lower respiratory infections	5.2
5	Alzheimer's disease and other dementias	3.5
6	Trachea, bronchus, lung cancers	3.0
7	Diabetes mellitus	2.8
8	Road traffic injuries	2.5
9	Diarrhoeal diseases	2.4
10	Tuberculosis	2.3

2016 WHO Global Health Estimates

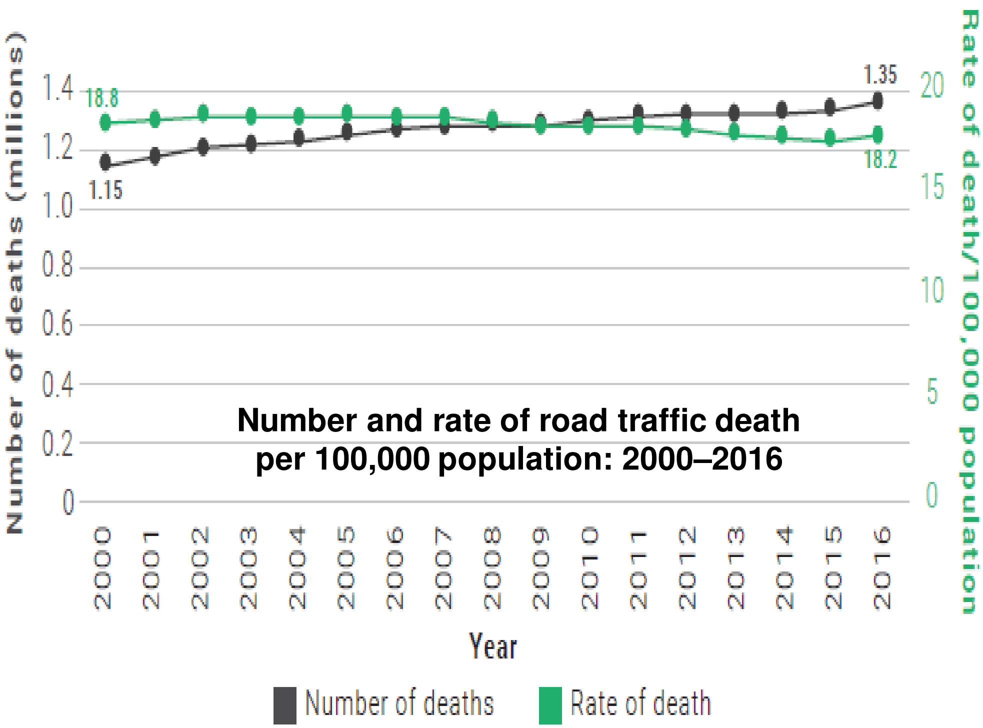
World Health Organization

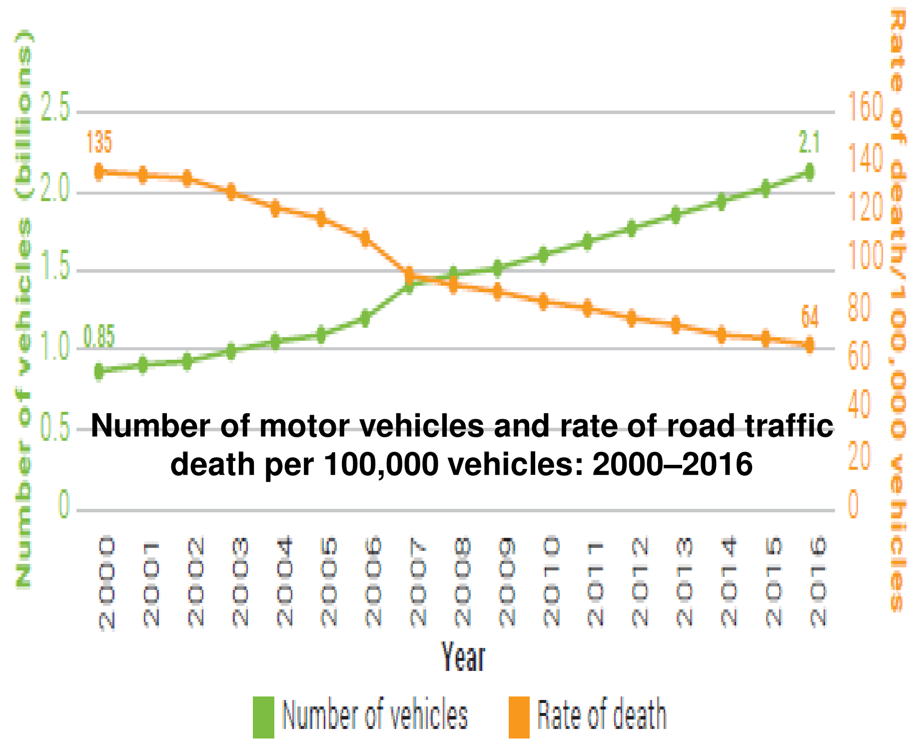
- **Road traffic injury is the leading cause of death for people aged 5 - 29, in 2016.**
- **Some reasons for this trend: demographics, rapid urbanization, poor safety standards, lack of enforcement, distracted or fatigued driving, others under the influence of drugs or alcohol, speeding, failure to wear seat-belts or helmets.**

Global Status Report on Road Safety WHO 2018

Leading Causes of Death, All Age Groups in 2016

- Between the year 2000-2016, the rate of death relative to the size of the worlds population has stabilized and declined relative to the number of motor vehicle in recent years (0.85 Bil – 2.1 Bil)

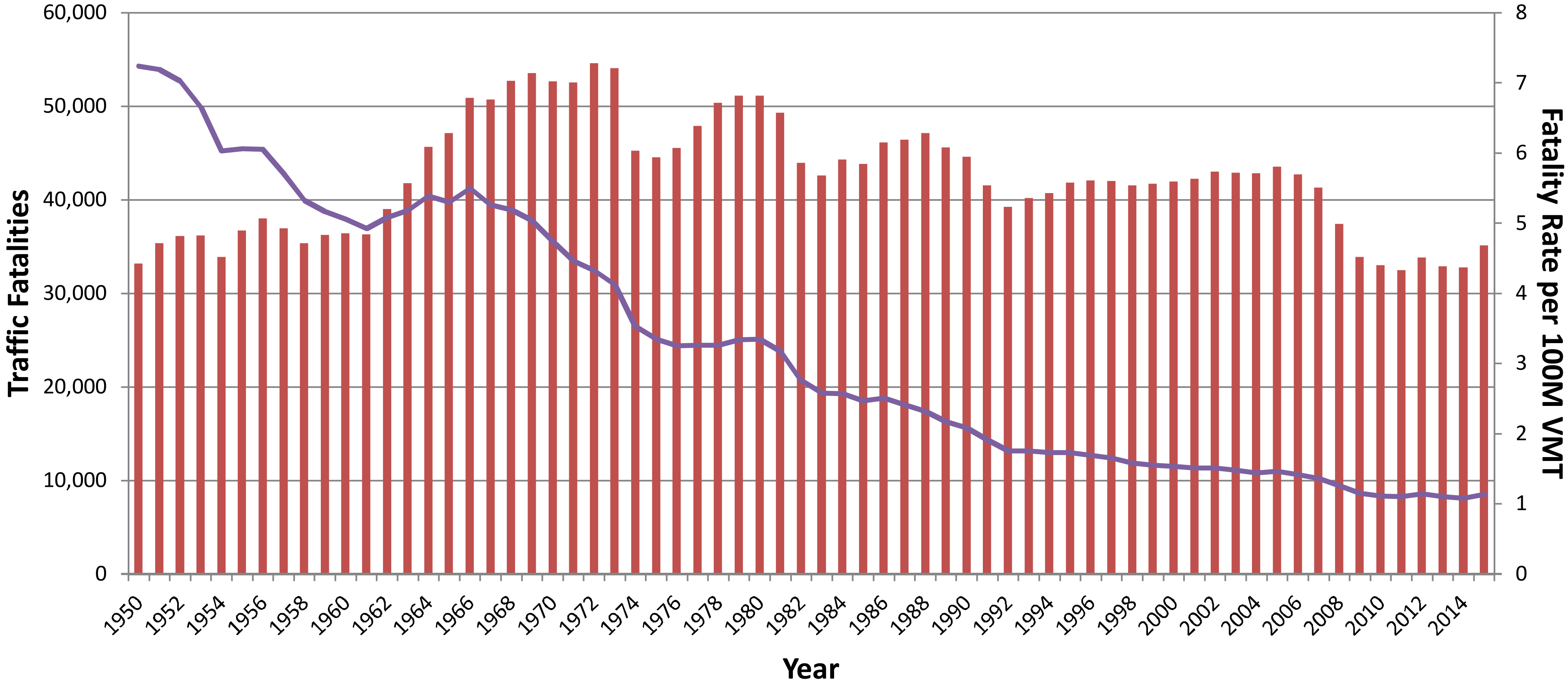




- While this does not suggest that problem is not worsening, the world is far from achieving the 50% target reduction in the number of deaths by half by 2020.
- The data shows that the progress has not occurred at a pace fast enough to compensate for rapid population growth and increasing motorization

Global Status Report on Road Safety WHO 2015

1950 - 2015 US Traffic Fatalities by Calendar Year

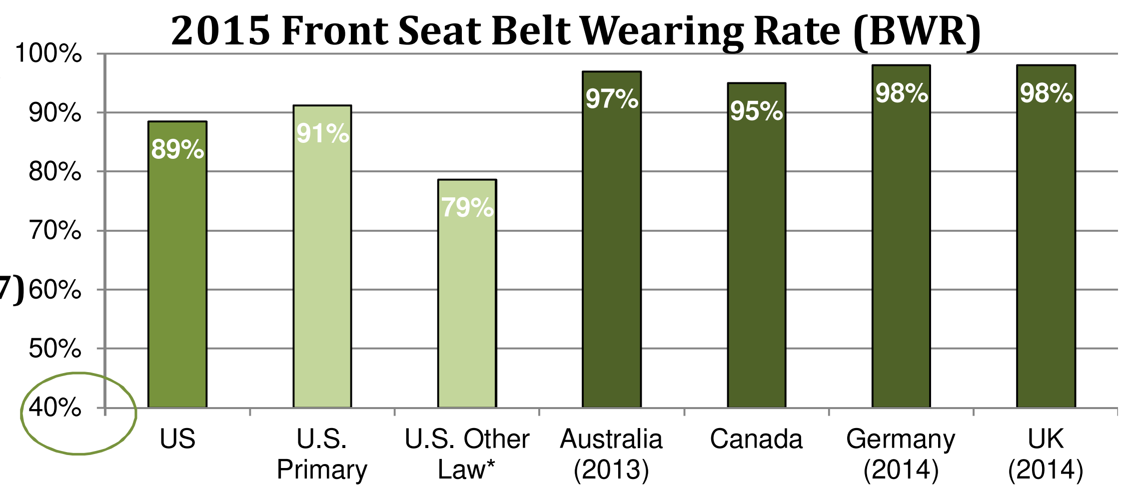


- **Year-over-year increases in traffic fatalities often occur during periods of economic recovery**
- **Fatality rates continue to trend downward (attributed to vehicle design improvements, public domain testing and regulations (But Increased In 2015, 2016, and 2017)**
- **OEMs are poised to contribute more with introduction of DAT, CAT, and AD**
- **These new technologies will not eliminate crashes all together and the need to mitigate injuries and reduce fatalities in the remaining crashes is still needed**
- ***Safer Driver/Road User Behaviors, Infrastructure Improvements and Vehicle Safety Enhancements Will Continue Drive Traffic Safety Improvements***

Sources: *Traffic Safety Facts 2015 Annual Report, NHTSA*
Highway Statistics Summary to 1995, FHWA, fi200.xls; *Traffic Safety Facts 2010* (DOT HS 811659), *2011 Motor Vehicle Crashes Overview* (DOT HS 811701), NHTSA
Road Safety in the United States: Are the (Relatively) Good Times Over?, UMTRI-2012-26, September 2012

2017 U.S. Safety Facts and Restraint (Belts & Bags) Use

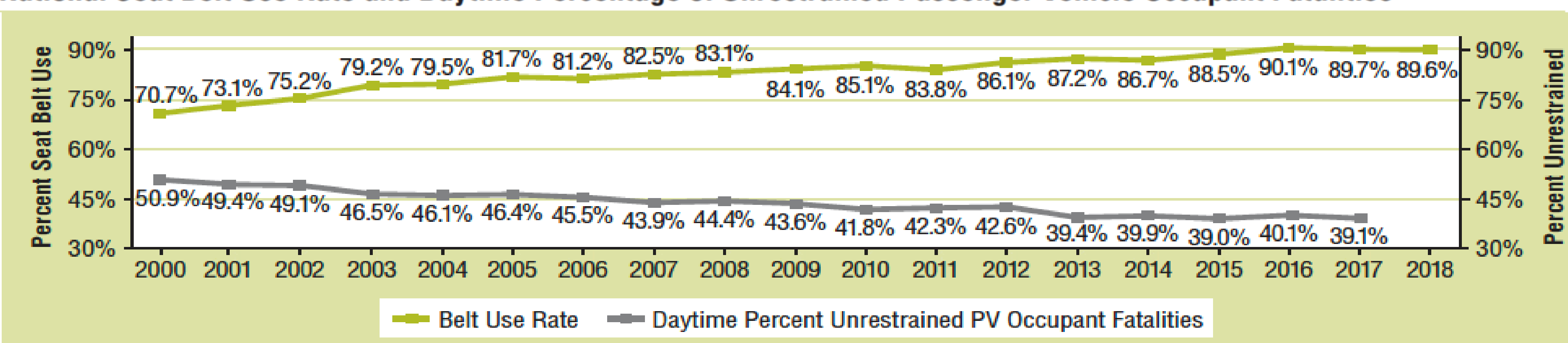
- **Although the U.S. safety belt wearing rate has generally been increasing, it remains lower than Australia, Canada & many countries in Europe (e.g., Germany, UK)**
- **Belt use up from 83.1% in 2008 to 90.1% in 2016 then drops to 89.6% in 2018 (NOPUS 17)**
- **Incremental increase is difficult to achieve**
- **Vehicle based technological (e.g. SBAS) have the potential to increase belt usage rates**



*U.S. Primary & Other Law Rates for All

Sources: US- *Seat Belt Use in 2014*(NHTSA, DOT HS 812 113); IRTAD *Road Safety Annual Report 2016*

National Seat Belt Use Rate and Daytime Percentage of Unrestrained Passenger Vehicle Occupant Fatalities



Source: NOPUS and FARS

- **Countries with Belt Wearing Rates higher than the US have had long-standing, very aggressive public education and law enforcement efforts**
- **Current demographic trends (obesity, elderly, law enforcement officers) may contribute to low BWR**
- **Ford continues to support increased safety belt usage through the development and use of Digital Human Body Model to help develop advanced safety belts**

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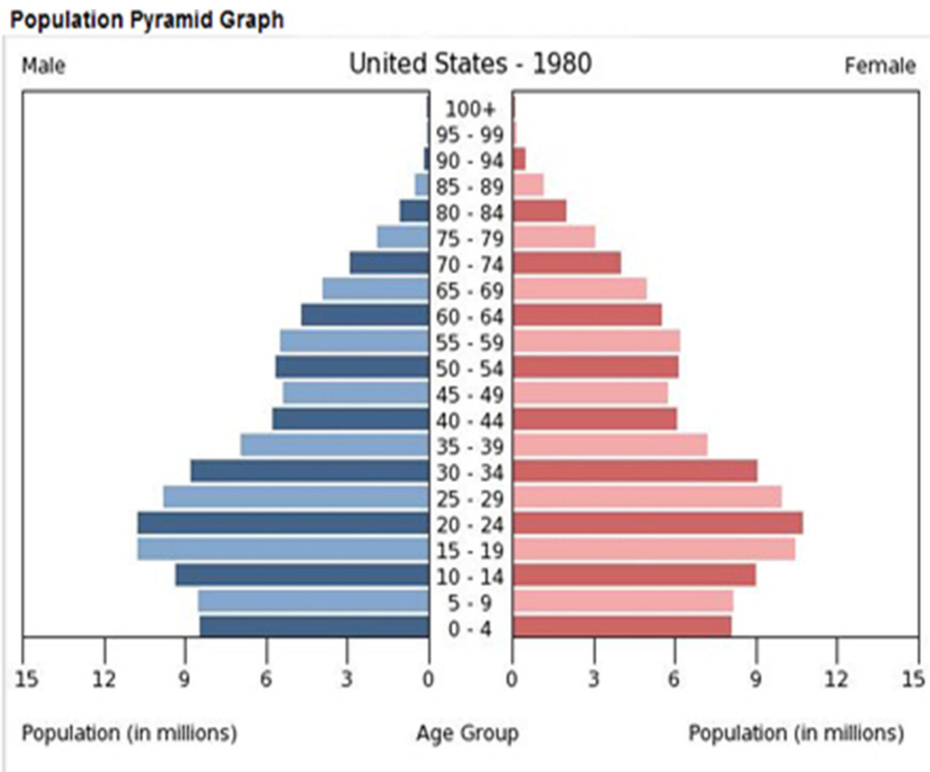
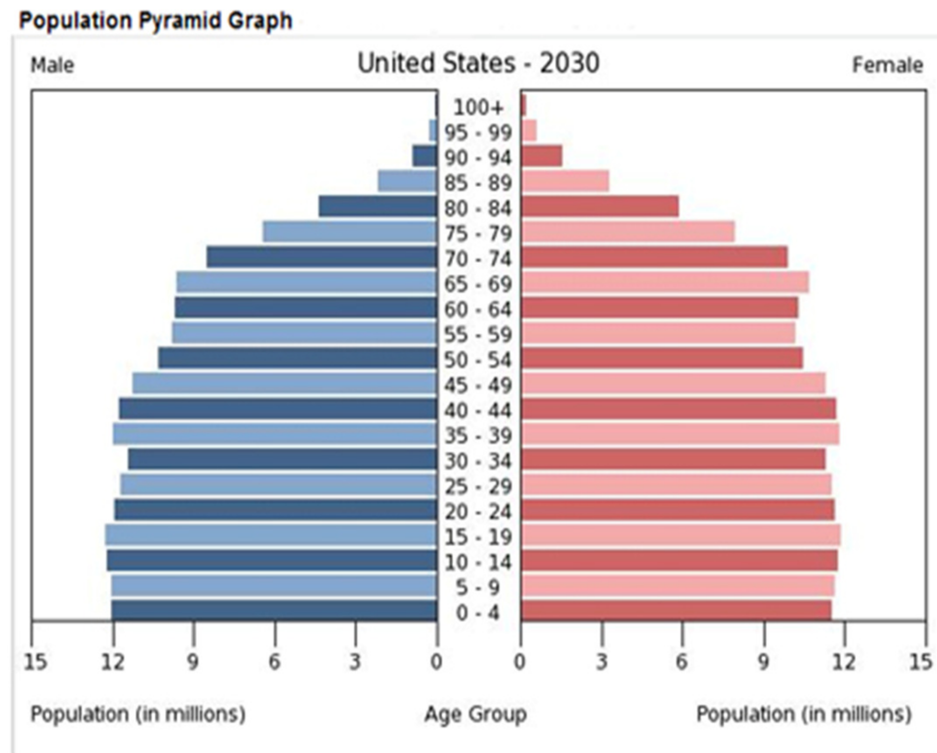
Changing Age and Gender Population Distribution: In 2030, the U.S. will have more equal numbers of all age groups



1980



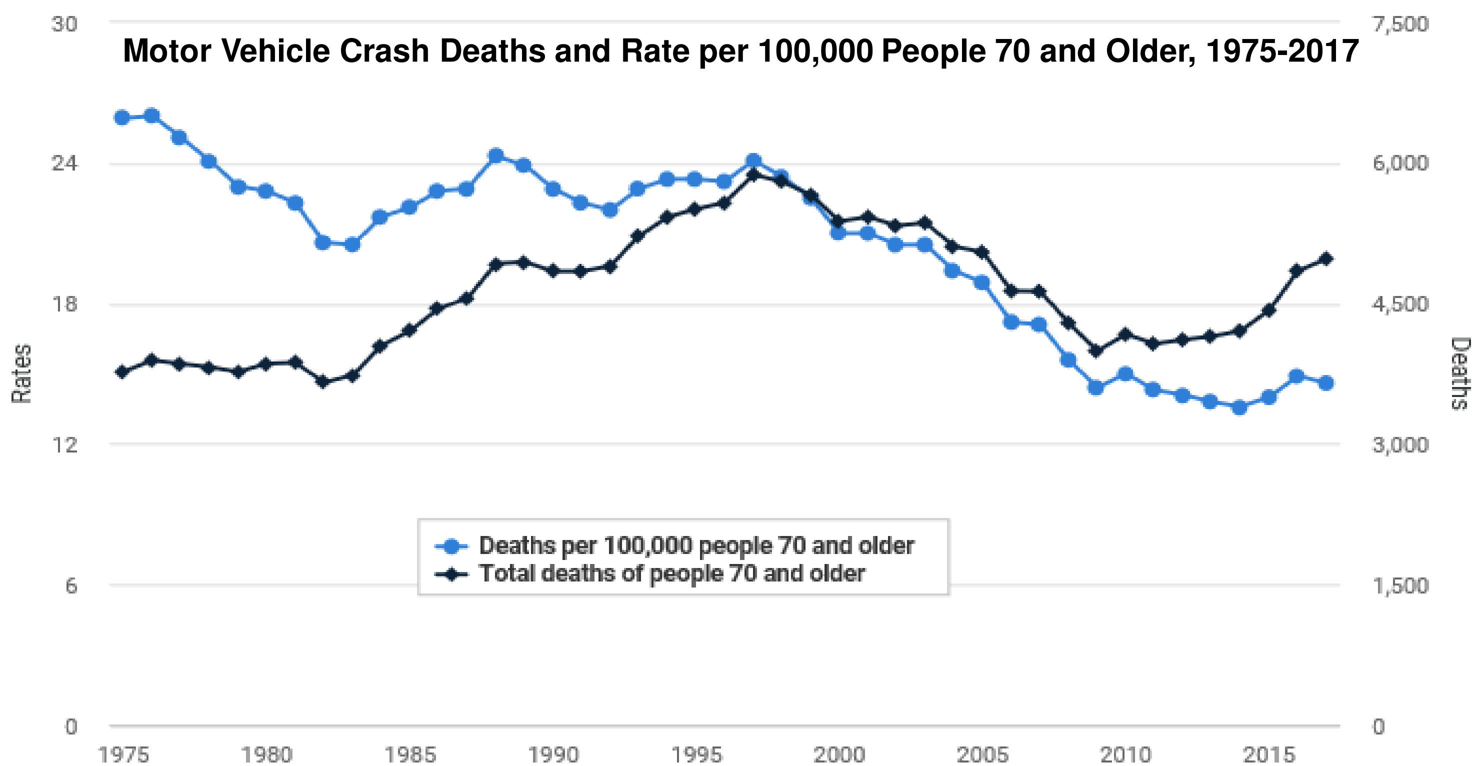
2030

- **Older age groups are projected to be the fastest growing segment of the US population.**
- **The increasing number of older occupants presents continued challenges for restraint system design and absence of evaluation tools to balance customer safety, comfort, and convenience.**

Source: **US Census**

2017 IIHS Study on Elderly Fatalities in Motor Vehicle Crashes Based on FARS

- There were almost 42 million licensed drivers age 65 and older in 2016 in the US, which is a 56% increase from 1999
- The elderly occupants are more vulnerable to get seriously injured or die in a motor vehicle crash. This is largely due to chest injuries associated with low bones density
- A total of 4,974 people ages 70 and older died in motor vehicle crashes in 2017
- This is 15% fewer than in 1997, when deaths peaked, but a 32% increase since 1975
- The rate of fatalities per capita among older people has decreased 44% since 1975.
- Seventy-five percent of people 70 and older killed in motor vehicle crashes in 2017 were passenger vehicle occupants, and 16 percent were pedestrians



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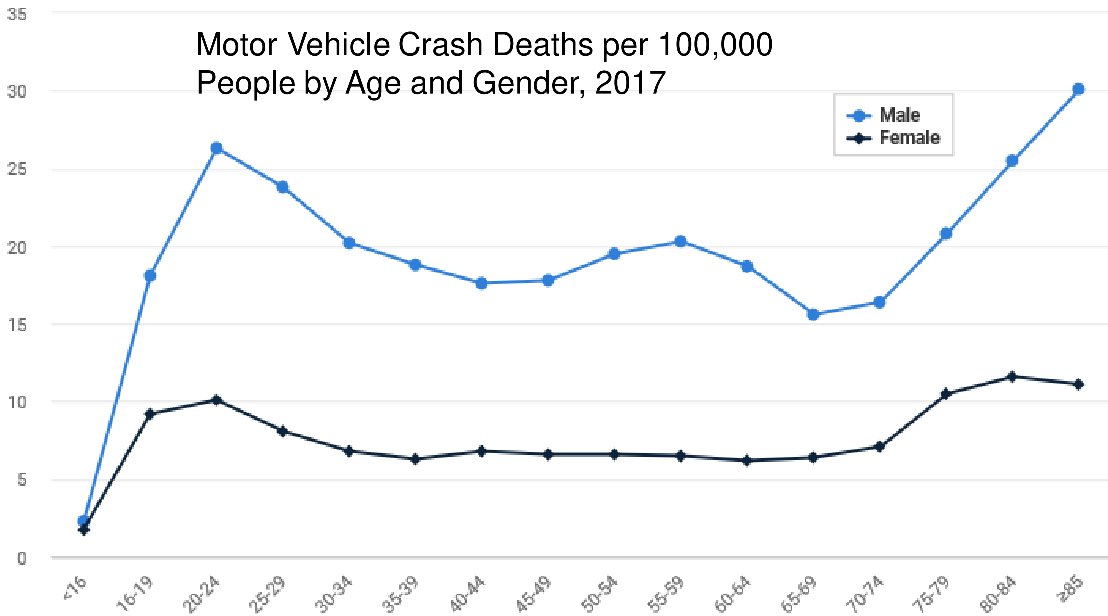
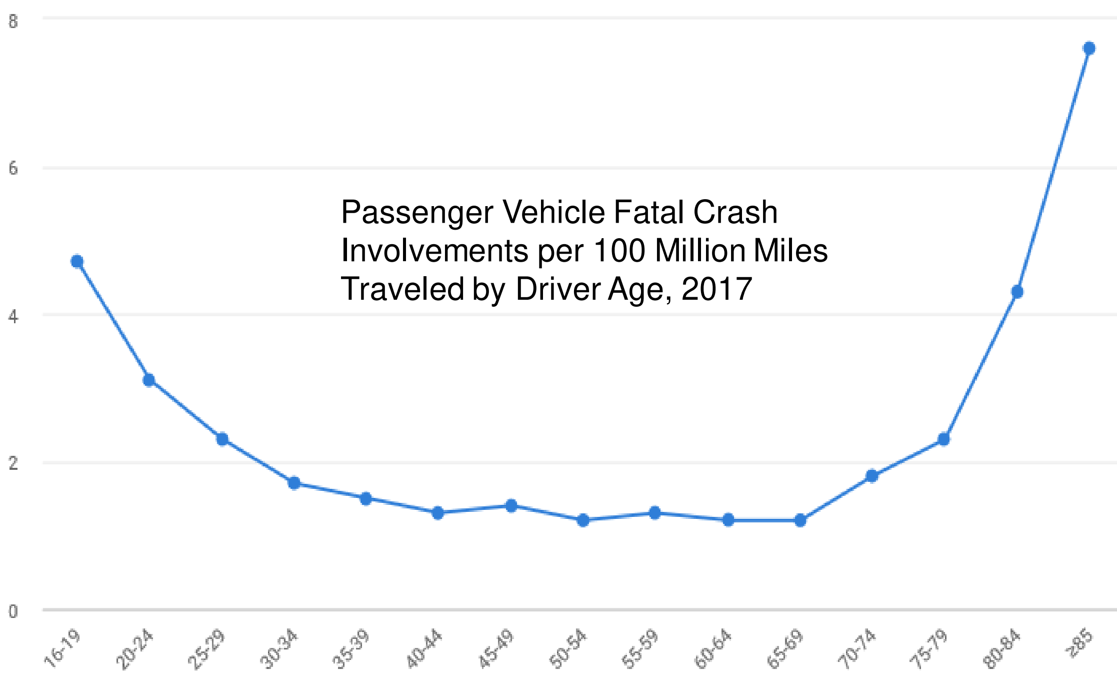


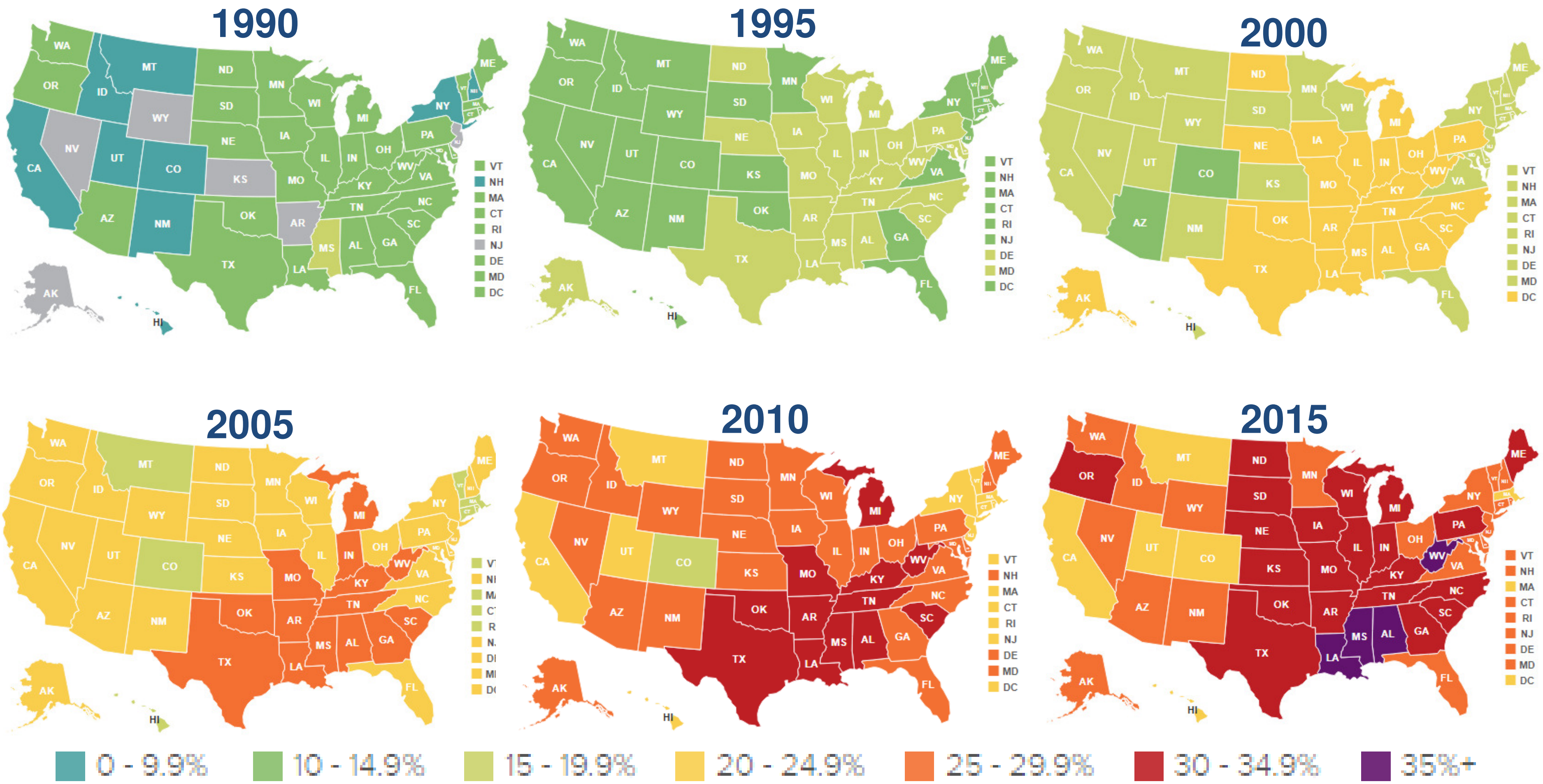
- In 2017, motor vehicle crash death rates per capita increased among males starting at ages 70-74 and among females gradually beginning at ages 65-69
- Males had substantially higher death rates than females for ages 16 and older.



- Per mile traveled, fatal crash rates increase noticeably starting at age 70-74 and are highest among drivers 85 and older
- ***Currently no regulations, and no crash dummy to assess performance and restraint***
- ***HBM has potential use in driving dummy design and developing risk curves/injury criterion***

Obesity is Increasing Among U.S. Adults

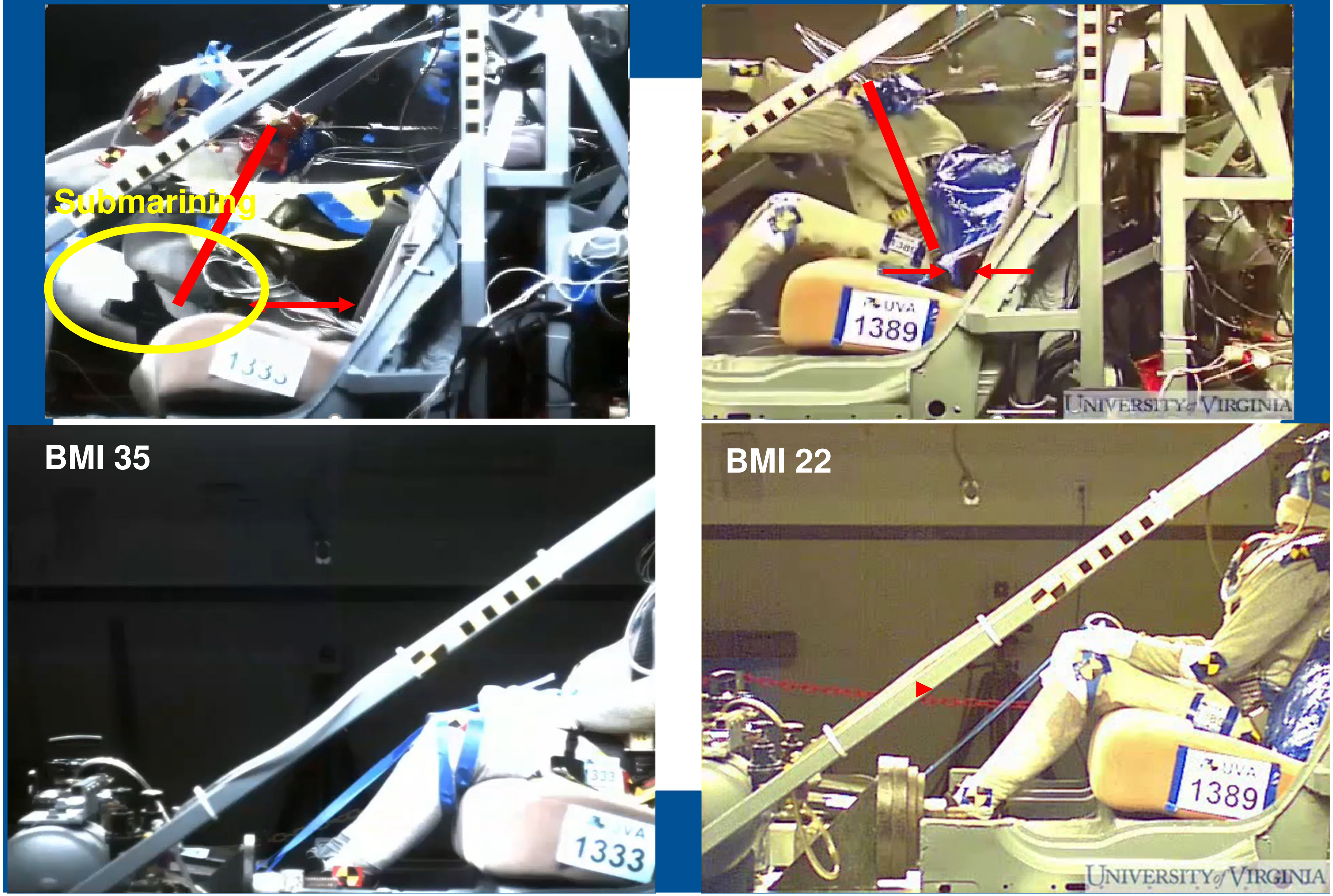
Percent of State Population with BMI* ≥ 30 by Calendar Year



- **Body Mass Index (BMI) is the ratio of an adult's weight to height: BMI = W (kg) / [H (m)]^2**
- **Today, Obesity is defined as BMI≥30 based on standing posture. *New definition is needed!***
- **Adult obesity rates exceed 35% in 4 states, 30% in 25 states and are above 20% in all states**
- **Obese crash dummy is researched and no tools are available to evaluate belt fit on obese**

Data Source: The STATE of OBESITY (https://stateofobesity.org/)

Rear-seat frontal impact sled tests



Source: 2019 G/I meeting (University of Virginia Center for Applied Biomechanics)

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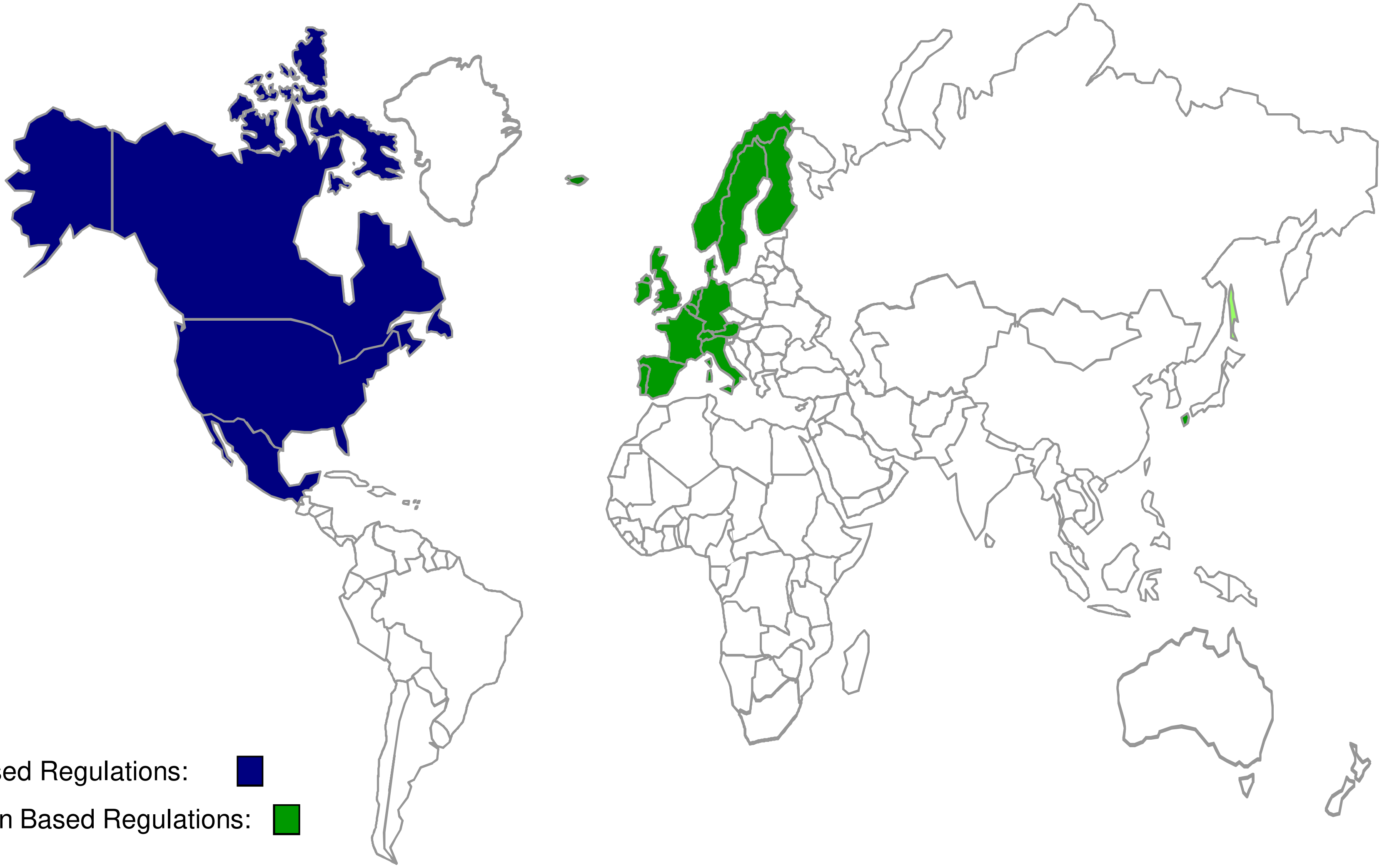
-

Historical Global Regulatory Overview

History: A Simpler World—North America and Europe



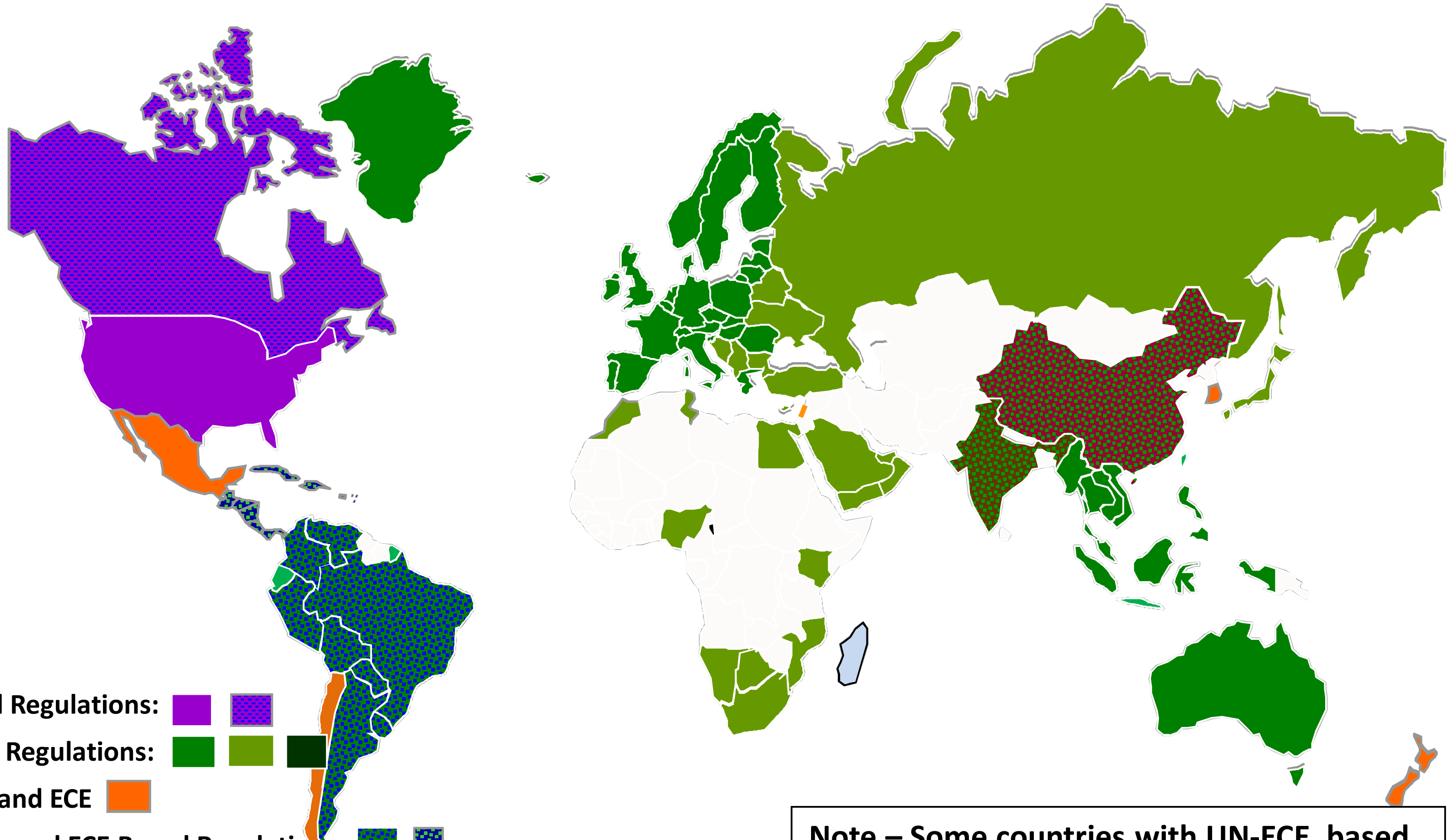
Key:

U.S. Based Regulations:

European Based Regulations:

Global Regulatory Overview

Current State: Complex, Expanding Global Framework



Key:

U.S. Based Regulations:

ECE Based Regulations:

Both USA and ECE

Mix of U.S. and ECE Based Regulations:

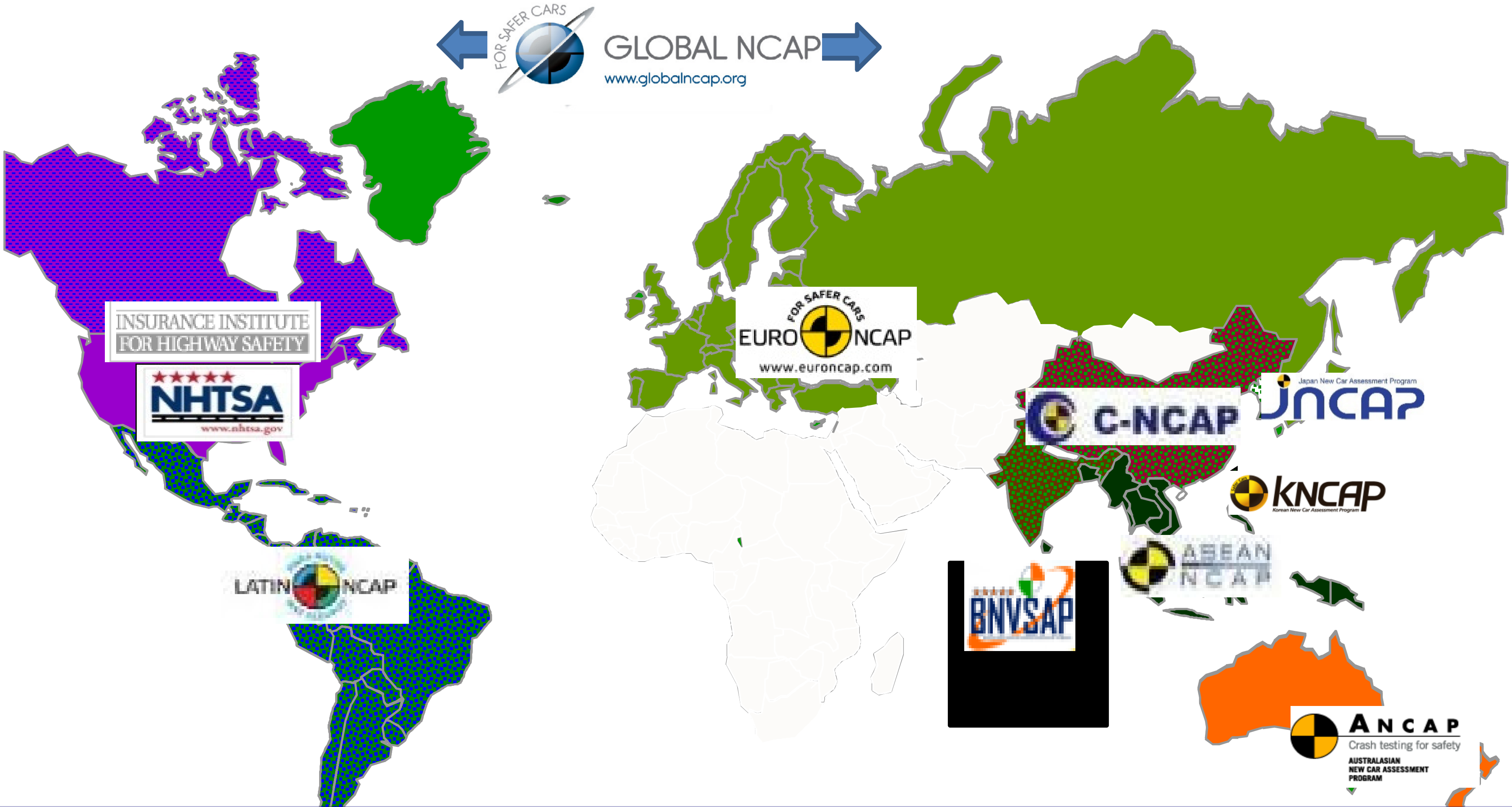
No Regulations or gravitating towards ECE

China , India (both generally based on ECE Regulations)

Note – Some countries with UN-ECE based requirements accept import of vehicles meeting FMVSS requirements.

The global regulatory framework has shifted from a two-system framework to a more complex regulatory framework dominated by ECE based regulations which can vary by region.

Global Safety Public Domain Organizations



Public domain organizations continue to expand assessment complexity:

- **High interest incorporation of Driver Assist and Active Safety technologies**
- **Focus on 2nd row ratings and new crash dummies/injury criteria (THOR/WSID/Qs/BrIC)**
- **New crash conditions (e.g. Euro-NCAP MPDB and NHTSA’s Oblique Impact)**
- **As the PD assessments expand, there seems to be a divergence of harmonization**

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Motivations for Digital Models for Human Body

- **Human Body Models (HBM), enabled by FEA are deemed necessary to:**
  - **Predict tissue level injuries as opposed to forces and displacements using crash dummies**
  - **Help identify biomechanics issues, injury trends and evaluate restraint performance in non-conventional seating configurations in future autonomous vehicles cabins (Only Tools Today)**
  - **Help guide the development of future crash dummies for AV/UX**
  - **Current FE HBM can serve as the base for developing Elderly/Obese/children HBMs**
  - **Vulnerable occupants HBMs can be used to generate risk curves for various body parts to help develop new injury criteria**
  - **Can be used for real world accident reconstructions when combined with vehicle models**
  - **Potential use in Virtual Certifications in regualtions/puplic domain ratings (Euro_NCAP/BrIC)**
  - **Injury criteria for children is tentative and is based on old research. Child HBMs can be used to generate risk curves and develop new injury criteria.**

Some Limitations of Digital Models for Human Body

- **Require more knowledege of material properties of body parts tissue**
- **Expermental validation of the Human Body Model is cadaver based (lack of muscles, aged, prospensity)**
- **Responses can only simulate cadavaric tests and not living human**
- **Child's body is not a miniature adult, scaling of models and injury criteria has limitations**
- **HBMs results can be FE Code or solver dependent**

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Development and Validation of Age-Dependent FE HBMs (35Year, 55 Year and 75 Year Old)

Geometrical Changes with Age

- Kent et al. (2005) reported the following relation between the rib inclinations and age (with the ribs becoming more perpendicular to the spine as age increases): 161 sample; 18y-89y in sagittal plane

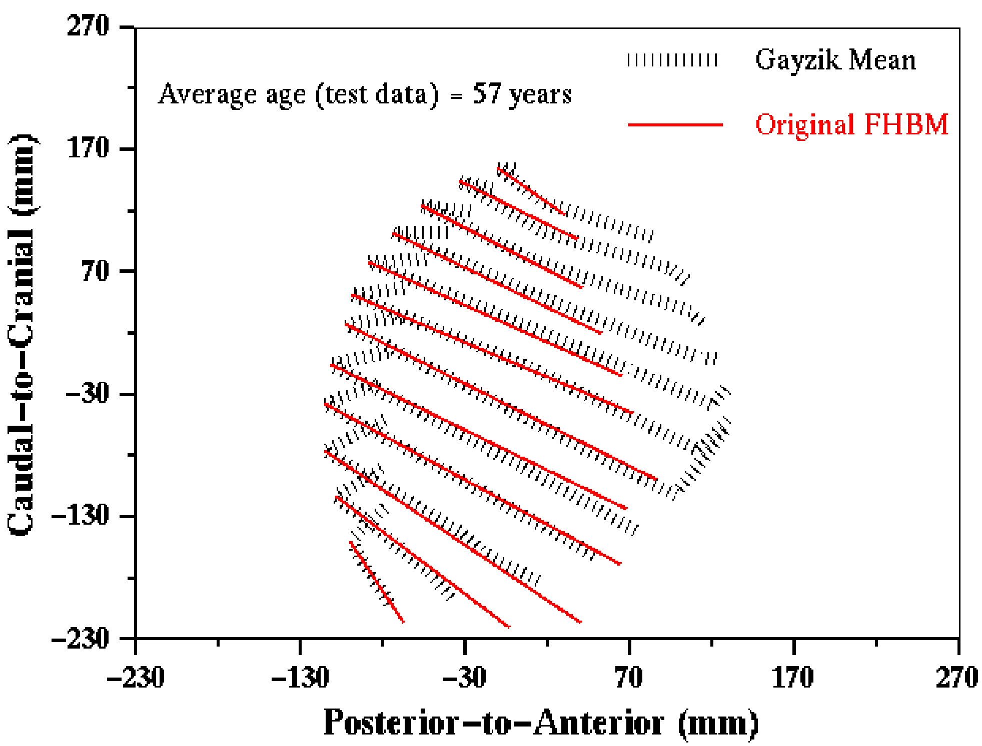
$$\textbf{Rib Angle}_{\text{(degrees)}} = 0.0811\ \textbf{Age}_{\text{(years)}} + 48.962$$

- Stein and Granik (1976) derived the following equation of the change in cortical rib area with age:

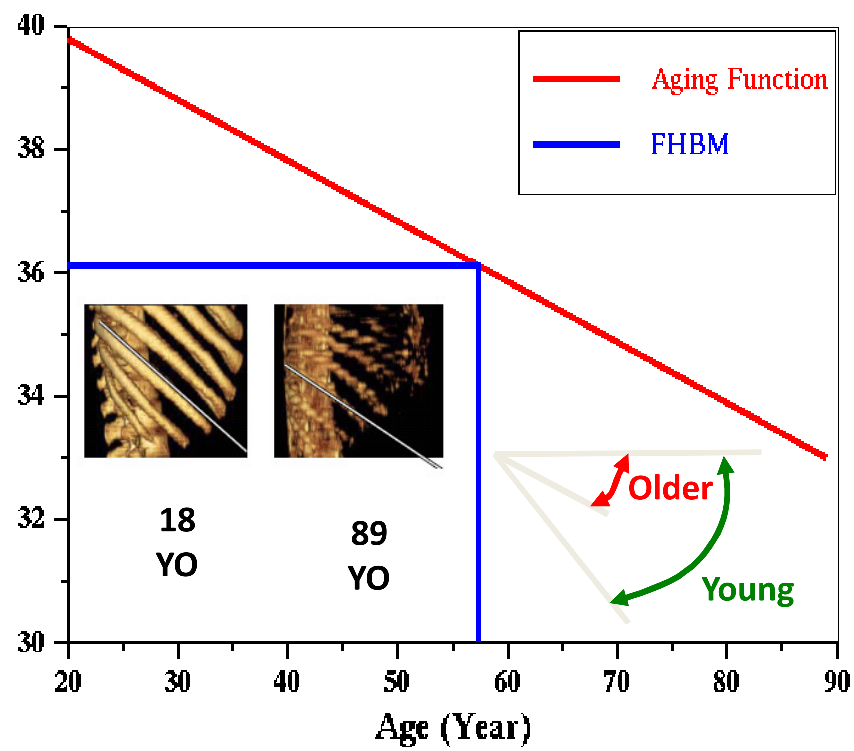
$$\textbf{Rib Cortical Area}_{(mm^2)} = 32.9 - 0.19\ \textbf{Age}_{\text{(years)}}$$

- Ruff and Hayes (1988) reported a 0.35% annual decrease in the cortical bone thickness of the femur.

Rib Inclinations Using 63 Subjects (Gayzik et al.)



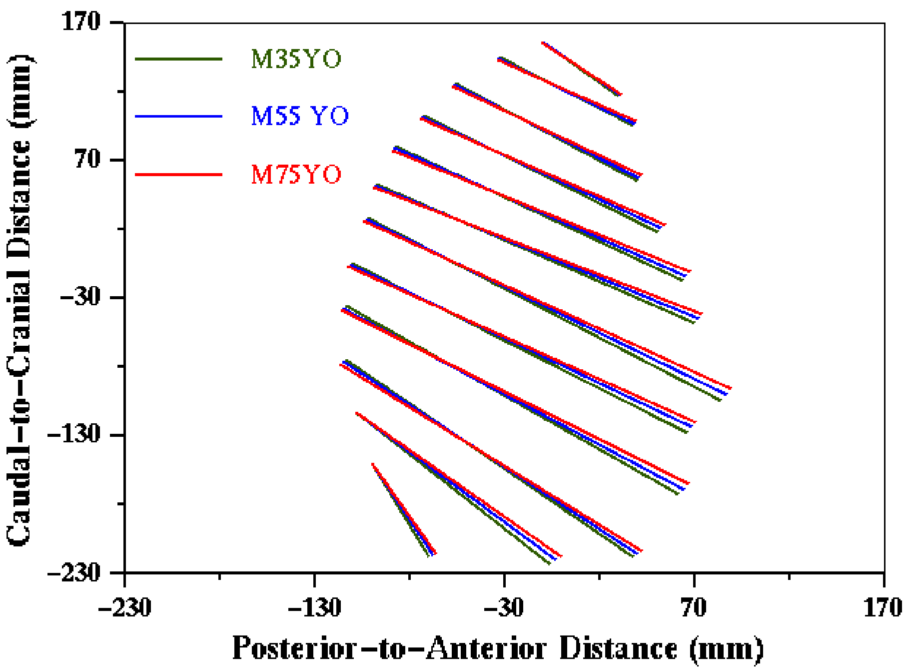
Ninth Rib Angle Changing Function (Kent et al.)



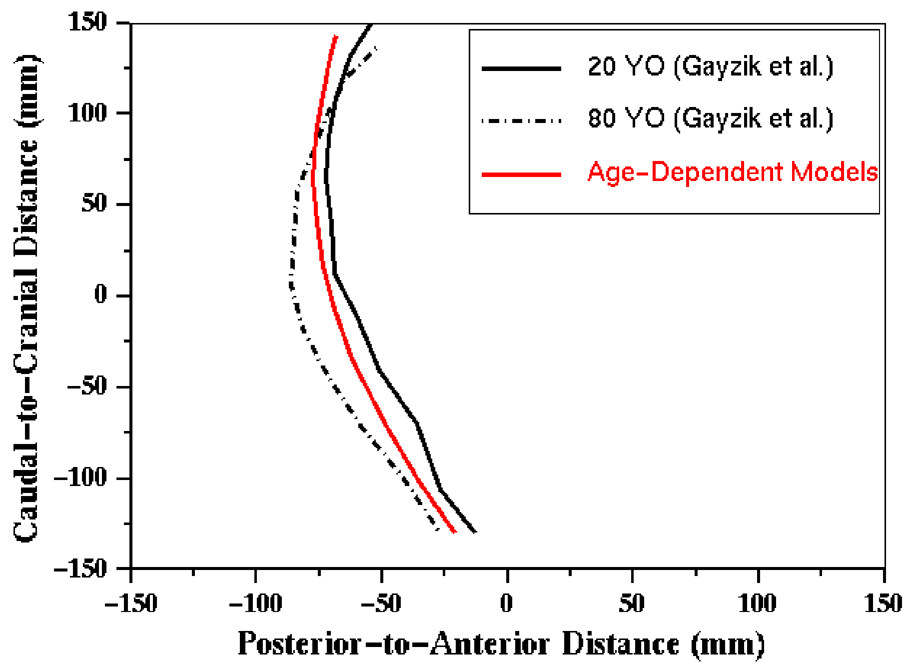
Geometrical Changes

- The following geometrical changes were made to the original FHB model to develop the 35- and 75- year old models:
- The rib inclinations were changed following Kent et al. rib angle and age relation.
- The rib cortical shell areas were changed based on Stein and Granik relation.
- The cortical shell thickness of all long bones were changed based on Ruff and Hayes criterion.

Rib Inclinations



Spine Curvature

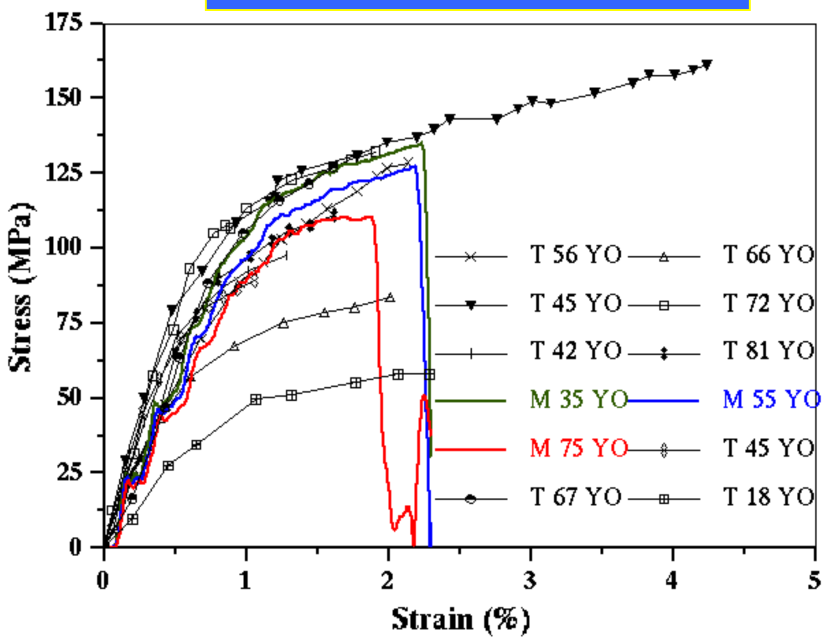


Structural Changes

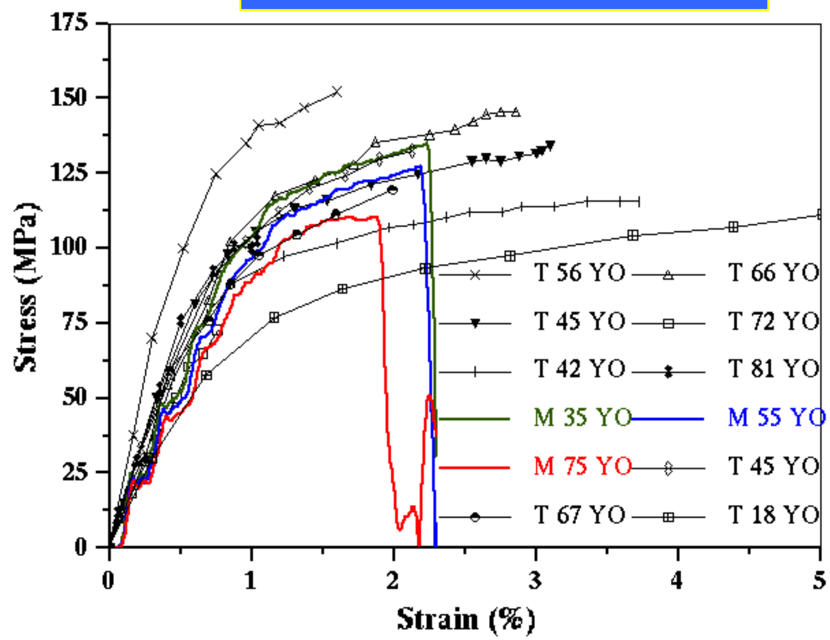
- The following structural changes were made to the original Ford human body model to develop the age-dependent models:
- The modulus of elasticity, UTS, and yield stress of all bones and ribs were changed following Dokko's aging function.
- The same parameters of the skin were changed following Yamada's aging function.
- The bulk moduli of the flesh and intercostal muscles were changed following Yamada's aging function.

Cortical Rib Tension Test (Kemper et al.)

Anterior Location



Lateral Location



A “Closure Model” via Matched Simulations for Generating Thoracic Risk Curves

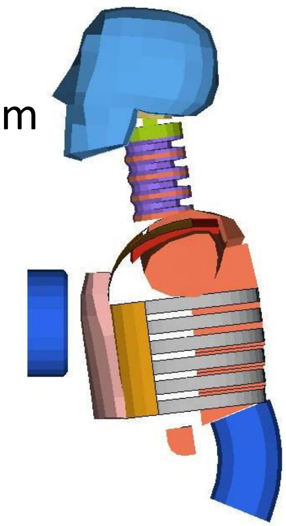
Test Dummy (HIII50)

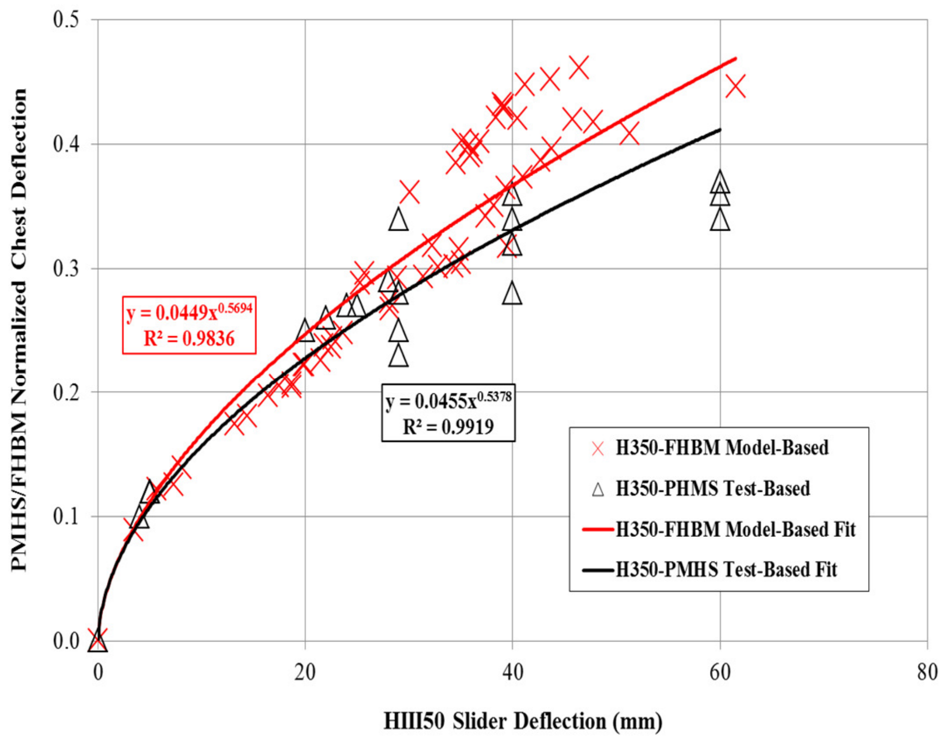
Closure Equation Derivation, Chest deflection

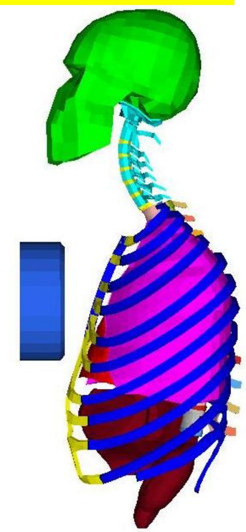
Mid-size Male Human (3 ages)

versus

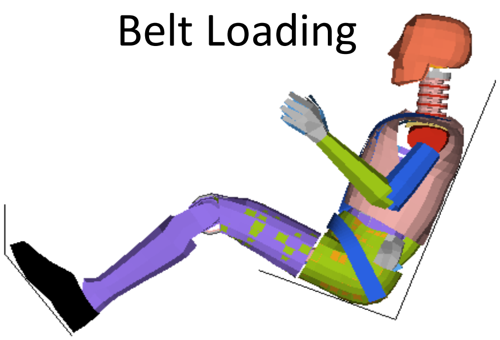
Pendulum Loading

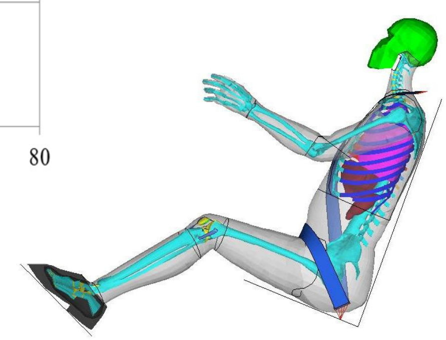






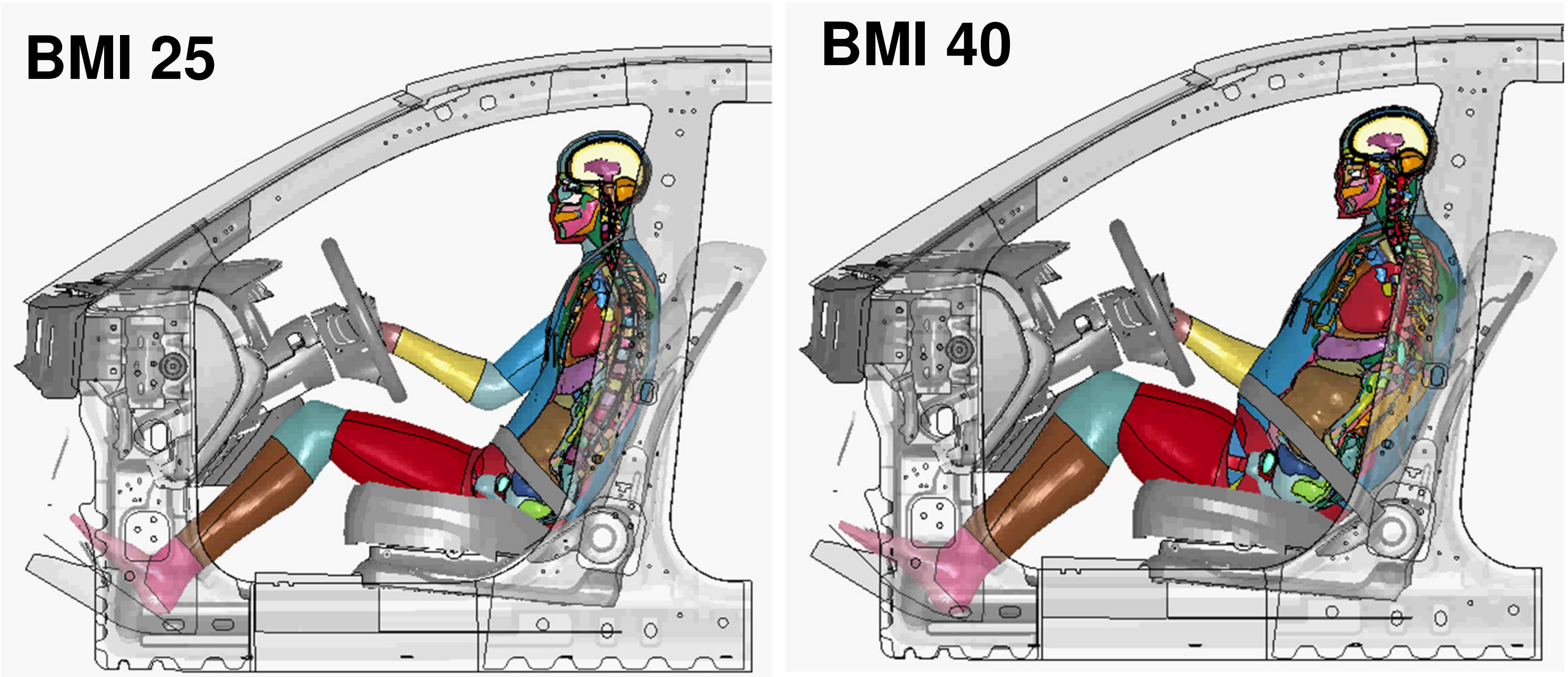
Belt Loading





versus

Parametric Study on Obesity



Source: Ford/UMTRI Joined Research

Trunk volume would be a better definition of obesity for automotive environment

- **Propose new definition for OBESITY based on sitting configuration**
- **Identify adult Obese population representative Posture and Weight**
- **To help develop a single adult Obese HBM for restraint evaluation**
- **To help develop future Obese crash dummy**

Selecting an Appropriate Database

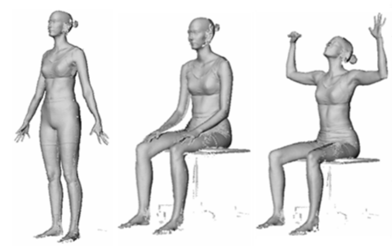
NHANES

- The **N**ational **H**ealth **a**nd **N**utrition **E**xamination **S**urvey (**NHANES**) is a program of studies designed to assess the and nutritional status of adults and children in the United States and to track changes over time. The results shown are for ~20,000 male subject age 18 and older, 1999-2012

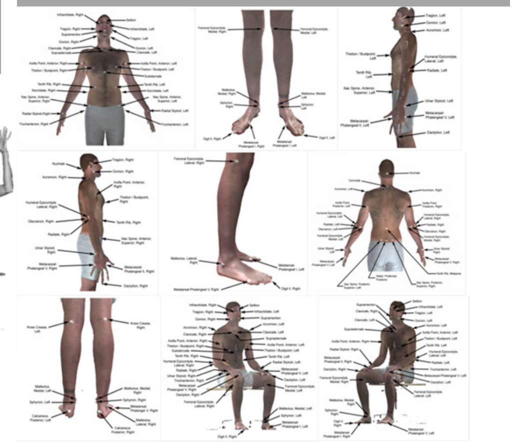
CAESAR

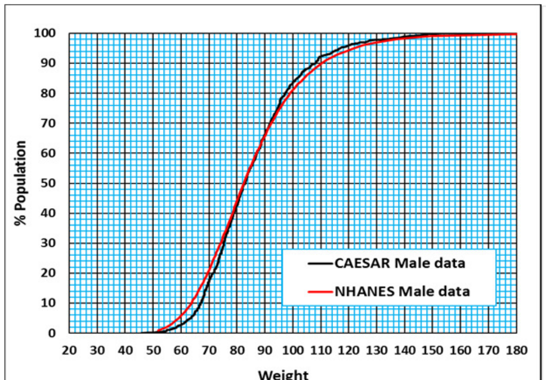
- The **C**ivilian **A**merican and **E**uropean **S**urface **A**nthropometry **R**esource (**CAESAR**) project was conducted between 1998-2001. Data represented 2,400 *North American* male and female subjects of age 18-65 at 12 Regional Data Collection Sites

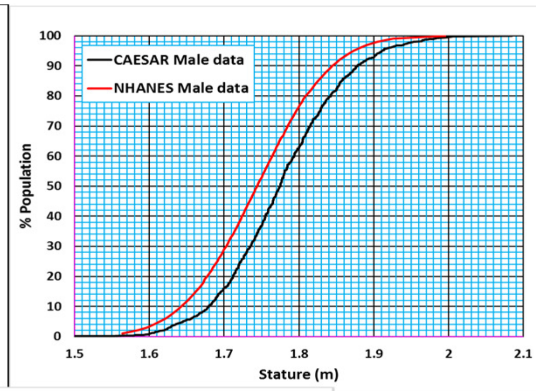
Individuals scan data in three different poses

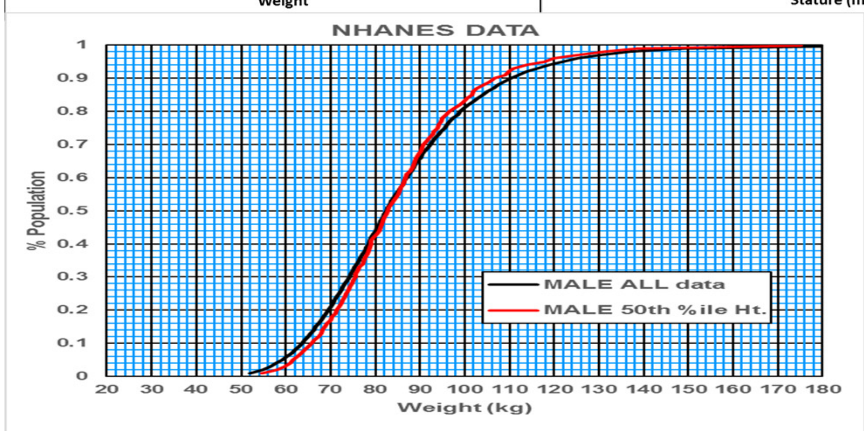


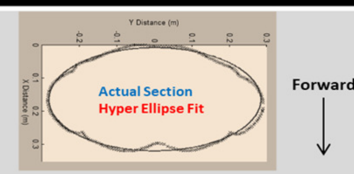
Number of landmark data









Section	Curve	Example
1	Hyper Ellipse	
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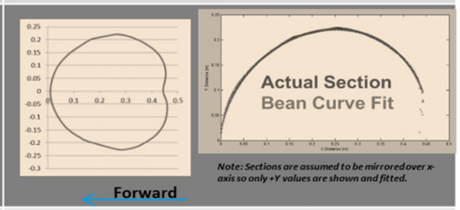
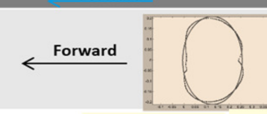
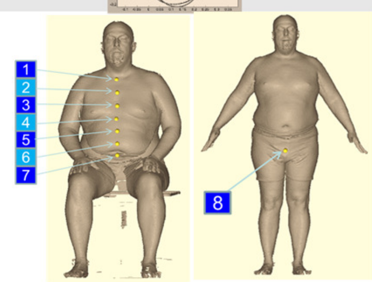
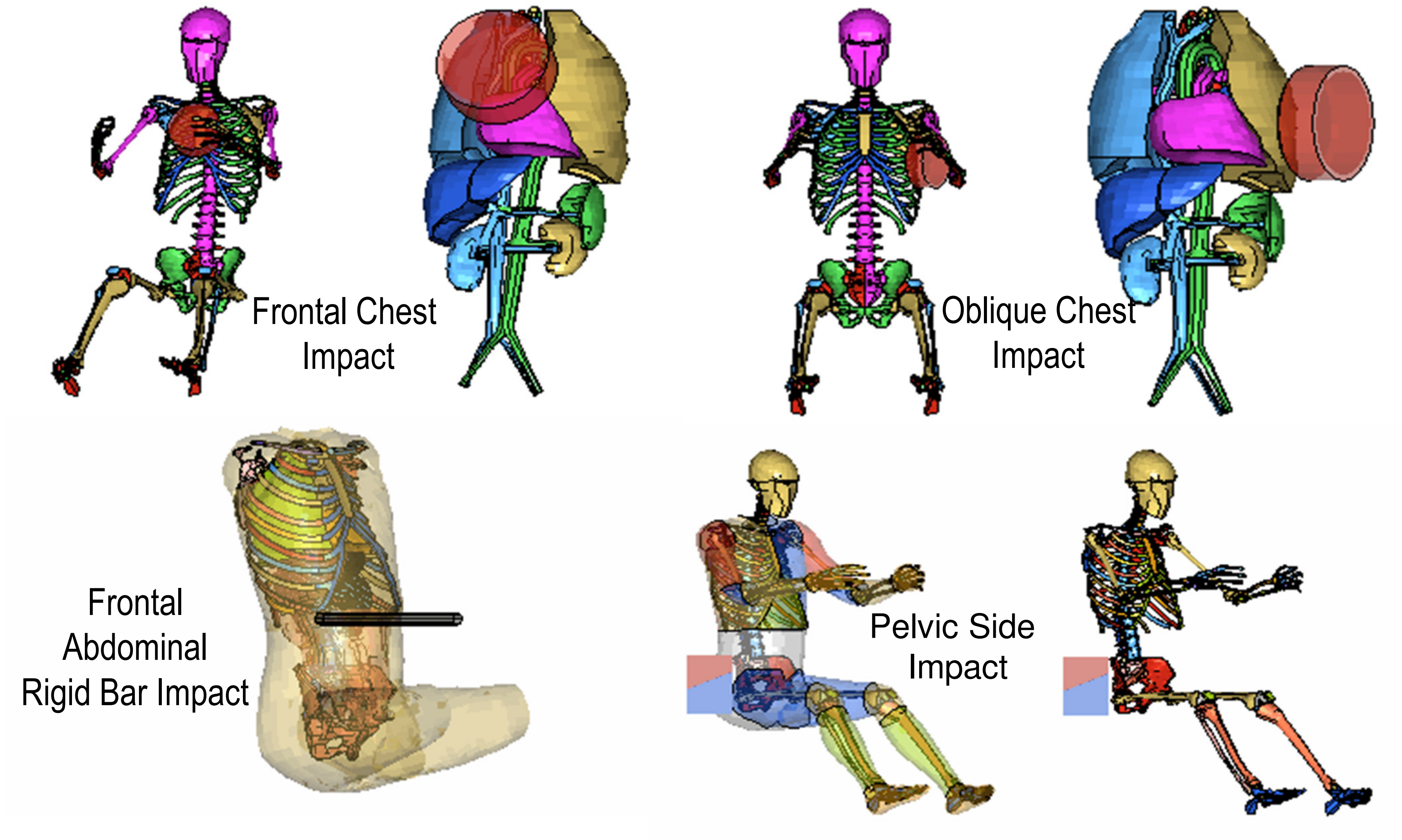
3		
4		
5	Modified Bean	
6		
7		
8	Ellipse	

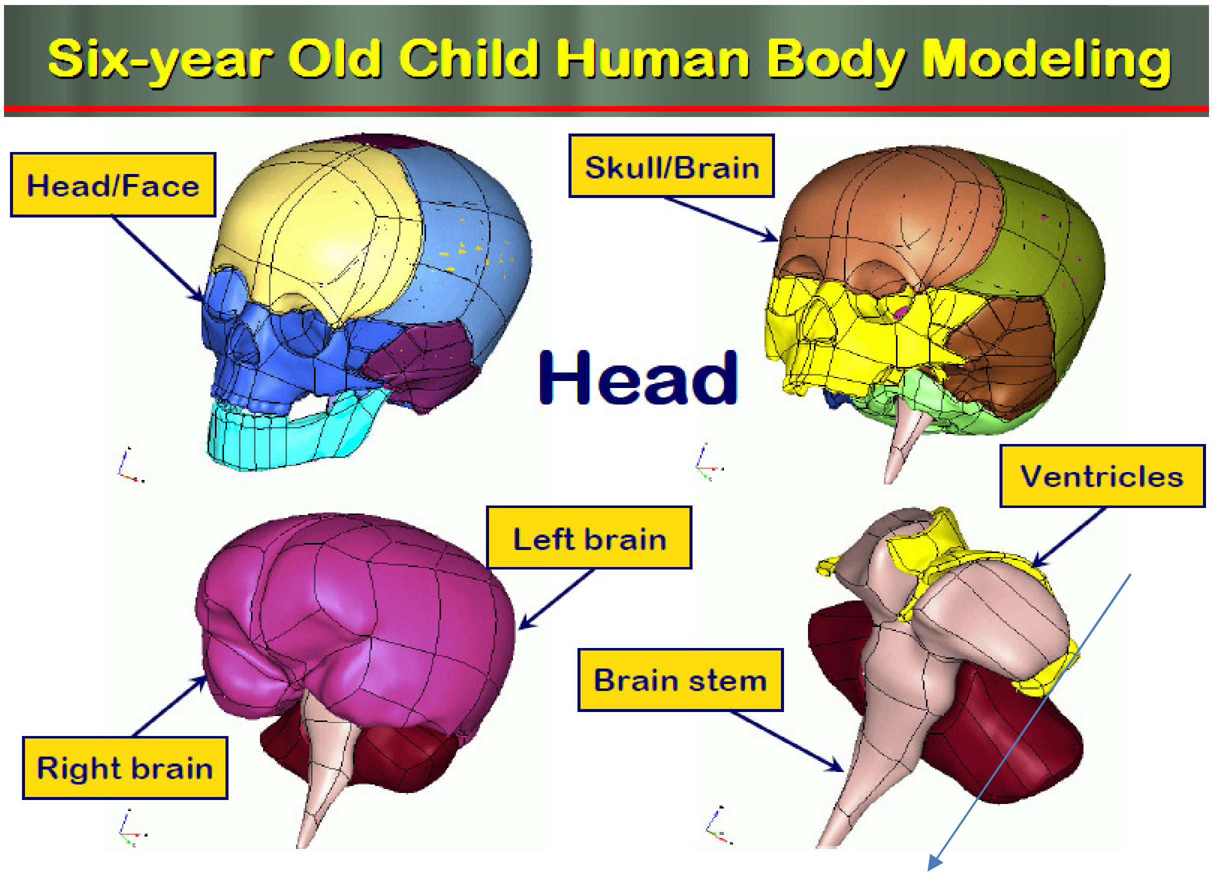
For this study, focus was on :
Male 50th Stature – 1.77 m;
95th%ile weight – 118 kg



Blunt Impact Test Simulations

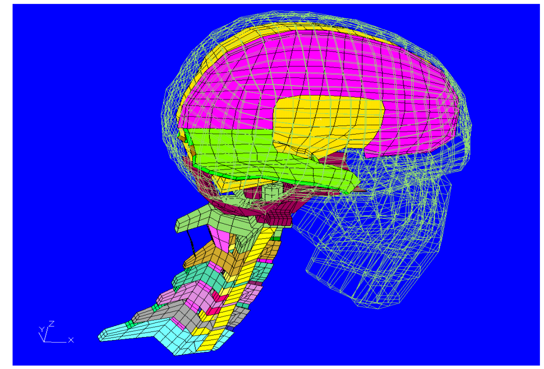


Human Head/Brain & Neck Models

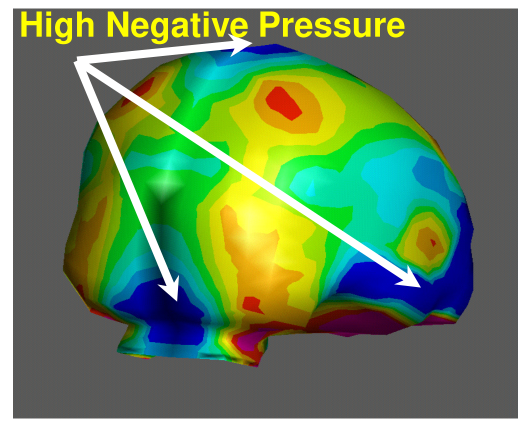


No scaling of mass and / or geometry

6-Year Old Head/Brain Model



Adult Head/Neck Model



Pressure of the Brain

Adult Head/Brain Model

In collaboration with Tianjin Univ. of Science & Technology

Fracture Modeling Inputs for a Human Body Model via Inference:
Application for Skull Fracture Potential

- An FE-based failure model should be validated relative to tests
- involving **post mortem human subjects (PMHS)**.

- However, such validations present challenges because,

  - Local fracture stress and fracture strain are <u>not</u> often measured in PMHS tests, and

  - When test-based fracture data are reported, they often demonstrate considerable variability.

- Yet, in separate analyses, analysts implicitly incorporate variability
- when deriving **a "risk curve"** — a function which relates a predictor variable to an injury probability.

Outline

Example application:
Skull fracture potential

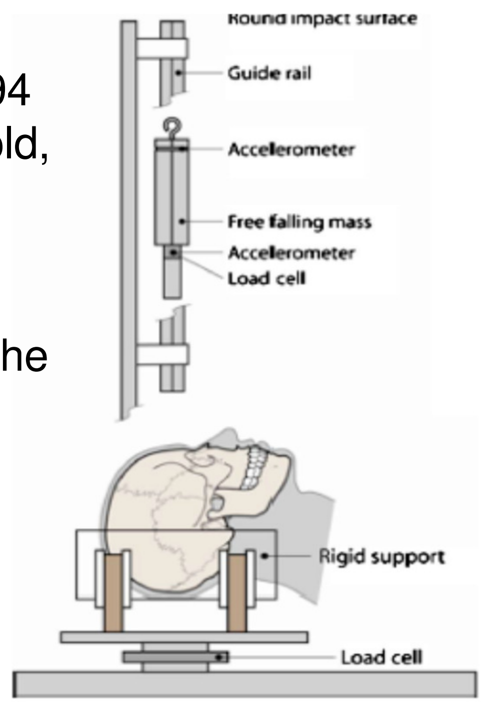
- A four-step process was developed to quantify failure criteria for a human body model:
  - Step 1: A "reference risk curve" was derived from a test-based cadaver dataset involving a specific test setup.
  - Step 2: Models of the test setup were generated, *subject to assumed failure criteria*, to produce the experimentally-observed spread of the response criteria used for the reference risk curve.
  - Step 3: The model-based outcomes were analyzed subject to the same statistical approach applied in Step 1.
  - Step 4: Iteration was applied on the failure criteria until the model-based risk curve approximated the test-based risk curve (i.e., the reference).

Step 1: Reference Risk Curve

- We considered a PMHS dataset (n=46) developed by Cormier et al. (2011).

<u>PMHS Details</u>:

- All test subjects were men.
- The age range was 41- 94 yrs old, (Average =72 yrs old, std dev = 16).
- Height and weight were measured for nearly all of the cases.
- Details such as head circumference were not reported.

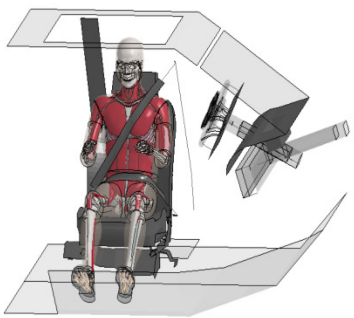


Cormier et al. (2011)

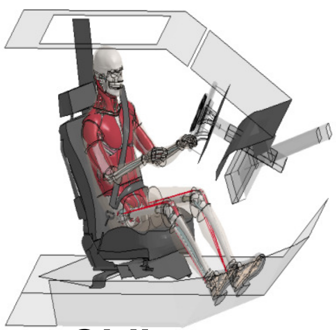
<u>Test Details</u>:

- The test involved dynamic loading (speed range = 1.6 – 5.7 m/s).
- The head was rigidly supported.
- Contact was to the frontal bone (either left or right aspect) via a rigid impactor.
- Load time history was measured via a load cell, and peak force was estimated.
- Acoustic emission sensors were used to estimate the time of fracture and a corresponding "fracture force."

AVs Regulatory, Flexible Interior Use Cases and Safety Challenges



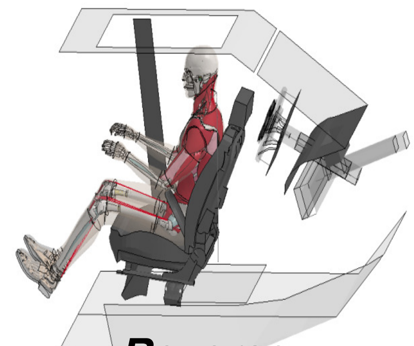
Lateral



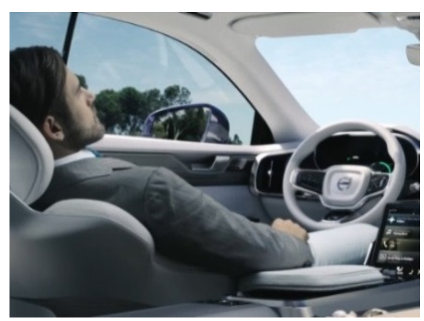
Oblique

- Applicability of current Safety Standards (FMVSS)
- Development of New AV Safety Standards
- Biomechanics investigations of flexible seating confi
- Monitoring occupant behaviors during driving:
  - Dynamic position & posture estimation/tracking
  - Vision Based Driver State Monitor Technologies
  - High accuracy in-cabin vision systems
- Sensing technologies for occupant detection and identification
- Innovations in restraint and seats adaptivity
- Cybersecurity and privacy
- Integrated safety technologies
- others

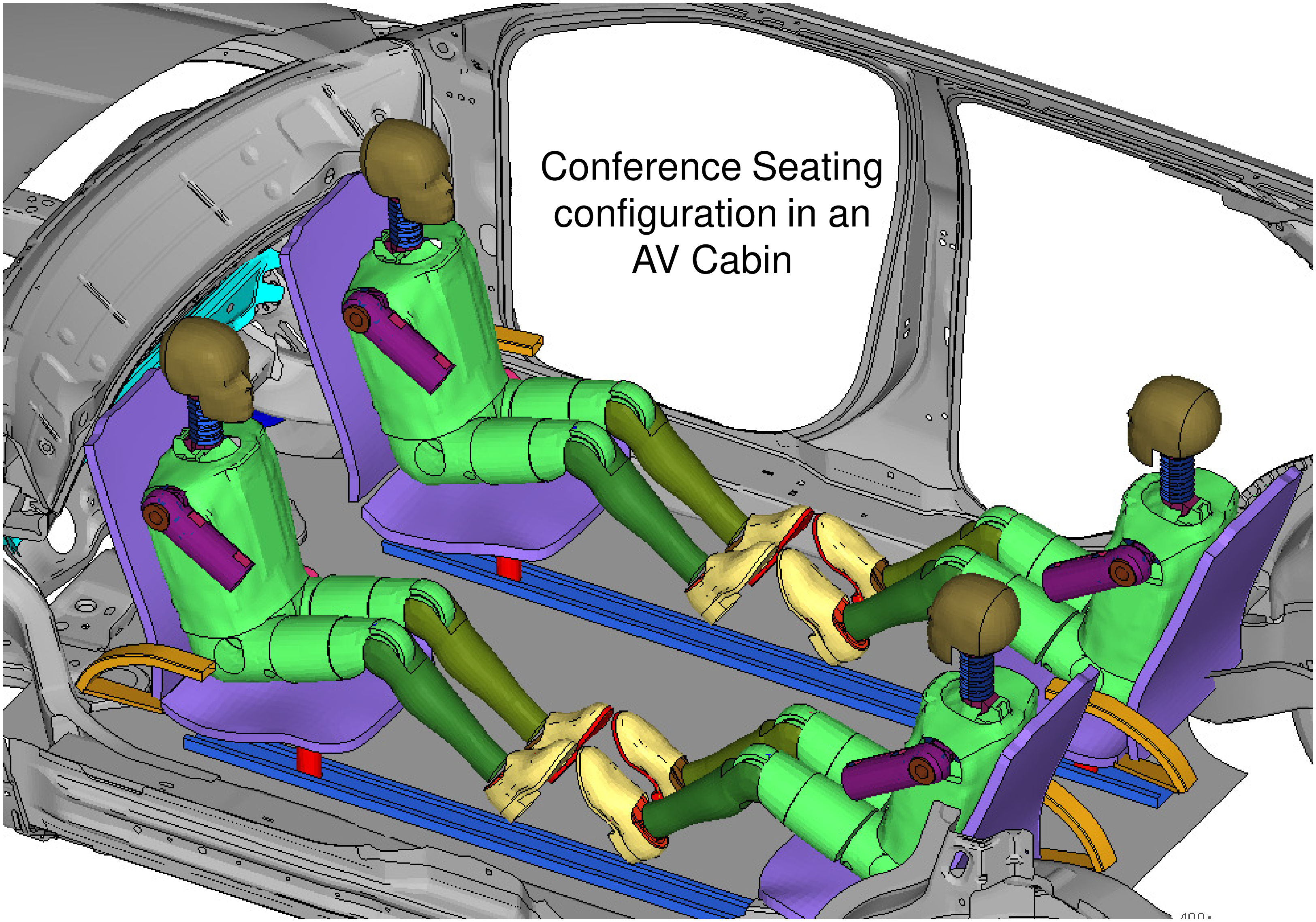
Reclined



Reverse



Rear-Facing Occupants in Generic AV Environment



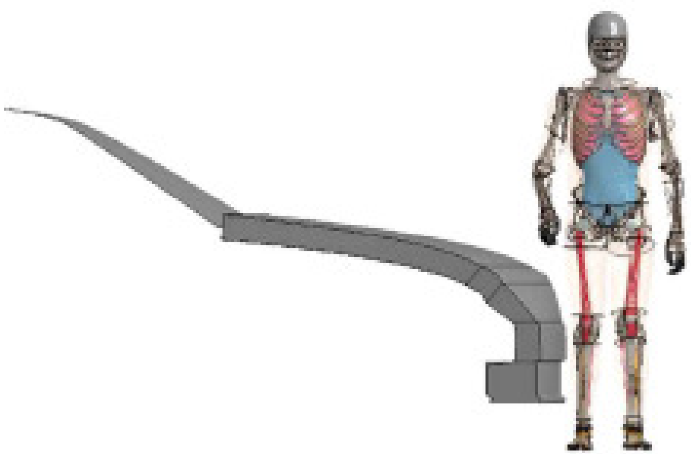
Euro_NCAP Electronic Certification for Active Devices in Pedestrian Impact

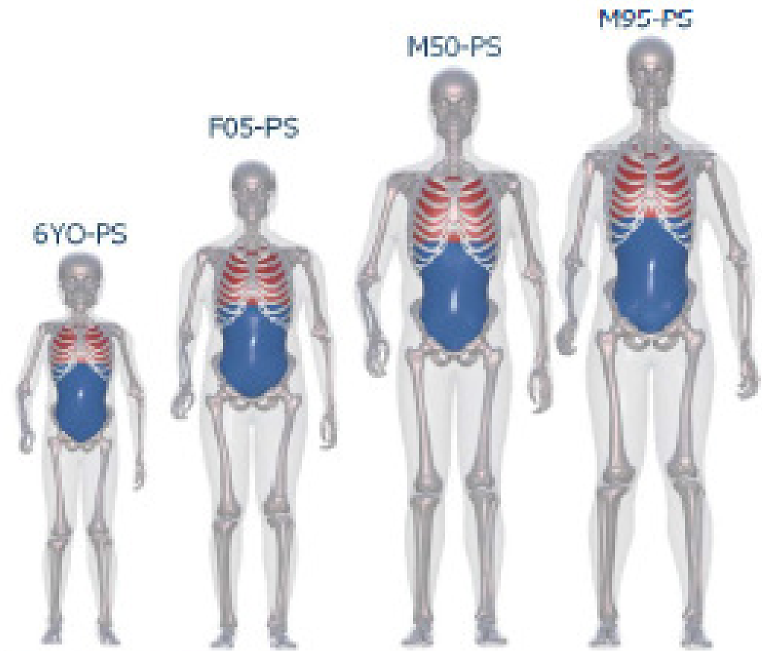
Digital Certification

Pedestrian Models in EuroNCAP

- What potential pedestrian would be hardest to detect in a strike?
- Where will the head strike?
- Evaluation of active bonnet systems in new cars

www.euroncap.com





Thank You
Q?