Erkenntnisse aus der Unfallforschung und Analyse für die Entwicklung des Biofidel Dummys

- Findings vom accident research and analysis for the development of a biofidelic dummy as a surrogate for vulnerable road users (VRU) -

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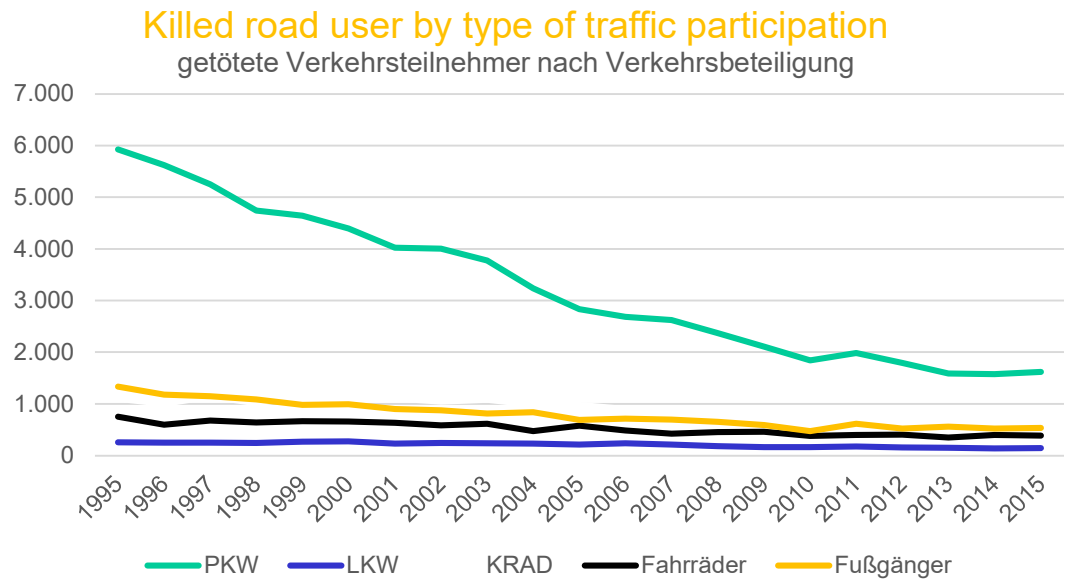
Member of the Board of the European Association for Accident Research and Analysis, EVU

Vehicle-Pedestrian Dummy-Crash Tests – Throw Distance: SUV (75 kph): Complete Hit is actually a Partial Hit

Reduction of killed road users mainly in Passenger Cars

Abnahme der getöteten Verkehrsteilnehmer überwiegend nur bei Pkw-Insassen



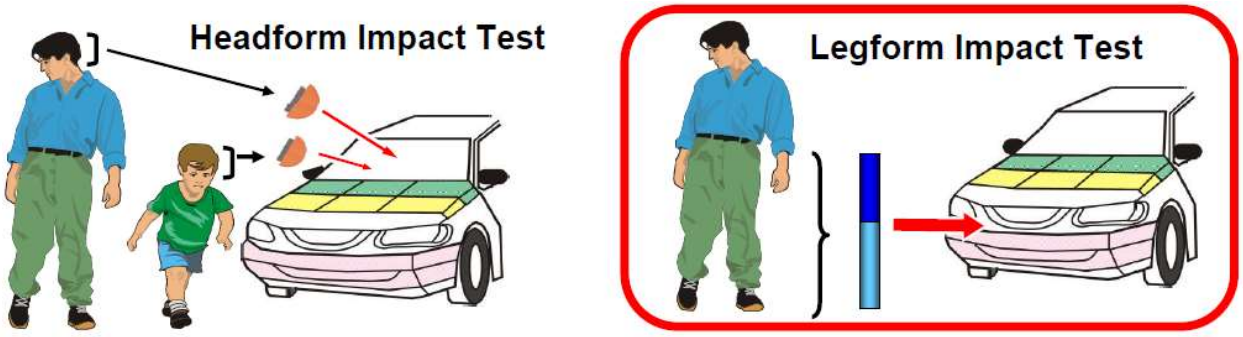
Pkw = Cars Lkw = Trucks Krad = Motorcycles Fahrräder = Bicycles Fußgänger = Pedestrians

Verkehrstote in Deutschland von 1995-2015 nach Verkehrsbeteiligung

[**DESTATIS Statistisches Bundesamt**, Verkehrsunfälle, 2017, URL: http://bit.ly/1DMqiJM, Stand: 23.12.2017]

Component-Tests to determine probability of pedestrian injuries

Komponenten-Test als Maß für Verletzungswahrscheinlichkeit bei Fußgängern



Komponententests (Kopf- / Bein- / Hüft- Impaktoren) zur Feststellung der Verletzungswahrscheinlichkeit an vermuteten Hauptanprallstellen am Fahrzeug

Component tests (head & leg impactor) to determine probability of injury to suspected major impact points on cars

Quelle: Atsuhiro Konosu, Japan Automobile Research Institute, Japan, 2008

DEKRA-Testing of the Biofidel-Dummy 2018

Test des Biofidel-Dummys 2018 durch DEKRA

Mercedes Benz A-Klasse vs. Biofidel-Dummy 3.1 mit v_k = 72 km/h

Further findings from crash tests and real case studies

Erkenntnisse aus bisherigen Versuchen und realen Unfällen:

Not only collision speed but also size, -mass and mass-distribution of the pedestrian as well as the geometric shape of the car have a significant effect on the damage of car and injuries as well as on pedestrian-movement. But, head impacts against bonnets are practically non-existent in reality. Some component tests may therefore be less likely significant for effectiveness in terms of safety improvements for vulnerable road users

Nicht nur die Kollisionsgeschwindigkeit und die Geometrie des Fahrzeuges, sondern auch Größe, Masse, Massenverteilung des Fußgängers haben einen Einfluss auf den Schadenumfang und die Verletzungen, sowie die Bewegung des Fußgängers. Kopfanprall gegen Motorhauben kommen aber fast nie in der Realität vor. Manche Komponententest dürften daher eventuell weniger aussagekräftig sein für die Bewertung der Effektivität von passiven Schutzmaßnahmen für vulnerable Verkehrsteilnehmer

General remarks on reconstruction of pededestrian accidents

Allgemeines zur Rekonstruktion von Fußgängerunfällen

- **Kinematics of the movement of the pedestrian is often not clarified entirely, thus it can not always be made an assignment of injuries at certain points of impact**
  Oft sind keine Spuren vorhanden, um den Hergang und insbesondere die Kinematik der Fußgängerbewegung eindeutig zu klären, so dass nicht immer eine Zuordnung von Verletzungen zu bestimmten Anprallstellen erfolgen kann

- **reconstruction parameters mainly result from test vehicles built 1965 – 1995**
  Rekonstruktionsparameter resultieren überwiegend aus Versuchen mit Fahrzeugen von 1965 bis 1995 (Kühnel, Rau, Karnahl, Schultz, Otte u. a.)

- **former vehicles are not comparable to todays; earlier unfolded length between road surface and head impact point is no suitable comparison measure more**
  Damalige Fahrzeuge sind nicht mit heutigen vergleichbar, z. B. sind damalige Abwicklungslängen heute kein geeignetes Vergleichsmaß

- **comparison with Dummy experiments is difficult because the severity of damage of the vehicle also depends on which type of Dummy is used**
  Vergleich mit Dummy-Versuchen schwierig, weil die Beschädigungsintensität am Pkw auch von der Art des Dummys abhängt

Forensic Dummys - University of Žilina
Dummys für die Forensik

Žilina-Dummy



- rigid steel frame (starres Stahlskelett)
- too elastic plastic casing (zu elastische Kunststoffverkleidung)
- low purchase price (niedriger Anschaffungspreis)

Forensic Dummys - University of Žilina
Dummys für die Forensik

Crash Test: passenger car vs. Žilina-Dummy ca. 50 km/h

Forensic Dummys - University of Žilina
Dummys für die Forensik

Damage after pedestrian impact (Schadenbild nach Crashversuch)

sharp dent on the hood
(scharfkantige Dellen auf der Motorhaube)

deformation of the rigid front structure
(Deformation der steifen Frontstruktur)

→ unrealistic damage pattern
unrealistisches Schadenbild

Own development & testing
Eigene Entwicklung & Erprobung

- **there was no Dummy before 2009, which :**
  Es gab noch keinen Dummy, der:
  - **moves realistically** (sich real bewegen kann),
  - **produces realistic damage** (reale Schadenbilder am Fahrzeug erzeugen konnte) **&**
  - **is cheap enough to carry out a lot of tests on forensic purpose** (günstig genug ist, um (Massen-) Versuche im forensischen Bereich durchführen zu können)

development potential use to be and still is existing !
Entwicklungspotential war und ist vorhanden !

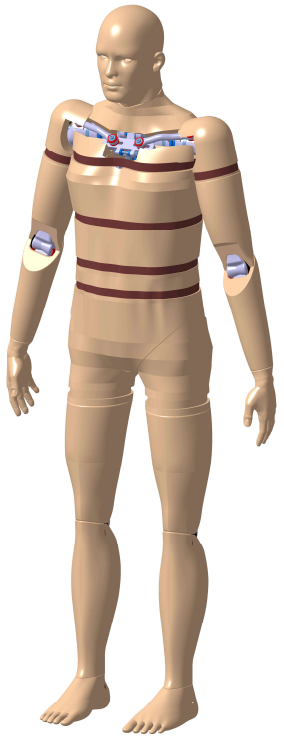
Aims of development of a biofidelic Dummy
Entwicklungsziele beim BD-Dummy

➢ **create a realistic motion behaviour by :**
Erzeugung eines realen Bewegungsablaufes durch:

- **realistic mass distribution of all parts of the body**
  realistische Massenverteilung aller Körperteile

- **realistic moments of inertia**
  Berücksichtigung der Trägheitsmomente

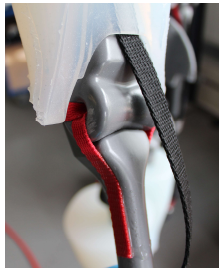
➢ **economy Wirtschaftlichkeit**



Aims of development of a biofidelic Dummy
Entwicklungsziele beim BD-Dummy

➢ **male 50-percentile substitute** 50% Dummy, männlich

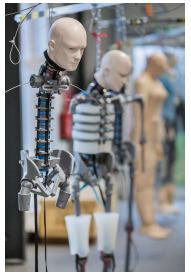
➢ **create of realistic damage by:** Erzeugung realer Schadensbilder durch:



- **elastic connection between the bones by tendons and ligaments**
  elastische Verbindungen zwischen den Knochen durch Sehnen und Bänder

- **Use of an anthropomorphic tissue and considering the strength of human bone**
  Verwendung von menschenähnlichem Gewebe sowie Berücksichtigung der Festigkeit menschlicher Knochen

Mainly no rigid or metal structures
keine steifen oder metallischen Strukturen

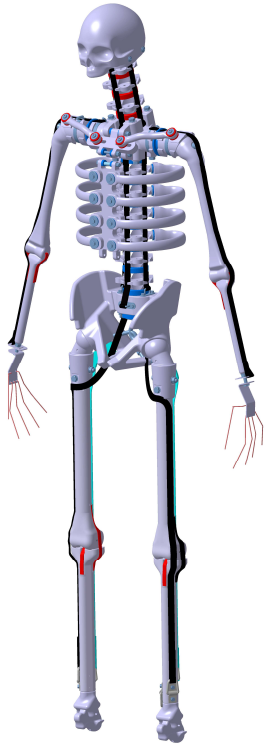


Developement of the 1st Prototype

Entwicklung des 1. Prototyps

- **Skeleton was made of wood in first prototype**
  Skelett bestand früher aus Holz

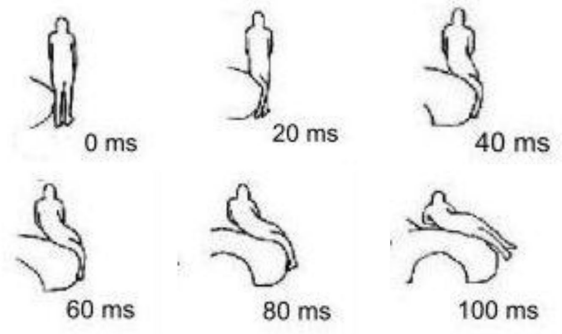
- **Nowadays, the bones consist of a compound material but still the selection of substitution materials is based on studies of elasticity and fracture behavior of human bones**
  Auswahl der Materialen basiert auf Untersuchungen zur Elastizität und zum Bruchverhalten menschlicher Knochen



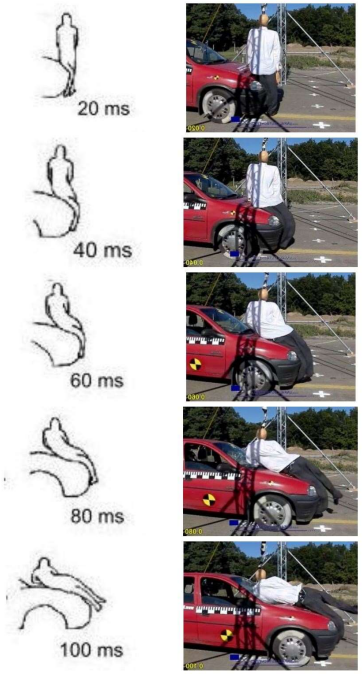
Development of a first Prototype in 2009

Entwicklung eines ersten Prototyps in 2009

PMTO Crash Test in steps of 20 ms



Source: Lex van Rooij u.a. (University of Virginia); Douglas Longhitano u.a. (Honda R&D Inc.): „The evaluation of the kinematics of the MADYMO human pedestrian model against experimental tests and the influence of a more biofidelic knee joint



Comparison PMTO vs. Biofidelic Dummy 2010

Muscle, soft tissue and skin-tissue have a major influence on contact phase (clinging behavior)

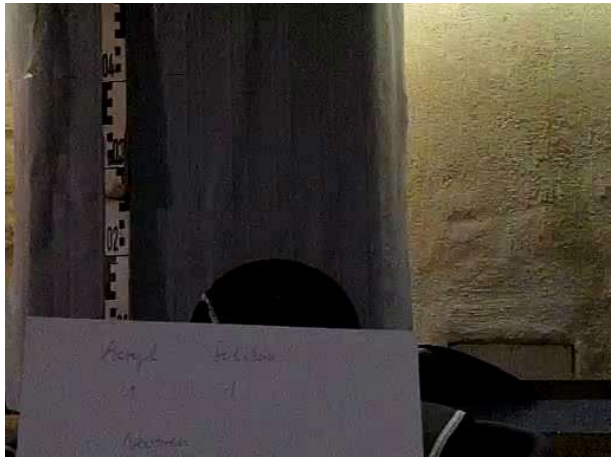
Muskel-, Weichteil- und Hautgewebe haben einen großen Einfluss auf die Kontaktphase (Anschmiege-Verhalten)

Selection of the new soft tissues materials

Auswahl der neuen Weichteilmaterialien

- **test on living objects: pendulum tests for determination of strength and resilience of human soft tissues**

  Test am lebenden Objekt: Pendelversuche zur Bestimmung von Festigkeit und Elastizität von menschlichem Weichteilgewebe



Biofidelic Dummy 3.0 – version 2016

Biofidel-Dummy 3.0 – Version 2016

Skeleton

- **soft tissue substitute consists of different multi-compound silicones with different Shore hardness values**
  Menschliches Ersatzgewebe bestehend aus Mehr-Komponenten-Silikonen mit unterschiedlichen Shore-Härten
- **material is suitable for long-term storage**
  Material ist langzeitlagerfähig

Comparison: crash test vs. real accident

Vergleich zwischen Crashtest und Realunfall

	real accident	crashtest
		
collision speed [km/h] Kollisionsgeschwindigkeit	53,0	52,6
longitudinal throwing width [m] Längswurfweite	16,0	16,0
cross-throw width [m] Querwurfweite	2,0	1,7
dynamic wrap around distance [cm] Dynamische Abwickellänge	240	230
dent offset [cm] Beulenversatz	10	0

Crash Test using biofidelic dummy

Experimentelle Simulation mit biofidelem Dummy - Überblick

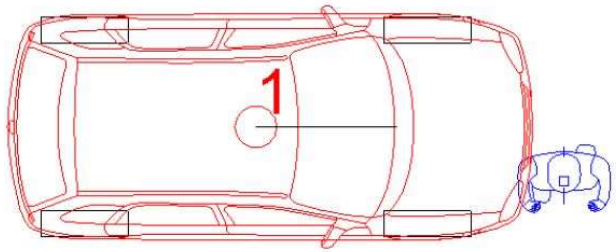
Opel CORSA B vs. BD-Dummy

- $v_{k\ vehicle}$ = 52,6 km/h
- $v_{k\ pedestrain}$ = 0,0 km/h
- frontal full-scale crash test

  Frontaler Test mit voller Überdeckung
- underlying real accident

  zugrunde liegender Realunfall

used measurement technology
UDS 1.3
UDS-AT
PicDAQ 5



Crash Test using a biofidelic dummy –[52,6 km/h]

Experimentelle Simulation mit biofidelem Dummy – Crash-Test [52,6 km/h]

Comparison of vehicle damages

Vergleich der Fahrzeugschäden (Crash Test ./. Accident)

accident vehicle

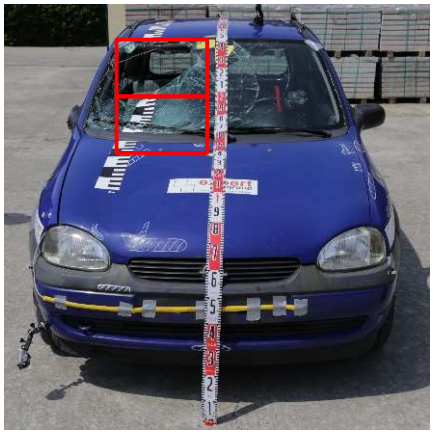
- **comparable wiping traces below the headlamps on the side of the impact [1]**
  vergleichbare Wischspuren unterhalb der anstoßseitigen Scheinwerfer [1]
- **comparable dents between headlight and radiator grille [2]**
  vergleichbare Eindellungen zwischen Scheinwerfer und Kühlergrill [2]

crashtest vehicle

Comparison of vehicle damages

Vergleich der Fahrzeugschäden (Crash Test ./. Accident)

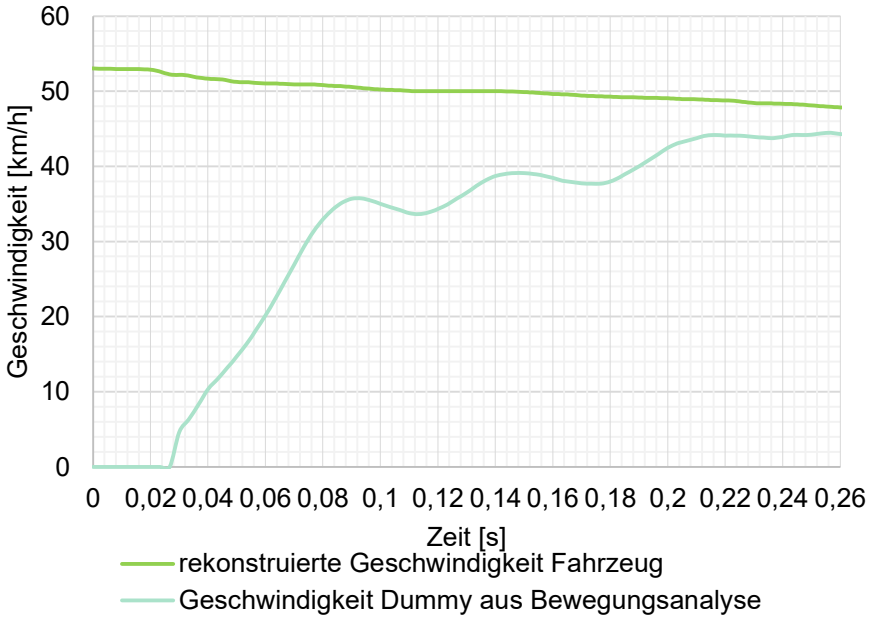
- **both vehicles show similar damage in the upper part of the windscreens**
  beide Fahrzeuge zeigen ähnliche Beschädigungen im oberen Bereich der Windschutzscheibe
- **Impact location of shoulder and head are recognizable on both windshields**
  Anprallstellen von Schulter und Kopf auf beiden Windschutzscheiben erkennbar



Analysis of biofidelic dummy movement

Analyse der Bewegung des biofidelen Dummys – Crash Test [52,6 km/h]

$$\bar{v} = \frac{\Delta s_{gemessen}}{\Delta t_{Frame}}$$

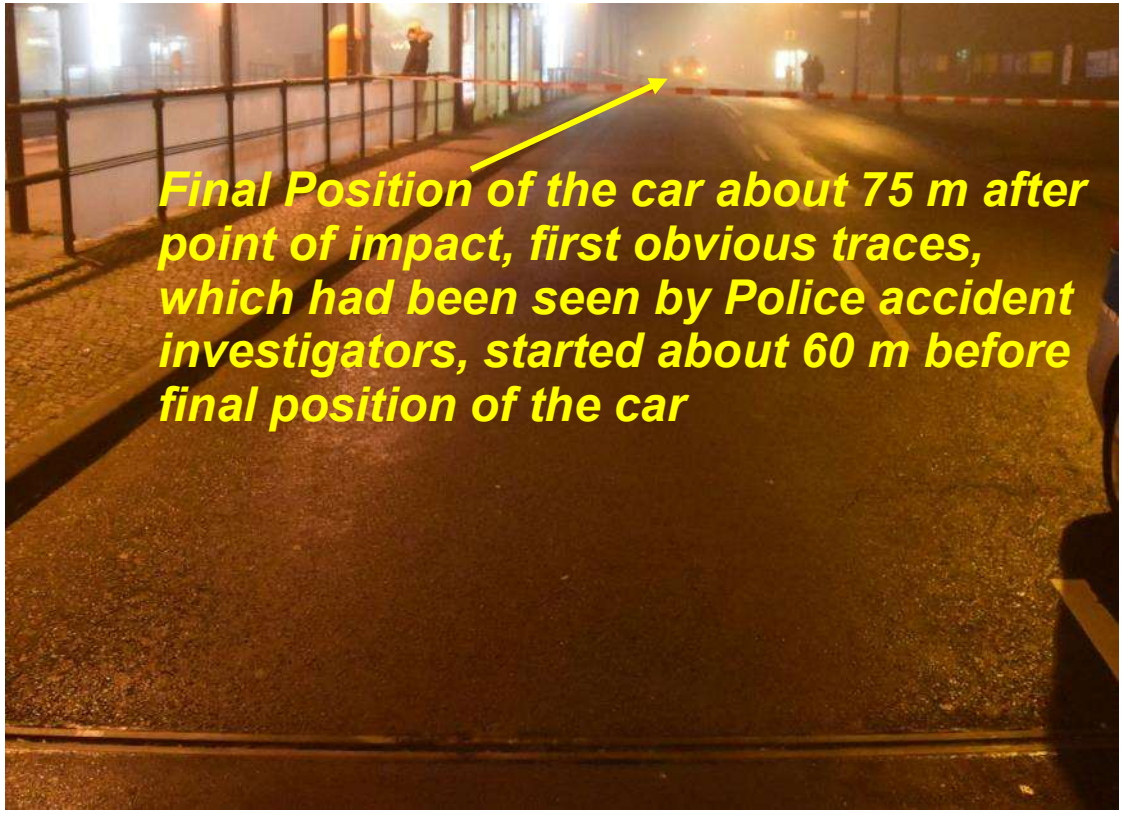


Quelle: Priester & Weyde (2016)

Nicht nur aus Crash-Tests wissen wir, dass ein Delta-V von 8 km/h nicht beim Fußgängeranprall zu erwarten ist, wie der folgende Fall zeigt

Not only from crash tests, but also from real world accidents we know – if we have acceleration data - that Delta-V of a normal car usually does not exceed 8 kph due to an impact against vulnurable road user [VRU]

Case Study: Car vs. Pedestrian



Accident Scene with nearly no traces on the actual point of collision

Case Study: Car vs. Pedestrian

No EDR Data even after a severe impact against a Pedestrian

BOSCH

CDR CRASH DATA RETRIEVAL

IMPORTANT NOTICE: Robert Bosch LLC and the manufacturers whose vehicles are accessible using the CDR System urge end users to use the latest production release of the Crash Data Retrieval system software when viewing, printing or exporting any retrieved data from within the CDR program. Using the latest version of the CDR software is the best way to ensure that retrieved data has been translated using the most current information provided by the manufacturers of the vehicles supported by this product.

CDR File Information

User Entered VIN	WVGZZZ1TZJ
User	Dr. Michael Weyde
Case Number	VU 2244
EDR Data Imaging Date	20
Crash Date	20
Filename	WVGZZZ1TZJ ACM_B VU CDRX
Saved on	Februar at
Imaged with CDR version	Crash Data Retrieval Tool 19.3
Imaged with Software Licensed to (Company Name)	Ingenieurbuero Priester und Weyde
Reported with CDR version	Crash Data Retrieval Tool 19.3
Reported with Software Licensed to (Company Name)	Ingenieurbuero Priester und Weyde
EDR Device Type	Airbag Control Module
Event(s) recovered	None

Pedestrian was killed by a Volkswagen Touran which was equipped with an U.S. EDR and an additional mounted Accident Data Storage System (UDS)

Case Study: Car vs. Pedestrian

Even after such a severe impact against a pedestrian the Delta-V in the car is only about 6 kph within 0.15s

No Data in an U. S. EDR because Delta-V over 0.15 s is too low to trigger a recording

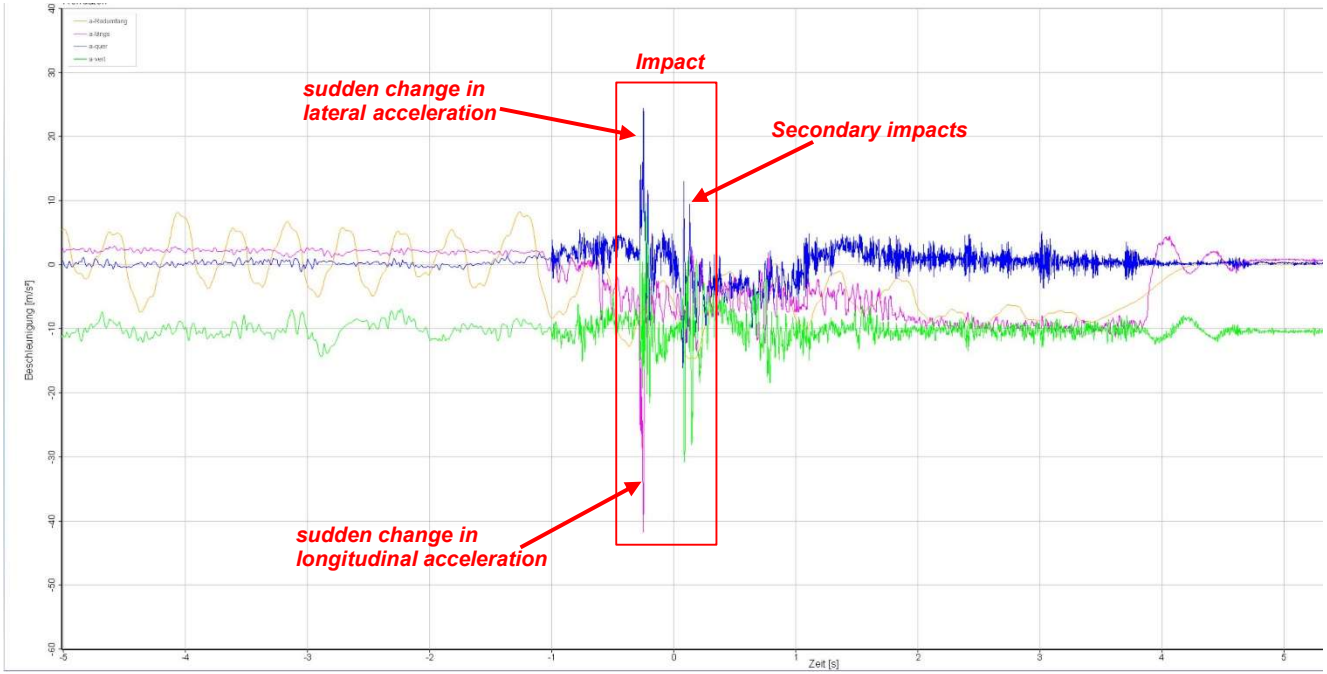
Data from UDS: Acceleration (top graphic) and wheel speed (graphic below) of the car about 2 s before and after the impact against the pedestrian, as well as average values over 0.15 s during impact

Case Study: Car vs. Pedestrian

Although the car was braked prior to the impact, it is clearly possible to differentiate normal driving from an impact against a pedestrian by evaluation of the change in acceleration, the so called Jerk, even if the Delta-V during impact is rather small

Data from UDS: Acceleration (top graphic), wheel speed (graphic in the middle) and status data (lowest graphic) about 0.6 s before and after the impact against the pedestrian, as well as average values over 0.25 s before impact

Case Study: Car vs. Pedestrian



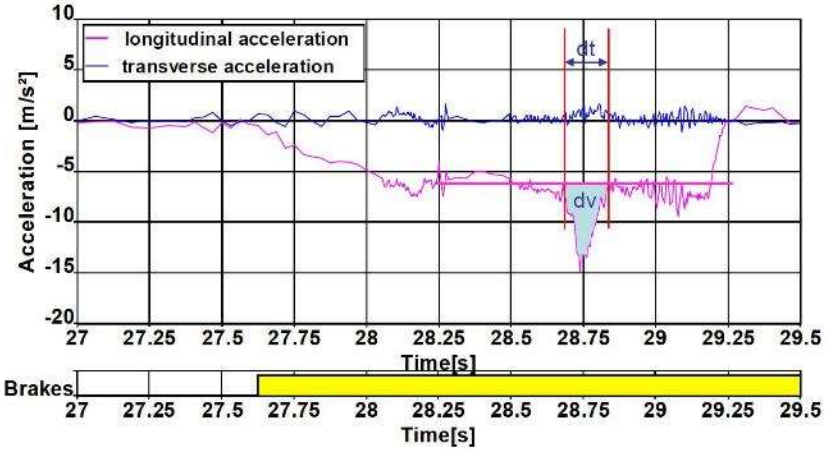
The acceleration chart allows clear differentiation betweed normal driving and an impact by the sudden change in acceleration

Data from UDS: Acceleration over time - about 5 s before and after the impact against the pedestrian

Jolt-Trigger, described in VERONICA-Project*

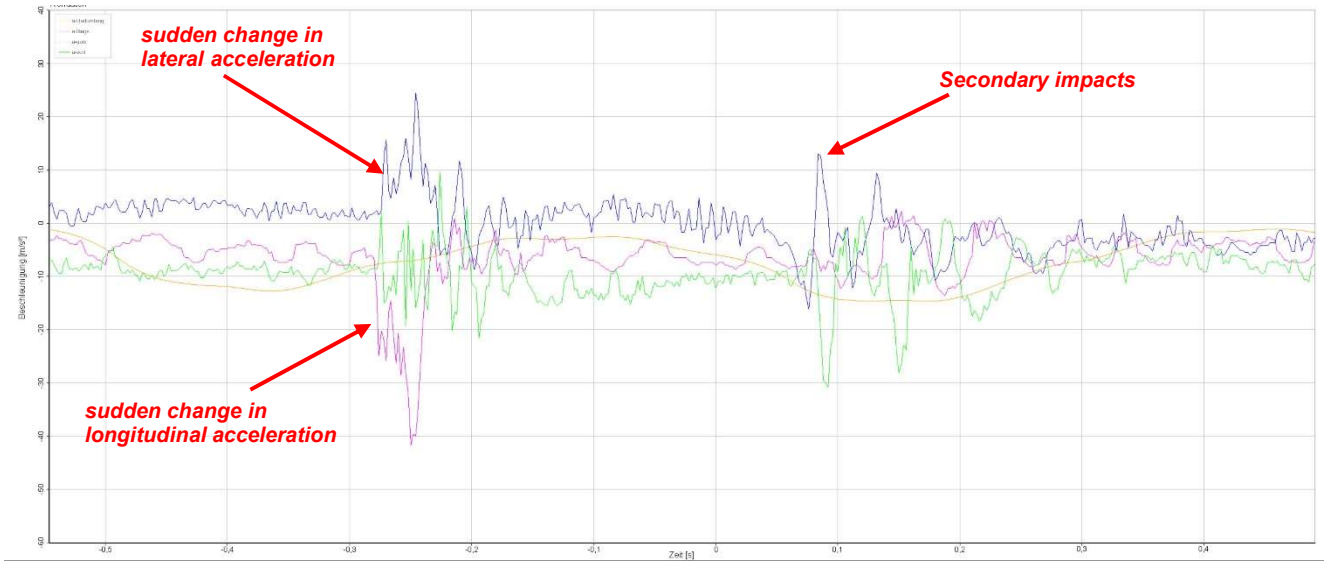
- ***Evaluation of acceleration to determine a distinctive relative change, a Jolt, is state of the art not only to trigger an Airbag Deployment, but also to recognize any kind of impact***

- ***Delta-V on its own is insufficient to differentiate normal driving from an impact against a vulnerable road user***



*)
EUROPEAN COMMISSION
DIRECTORATE-GENERAL FOR ENERGY AND TRANSPORT
Vehicle Event Recording based on Intelligent Crash Assessment
VERONICA – II
(EC Contract No. TREN-07-ST-S07.70764)
Authors: Schmidt-Cotta, Ralf-Roland e.a.
10-06-2009

Case Study: Car vs. Pedestrian



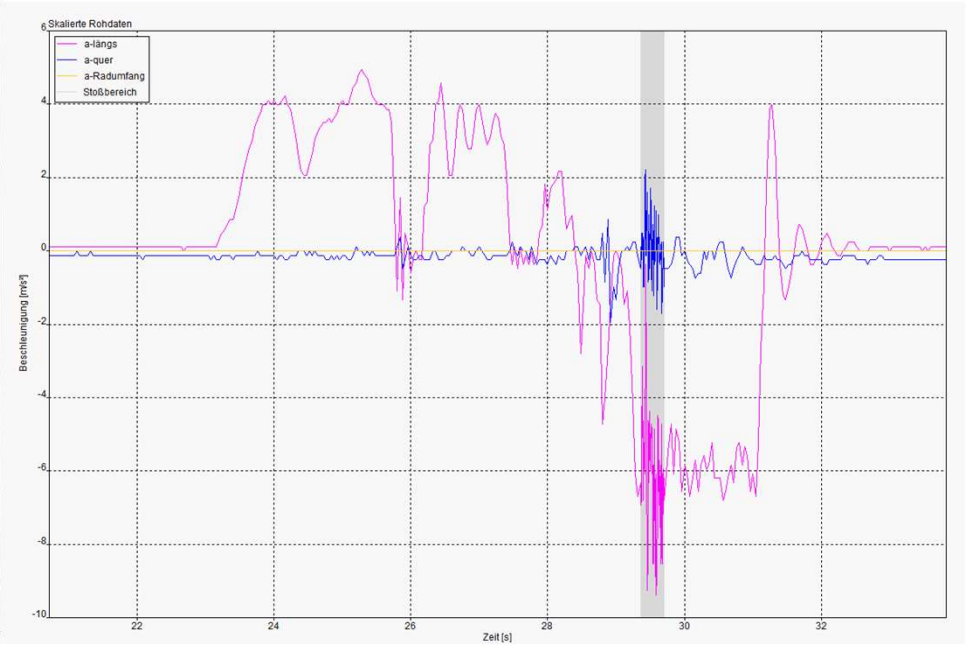
By analysing acceleration data it is possible to differentiate driving from an impact by the sudden change in acceleration:
Whereby the Jerk in longitudianal direction is approximately 500 m/s³ within 4 ms and 1.200 m/s³ within 30 ms due to the VRU contact

Data from UDS: Acceleration over time - about 0,5 s before and after the impact against the pedestrian, and the calculated min-/max-values

Interim Conclusion:

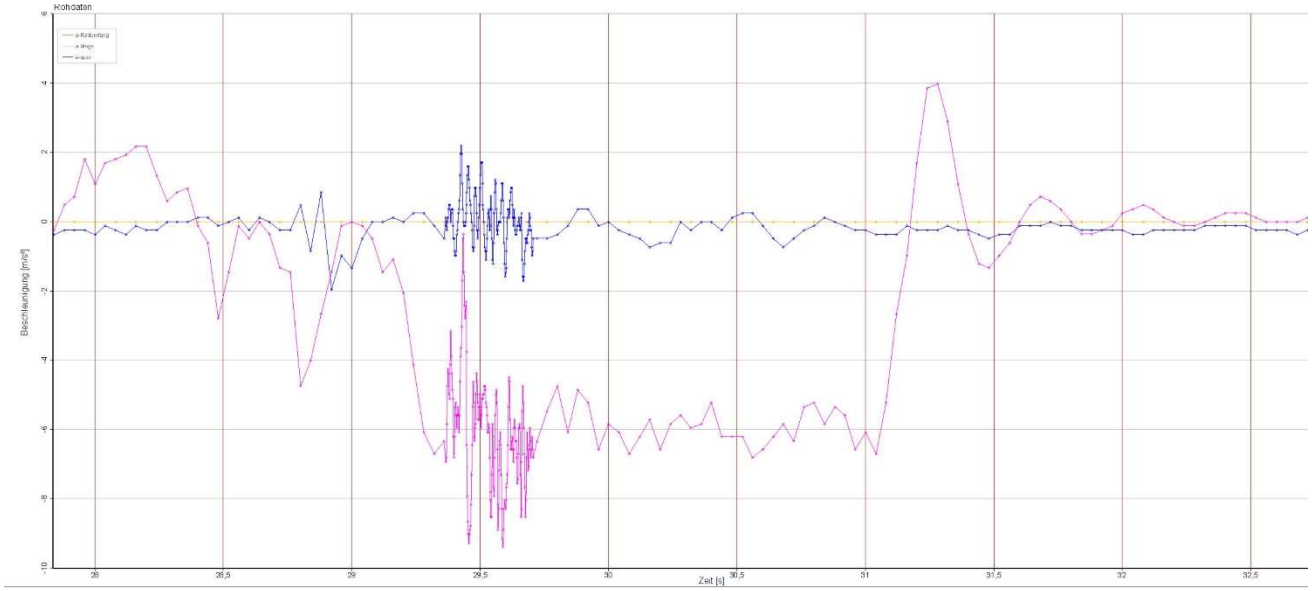
- **Delta-V on its own is not suitable to differentiate an impact from normal driving**
- **Delta-V is generally below 8 kph in a normal car during an impact against a pedestrian or cyclist, thus we need a different trigger for crash detection**
- **The Jerk - derived from acceleration – will not allows us to detect all impacts, but more than a Delta-V trigger of 8 kph within 150 ms**
- **To find a suitable Jerk-Trigger we need crash test with a suitable surrogate for vulnerable Road Users, thus a biofedelic dummy**

CTS Crash Test 18881:
VW Touareg vs. Biofidelic Dummy



longitudinal and lateral acceleration-values over time
collision speed = approx. 40 kph

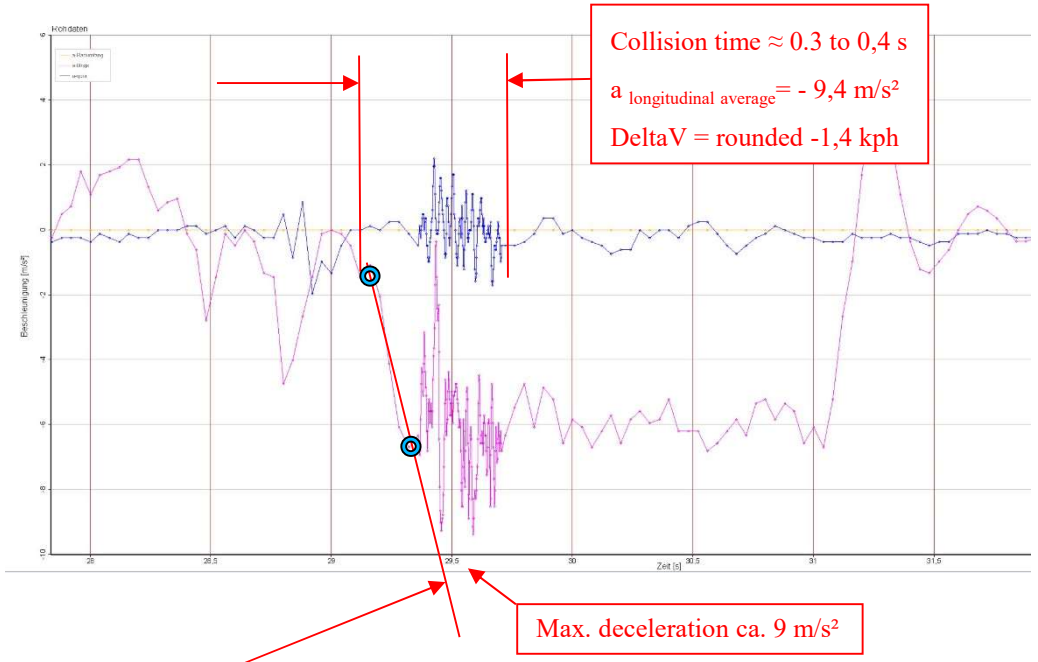
CTS Crash Test 18881:
VW Touareg vs. Biofidelic Dummy



longitudinal and lateral acceleration-values over time
collision speed = approx. 40 kph

CTS Crash Test 18881:
VW Touareg vs. Biofidelic Dummy

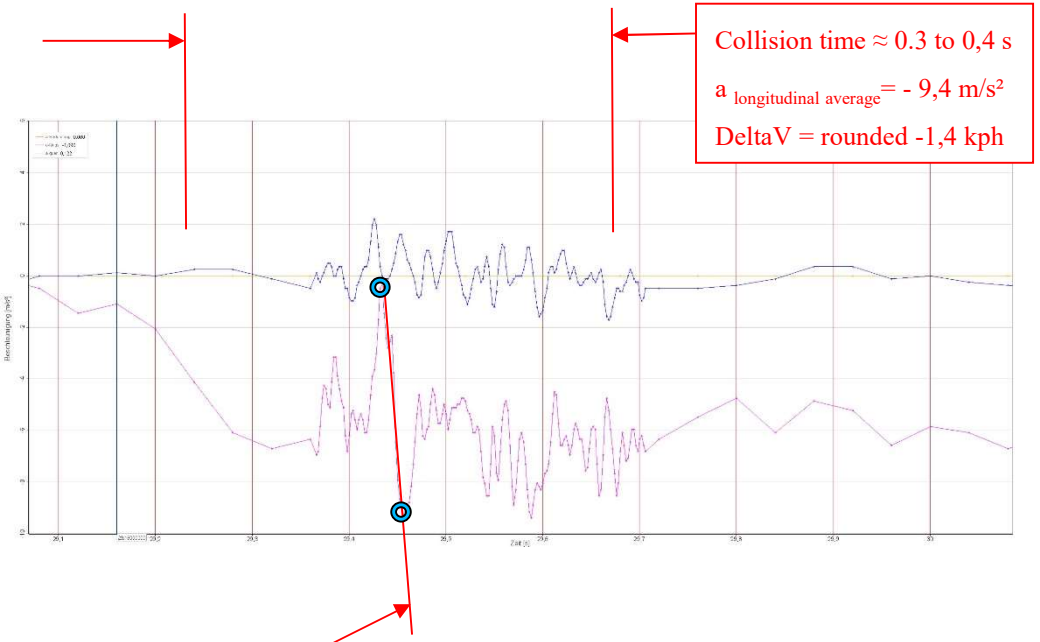
- **The beginning of on impact against a VRU is not significant**
- **Therefore, the acceleration signal is evaluted during the entire impact**
- **Then, we can detect a significant change in acceleration, a Jerk, even in this minor crash against a biofidelic dummy**



The curve of acceleration in the diagram above seems to show a steep drop in the course of acceleration at the beginning of the impact. But, during ca. 0.16 s the longitudinal acceleration changes only from ca. -1,1 to -6,7 m/s² (Jerk: da/dt:= 5,6 m/s²/0,16 s = 35 m/s³)

CTS Crash Test 18881:
VW Touareg vs. Biofidelic Dummy

- **Later, when the hip of the biofidelic dummy hits the car, the acceleration changes significantly**
- **During a period of approx. 5 ms there is a *JERK* of more than 500 m/s³ to be measured**
- **Therefore, we can detect an impact against VRU by the change in acceleration, the *JERK***



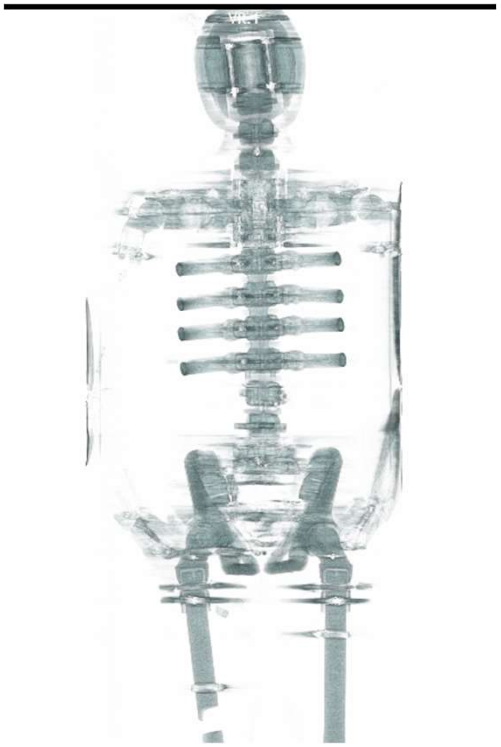
Later, during the impact, the change in acceleration is even higher at the beginning of the impact.
During ca. 0.006 s the longitudinal acceleration changes from approximately -2.3 to -7.9 m/s²
Jerk: da/dt:= 5,6 m/s²/0,006 s = 933 m/s³

Interim Conclusion:

- **We can learn from real world accidents, if we have sufficient data from an accident or event recorder**
- **A Trigger criterion of 8 kph in US and UN-ECE EDR is not sufficient to detect impacts a against VRU**
- **A Jerk exceeding 500 m/s³ within 5 ms seems to be reasonable in order to detect impacts against VRU**
- **We have to use a biofidelic dummy as a suitable surrogate for the VRU, because only such type of dummy will give us acceleration values in VRU-crash-tests similar to real world accidents**

Determination of damages on the dummy

Schadenfeststellung am Dummy
in Kooperation mit der Rechtsmedizin an der Charité Berlin



➢ Fatalities and Dummys can be scanned by the computer tomograph

Feststellungen von Dummys-Schäden und Verletzungen der Getöteten – insbesondere Frakturen des Skeletts auch ohne Demontage möglich

➢ Comparative study with the CT scan data from real traffic accidents in fatalities

Vergleichende Untersuchung mit den CT-Scan-Daten aus realen Verkehrsunfällen bei Getöteten

Correlation between contact force and fracuture probability

Korrelation von Kontaktkräften und Verletzungswahrscheinlichkeit

- **making use of the positive cooperation between accident reconstructionists and legal medicine of the Charité in Berlin**
- **Comparative study with PMCT scan data from real traffic accidents in case of all fatalities in order to determine position, intensity and direction of force on the skeleton precisely by a precise determination of all fractures in terms of position and dislocation**

  Vergleichende Untersuchung mit den CT-Scan-Daten aus realen Verkehrsunfällen bei Getöteten durch die Zusammenarbeit der Unfallanalytiker mit den Rechtsmedizinern der Charité Berlin
- **Establishment of a database for determining the correlation between forces and injuries**

  Aufbau einer Datenbank zur Feststellung der Korrelation zwischen Kräften und Verletzungen

Rechtsmedizin Berlin

Feststellung und Dokumentation der Verletzungen mittels postmortalen Schichtröntgenuntersuchungen (pmMSCT) hier: primäre Anprallstelle in Form einer keilförmigen Unterschenkelfraktur „Messerer Keilbruch“ (linke Tibia nach Anprall eines Pkw [im Bild von links])

Further Development of a Biofidelic Dummy as a Surrogate for Vulnerable Road Users in full-scale Crash Tests

Prof. Dr.-Ing. Lars Hannawald – HTW Dresden

PD Dr. med. Sven Hartwig – Charité Berlin

Dipl.-Ing. Andreas Schäuble, M. Eng. – DEKRA Stuttgart

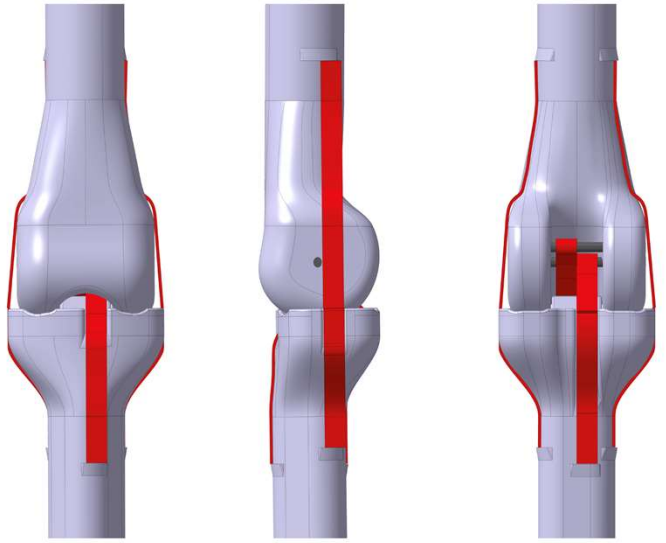
Dipl.-Ing. Peter Schimmelpfennig – Crashtest-Service.com Münster

Dr. Dipl.-Ing. Michael Weyde – Priester & Weyde Berlin

Knee Adaptation towards human skeleton

Knie - Anpassung der Ersatzknochen an das menschliche Skelett

- **comparable geometry and function like the human role model**
  mit menschlichem Vorbild vergleichbare Geometrie und Funktion
- **joint can perform anthropometric movements**
  Gelenk kann anthropomorphe Bewegungen ausführen
- **fails with certain loads**
  versagt innerhalb von gewissen Belastungsgrenzen



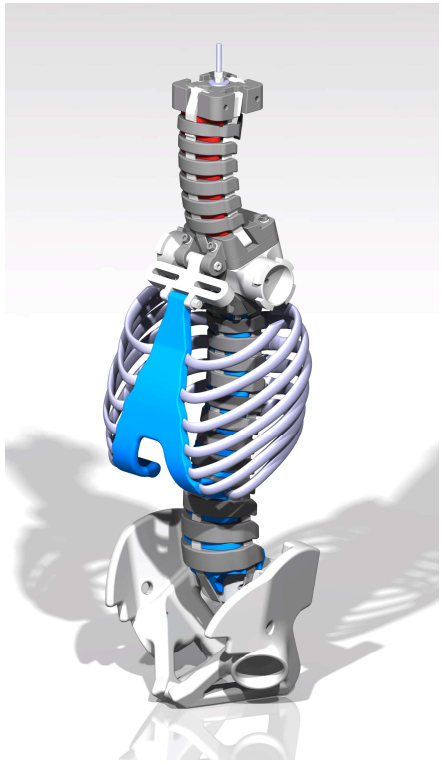
Testing of the Biofidelic-Dummy 3.1

Test des Biofidel-Dummys 3.1

„Knee Joint Injury“: Demolition of outer knee band (red Arrow shows direction of impact)
„Knie-Verletzung“: Außenband-Abriss beim Biofidel-Dummy aus DEKRA Crashversuch (roter Pfeil zeigt die Anstoßrichtung)

New construction of thorax and spine

Neu konstruierte Wirbelsäule und überarbeiteter Thorax



- **Sternum now more flexible and realistic**

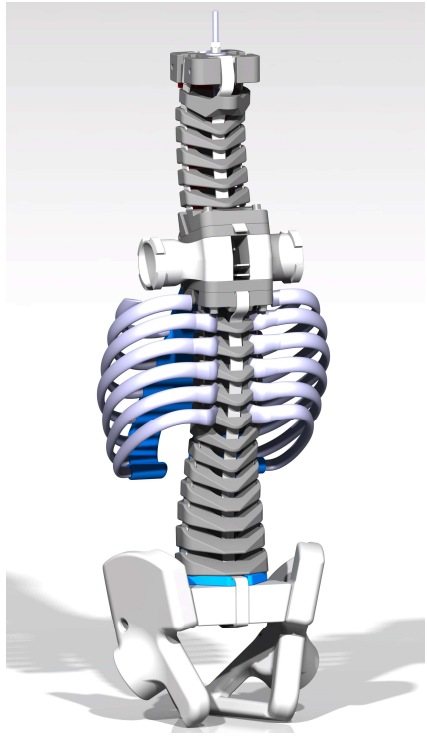
  Brustbein ist realistischer und flexibler

- **Higher number of rib pairs, which are more realistic shaped**

  Höhere Anzahl an Rippen, die realistischer geformt sind

- **Spine with more vertebrae and more realistic curvature**

  Wirbelsäule mit mehr Wirbelkörpern und realistischer Mehrfach-Biegung



Conclusions and Outlook:

- Biofidelic dummies could help us:

- to determine a suitable trigger for an EDR-Recording by intelligent JERK-Detection in order to detect also impacts against vulnerable road users, because due to its human like construction it is able to act as a surrogate for vulnarable road users (VRU)

- to proof technical constructions and developments of pedestrian protection systems on their realistic effectiveness in order to reduce injuries of vulnerable road users

Thank you very much for your attention!
… und Dank auch an die DEKRA Unfallforschung