



Overview of NHTSA Pedestrian Crashworthiness Research

SAE Government Industry Meeting
January 24-26, 2018



Overview

- Assessment of US fleet using EuroNCAP procedures
 - US vehicle fleet performance
 - Lab-to-lab consistency on global platform vehicles
 - Testing and evaluation of head countermeasures
 - Relative performance in lower extremity protection and Part 581 tests
 - Evaluation of the TRL upper legform

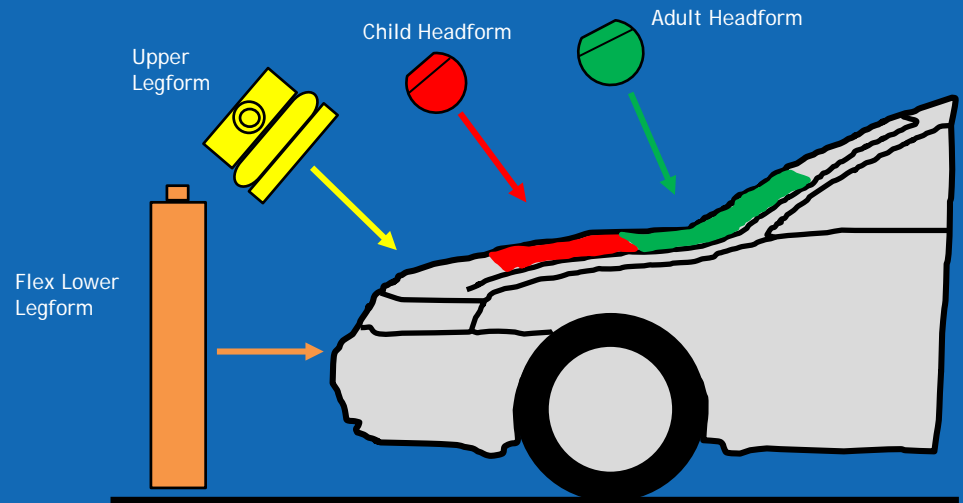


Overview

- **Assessment of US fleet using EuroNCAP procedures**
 - US vehicle fleet performance
 - Lab-to-lab consistency on global platform vehicles
 - Testing and evaluation of head countermeasures
 - Relative performance in lower extremity protection and Part 581 tests
 - Evaluation of the TRL upper legform
- **Pedestrian crash data analysis**
 - Frequency of US injuries associated with risk measured by tests
 - Isolated knee cruciate ligament injuries in the field
 - State data analysis: old vs new vehicles
 - Thorax injuries: do head/leg countermeasures protect against them?

Assessment of US Fleet Using EuroNCAP Procedures

- Current state of pedestrian protection in US fleet using established test methods
- EuroNCAP Test Procedures & Scoring
 - Head
 - Lower Leg (FlexPLI)
 - Upper Leg (TRL)





Assessment of US Fleet Using EuroNCAP Procedures

Vehicles Tested:

Model Year (MY)	Make	Model	Description
2017	Audi	A4	Passenger Car
2016	Chevrolet	Malibu	Passenger Car
2016	Chevrolet	Tahoe	Standard SUV
2016	Ford	Edge	MPV
2016	Ford	F-150	Standard Pickup Truck
2016	Honda	Fit	Passenger Car
2016	Nissan	Rogue	Small SUV
2016	Toyota	Prius	Passenger Car
2015	Toyota	Sienna	Minivan



Assessment of US Fleet Using EuroNCAP Procedures

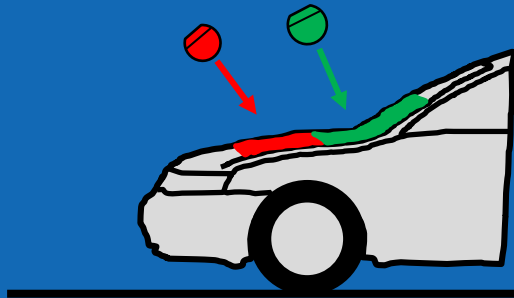
Vehicles Tested:

*Global platform vehicles

Model Year (MY)	Make	Model	Description
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2016	Chevrolet	Malibu	Passenger Car
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Assessment of US Fleet Using EuroNCAP Procedures

Head Test Results

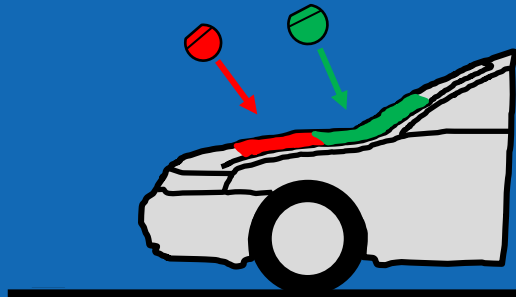


Vehicle	Head Scores (Max 24 pts)	
	VRTC	EuroNCAP
2017 Audi A4	17.00	--
2016 Chevrolet Malibu	16.36	--
2016 Chevrolet Tahoe	14.18	--
2016 Ford Edge	16.57	16.04
2016 Ford F-150	9.82	--
2016 Honda Fit	17.68	17.10
2016 Nissan Rogue	17.56	15.44
2016 Toyota Prius	18.36	16.91
2015 Toyota Sienna	16.67	--
Avg Score (% of Max)	16.02 (67%)	16.37 (68%)

- US vehicles performed similarly to the 4 EuroNCAP/EU models

Assessment of US Fleet Using EuroNCAP Procedures

Head Test Results

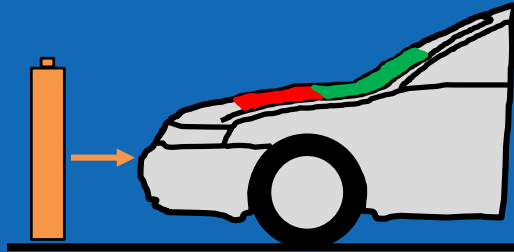


Vehicle	Head Scores (Max 24 pts)	
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2017 Audi A4	17.00	--
2016 Chevrolet Malibu	16.36	--
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2016 Nissan Rogue	17.56	15.44
2016 Toyota Prius	18.36	16.91
2015 Toyota Sienna	16.67	--
Avg Score (% of Max)	16.02 (67%)	16.37 (68%)

- US vehicles performed similarly to the 4 EuroNCAP/EU models
- VRTC and EuroNCAP head scores found to be relatively consistent for global platform vehicles

Assessment of US Fleet Using EuroNCAP Procedures

Lower Leg Results (FlexPLI)

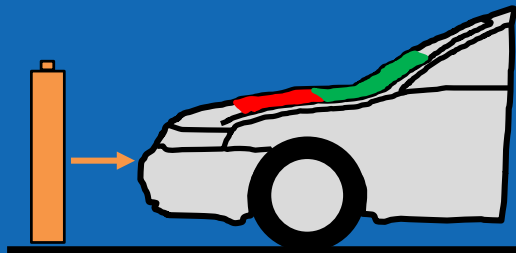


Vehicle	Lower Leg Scores (Max 6 pts)	
	VRTC	EuroNCAP
2017 Audi A4	2.24	--
2016 Chevrolet Malibu	1.99	--
2016 Chevrolet Tahoe	0.00	--
2016 Ford Edge	0.40	6.00
2016 Ford F-150	0.00	--
2016 Honda Fit	0.00	6.00
2016 Nissan Rogue	6.00	6.00
2016 Toyota Prius	4.41	6.00
2015 Toyota Sienna	0.00	--
Avg Score (% of Max)	1.67 (28%)	6.00 (100%)

- 4 EU global platform vehicles performed well when tested by EuroNCAP

Assessment of US Fleet Using EuroNCAP Procedures

Lower Leg Results (FlexPLI)

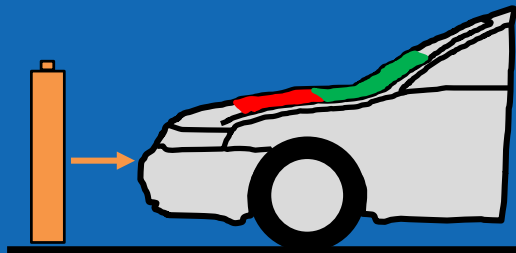


Vehicle	Lower Leg Scores (Max 6 pts)	
	VRTC	EuroNCAP
2017 Audi A4	2.24	--
2016 Chevrolet Malibu	1.99	--
2016 Chevrolet Tahoe	0.00	--
2016 Ford Edge	0.40	6.00
2016 Ford F-150	0.00	--
2016 Honda Fit	0.00	6.00
2016 Nissan Rogue	6.00	6.00
2016 Toyota Prius	4.41	6.00
2015 Toyota Sienna	0.00	--
Avg Score (% of Max)	1.67 (28%)	6.00 (100%)

- The front end/bumper part differences between US and EU versions varied by vehicle

Assessment of US Fleet Using EuroNCAP Procedures

Lower Leg Results (FlexPLI)

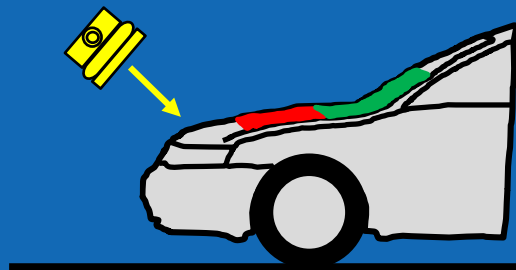


Vehicle	Part 581 Applicable to US Version?	Lower Leg Scores (Max 6 pts)	
		VRTC	EuroNCAP
2017 Audi A4	Yes	2.24	--
2016 Chevrolet Malibu	Yes	1.99	--
2016 Chevrolet Tahoe	No	0.00	--
2016 Ford Edge	No	0.40	6.00
2016 Ford F-150	No	0.00	--
2016 Honda Fit	Yes	0.00	6.00
2016 Nissan Rogue	No	6.00	6.00
2016 Toyota Prius	Yes	4.41	6.00
2015 Toyota Sienna	No	0.00	--
Avg Score (% of Max)		1.67 (28%)	6.00 (100%)

- Part 581 does not appear to be the sole obstacle for good pedestrian leg scores
 - Non-applicable vehicles: Nissan Rogue did well / Ford Edge did not
 - Applicable vehicles: Toyota Prius did well / Honda Fit did not

Assessment of US Fleet Using EuroNCAP Procedures

Upper Leg Results (EEVC/TRL)

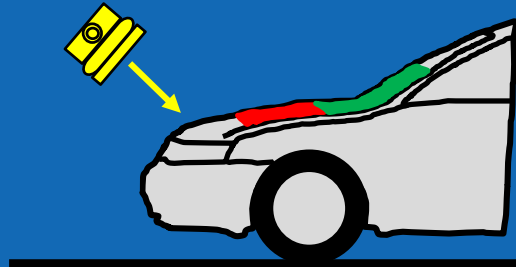


Vehicle	Upper Leg Scores (Max 6 pts)	
	VRTC	EuroNCAP
2017 Audi A4	5.17	--
2016 Chevrolet Malibu	3.40	--
2016 Chevrolet Tahoe	0.80	--
2016 Ford Edge	0.80	3.56
2016 Ford F-150	1.20	--
2016 Honda Fit	6.00	3.23
2016 Nissan Rogue	6.00	5.40
2016 Toyota Prius	5.91	4.82
2015 Toyota Sienna	2.44	--
Avg Score (% of Max)	3.52 (59%)	4.25 (71%)

- 4 EU global platform vehicles performed moderately well when tested by EuroNCAP

Assessment of US Fleet Using EuroNCAP Procedures

Upper Leg Results (EEVC/TRL)



Vehicle	Upper Leg Scores (Max 6 pts)	
	VRTC	EuroNCAP
2017 Audi A4	5.17	--
2016 Chevrolet Malibu	3.40	--
2016 Chevrolet Tahoe	0.80	--
2016 Ford Edge	0.80	3.56
2016 Ford F-150	1.20	--
2016 Honda Fit	6.00	3.23
2016 Nissan Rogue	6.00	5.40
2016 Toyota Prius	5.91	4.82
2015 Toyota Sienna	2.44	--
Avg Score (% of Max)	3.52 (59%)	4.25 (71%)

- Mixed performance within US models
 - Passenger vehicles performed moderately well
 - Pickups/SUVs did not score as well



Assessment of US Fleet Using EuroNCAP Procedures

Summary

Vehicle	Total Vehicle Scores (Max 36 pts)	
	VRTC	EuroNCAP
2017 Audi A4	24.41	--
2016 Chevrolet Malibu	21.75	--
2016 Chevrolet Tahoe	14.98	--
2016 Ford Edge	17.77	25.60
2016 Ford F-150	11.02	--
2016 Honda Fit	23.68	26.33
2016 Nissan Rogue	29.56	27.44
2016 Toyota Prius	28.68	27.73
2016 Toyota Sienna	19.10	--
Avg Score (% of Max)	21.22 (59%)	26.78 (74%)



Assessment of US Fleet Using EuroNCAP Procedures

Lab-to-Lab Consistency

- Tested 2016 Toyota Prius & 2016 Ford Edge
 - Same head impact locations as EuroNCAP

= Mfg Prediction
< Mfg Prediction
> Mfg Prediction

2016 Toyota Prius

Impact Location	HIC		
	VRTC	EuroNCAP	Manufacturer Prediction
C,1,-2	495	594	<650
C,5,-1	335	351	<650
C,5,+4	366	605	<650
C,1,-5	999	1043	1350-1700
C,7,±6	918	909	1000-1350
A,9,-4	722	1017	650-1000

2016 Ford Edge

Impact Location	HIC		
	VRTC	EuroNCAP	Manufacturer Prediction
C,6,-3	496	594	<650
C,2,3	915	767	650-1000
C,4,7	1127	1332	1000-1350
C,4,-5	569	642	650-1000
C,5,-2	496	573	<650
A,12,-6	449	503	<650
A,10,-5	1827	1904	>1700

- VRTC and EuroNCAP HIC results found to be consistent!

Assessment of US Fleet Using EuroNCAP Procedures

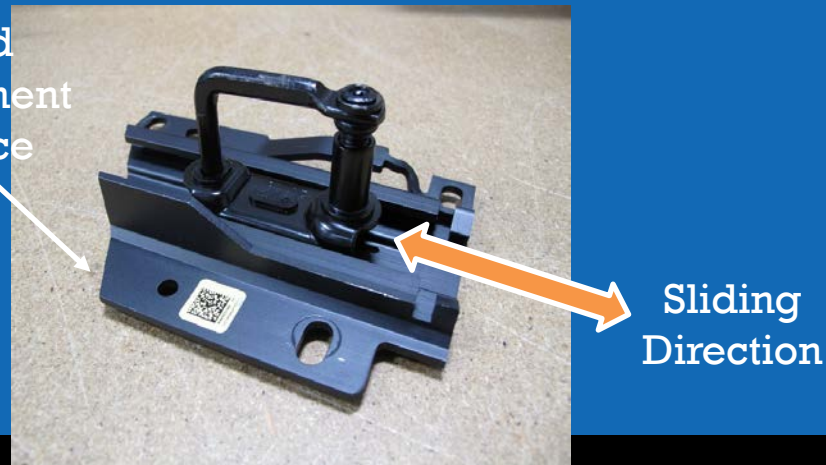
Active Hood Systems

- Outfitted two US vehicles with EU model active hood system parts (i.e. hinges, actuators, hood latch strikers)
 - 2017 Audi A4 (photos below) & 2017 Cadillac ATS

Hinge + Actuator



Hood Latch Striker



Assessment of US Fleet Using EuroNCAP Procedures

Active Hood Systems

- Performed tests in the undeployed state and deployed-static state

Undeployed



Deployed-Static



Assessment of US Fleet Using EuroNCAP Procedures

Active Hood Systems

- Head impact results

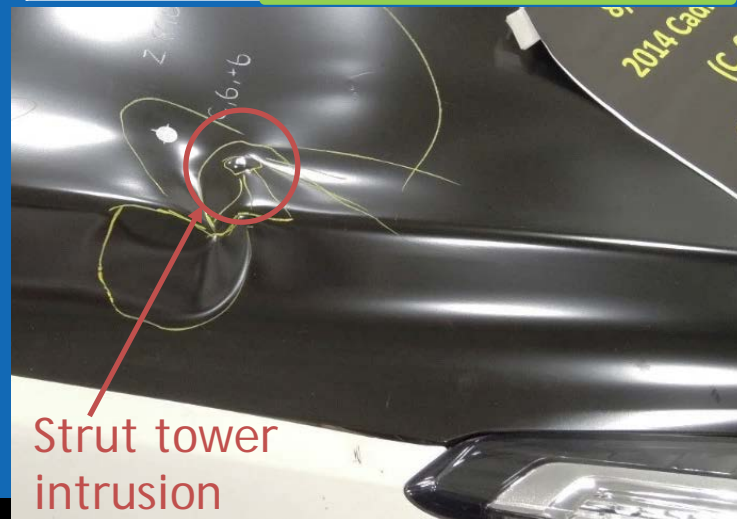
2017 Audi A4

Impact Location	HIC	
	Undeveloped	Deployed Static
C,1,0	945	795
C,7,0	621	698
C,9,-7	1053	1153
C,7,+5	703	556
C,3,-7	1085	766
A,8,0	875	450

Small decrease or similar HIC
Large decrease in HIC

2014 Cadillac ATS

Impact Location	HIC	
	Undeveloped	Deployed Static
C,6,+6	1923	400
C,5,0	2753	299
A,8,0	1793	232



Assessment of US Fleet Using EuroNCAP Procedures

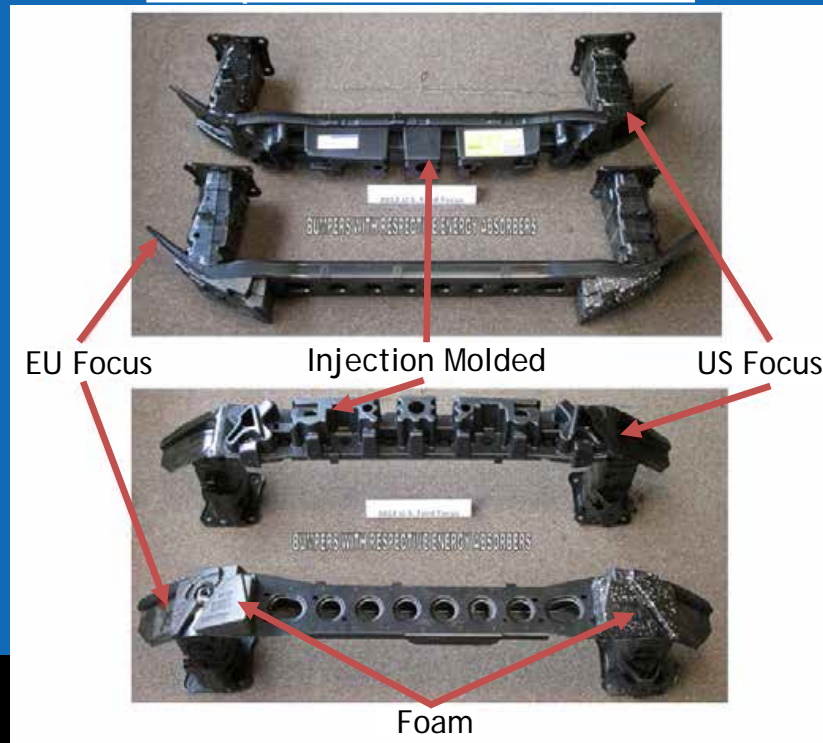
Relative performance in lower extremity protection and Part 581 tests

- 2011/2012 US Ford Focus
- 2012 EU Ford Focus

Front Underbody Deflector Panel



Bumper Beam & Absorber

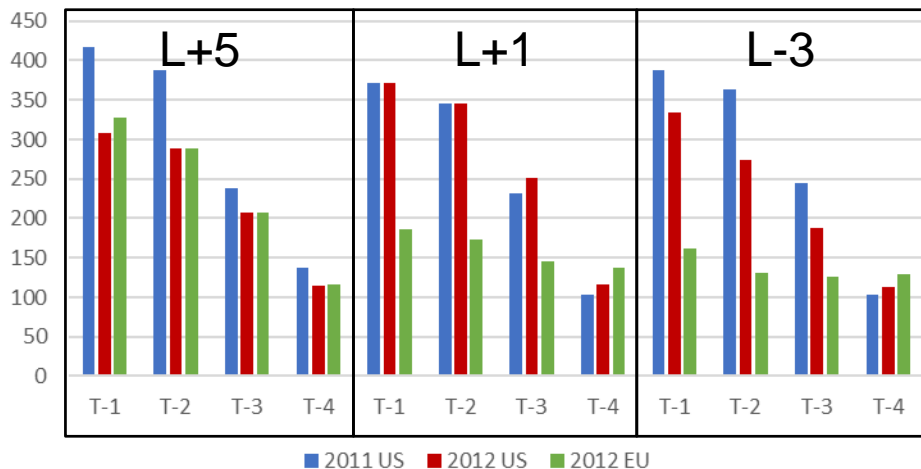


Assessment of US Fleet Using EuroNCAP Procedures

Relative performance in lower extremity protection and Part 581 tests

- Lower legform tests on Ford Focus
 - EU Focus is softer at inboard locations

Tibia Bending Moment (Nm)

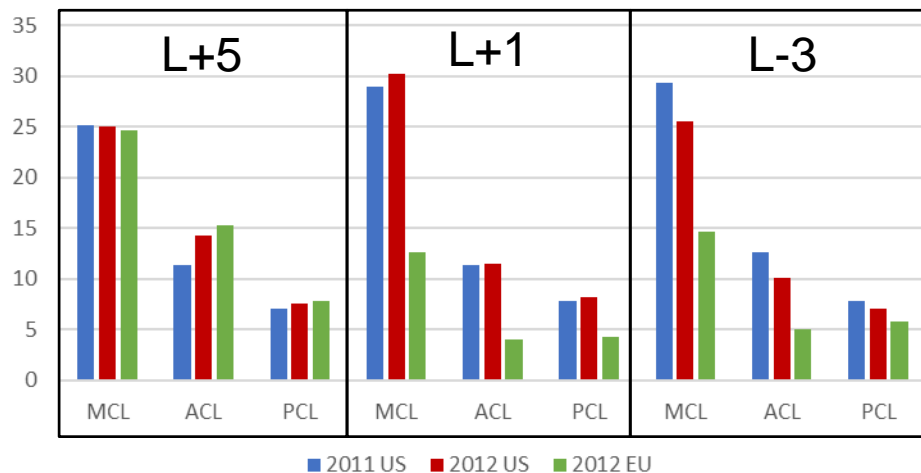


Assessment of US Fleet Using EuroNCAP Procedures

Relative performance in lower extremity protection and Part 581 tests

- Lower legform tests on Ford Focus
 - EU Focus is softer at inboard locations

Knee Ligament Elongation (mm)



Assessment of US Fleet Using EuroNCAP Procedures

Relative performance in lower extremity protection and Part 581 tests

- Part 581 tests on 2012 US Ford Focus & 2012 EU Ford Focus



Without Upper Plane



With Upper Plane

Assessment of US Fleet Using EuroNCAP Procedures

Relative performance in lower extremity protection and Part 581 tests

- Part 581 tests on 2012 US Ford Focus & 2012 EU Ford Focus

Left Corner Impact:

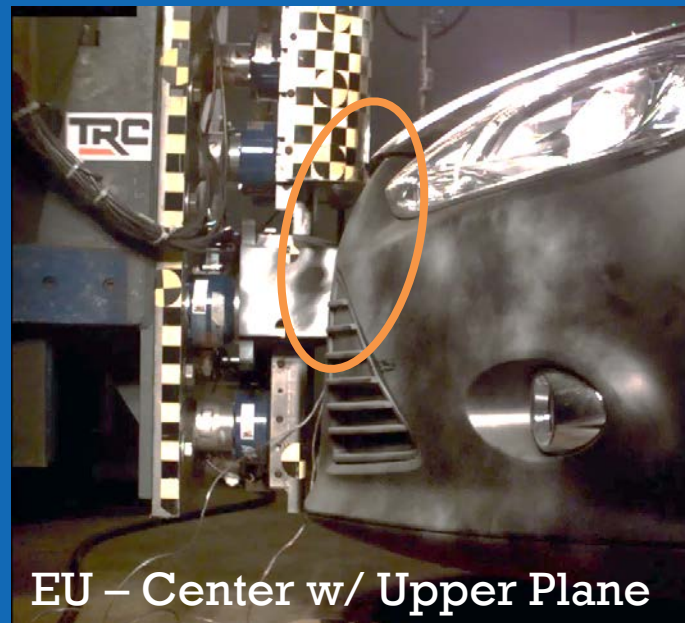
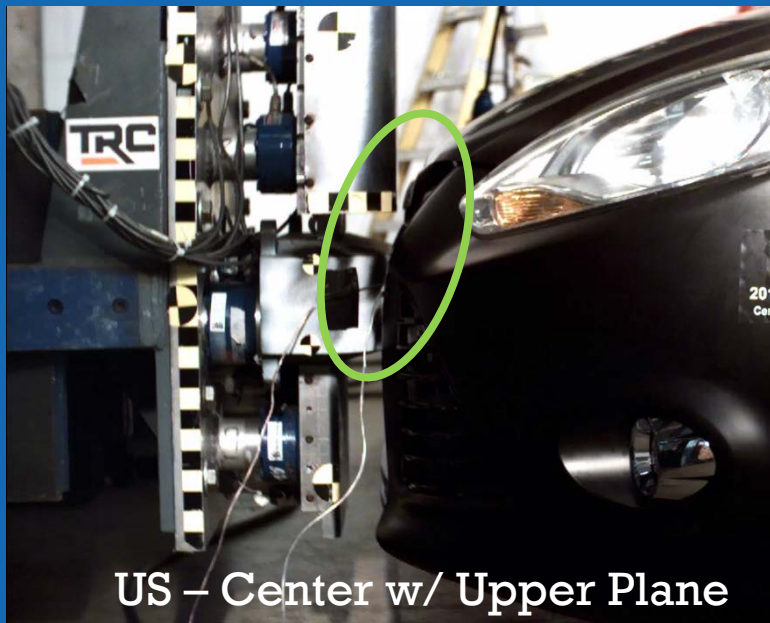
- 60° from centerline
- 16" high



Assessment of US Fleet Using EuroNCAP Procedures

Relative performance in lower extremity protection and Part 581 tests

- Part 581 tests on 2012 US Ford Focus & 2012 EU Ford Focus





Assessment of US Fleet Using EuroNCAP Procedures

Test Description			Pendulum Forces (N)		Vehicle Damage in Part 581 Tests		Flex Leg Measurements					
Speed	Impact Point	Note	Upper + Lower				Tibia Bending Moment (Nm)	MCL Elongation (mm)		ACL/PCL Elongation (mm)		
			US	EU	US	EU	US	EU	US	EU	US	EU
2.5 mph	Front Bumper 12 Inches Right of Centerline (between L+1 and L+5 in Flex test*)	without Upper Plane	-307	-584	Minor scuffs on fascia; small crack in front grille; no headlight damage	Hood dent; large scuffs on fascia; large crack in grille; no headlight damage	340	257	27.6	18.6	12.9	9.8
1.5 mph	Front Bumper Left Corner (L-3 in Flex test)	without Upper Plane	-279	-285			334	162	25.5	14.6	10.1	5.8
2.5 mph	Front Bumper Centerline (L+1 in Flex test)	with Upper Plane	118	-4575			372	186	30.2	12.6	11.5	4.3
1.5 mph	Front Bumper Right Corner (L+5 in Flex test)	with Upper Plane	124	162			308	327	25.0	24.6	14.2	15.3

*Flex leg measurements shown are average of L+1 and L+5



Assessment of US Fleet Using EuroNCAP Procedures

Test Description			Pendulum Forces (N)		Flex Leg Measurements							
Speed	Impact Point	Note	Upper + Lower		Vehicle Damage in Part 581 Tests		Tibia Bending Moment (Nm)		MCL Elongation (mm)		ACL/PLI Elongation (mm)	
			US	EU			US	EU	US	EU	US	EU
2.5 mph	Front Bumper 12 Inches Right of Centerline (between L+1 and L+5 in Flex test*)	without Upper Plane	-307	-584	Minor	Hood dent:	340	257	27.6	18.6	12.9	9.8
1.5 mph	Front Bumper Left Corner (L-3 in Flex test)	without Upper Plane	-279	-285					25.5	14.6	10.1	5.8
2.5 mph	Front Bumper Centerline (L+1 in Flex test)	with Upper Plane	118	-4575					30.2	12.6	11.5	4.3
1.5 mph	Front Bumper Right Corner (L+5 in Flex test)	with Upper Plane	124	162					25.0	24.6	14.2	15.3

Centerline impact shows a much higher force in the EU version due to the pendulum upper plane making contact with the hood

*Flex leg measurements shown are average of L+1 and L+5



Assessment of US Fleet Using EuroNCAP Procedures

Test Description			Pendulum Forces (N)		Vehicle Damage in Part 581 Tests		Flex Leg Measurements						
Speed	Impact Point	Note	Upper + Lower		US	EU	Tibia Bending Moment (Nm)	MCL Elongation (mm)	ACL/PLC Elongation (mm)		EU		
			US	EU					US	EU			
2.5 mph	Front Bumper 12 Inches Right of Centerline (between L+1 and L+5 in Flex test*)	without Upper Plane	-307	-584	Minor scuffs on fascia; small crack in front grille; no headlight damage	Hood dent; large scuffs on fascia; large crack in grille; no headlight damage	372	186	30.2	12.6	11.5	4.3	9.8
1.5 mph	Front Bumper Left Corner (L-3 in Flex test)	without Upper Plane	-279	-285			308	327	25.0	24.6	14.2	15.3	5.8
2.5 mph	Front Bumper Centerline (L+1 in Flex test)	with Upper Plane	118	-4575									
1.5 mph	Front Bumper Right Corner (L+5 in Flex test)	with Upper Plane	124	162									

More significant damage in the EU version due to softer components for pedestrian safety

*Flex leg measurements shown are average of L+1 and L+5

Assessment of US Fleet Using EuroNCAP Procedures

Test Description			Pendulum Forces (N)	Vehicle Damage in Part 581 Tests		Flex Leg Measurements					
Speed	Impact Point	Note	Upper + Lower			Tibia Bending Moment (Nm)		MCL Elongation (mm)		ACL/PCL Elongation (mm)	
					US	EU	US	EU	US	EU	
2.5 mph	Front Bumper 12 Inches Right of Centerline (between L+1 and L+5 in Flex test*)	witho Upp Plan				340	257	27.6	18.6	12.9	9.8
1.5 mph	Front Bumper Left Corner (L-3 in Flex test)	witho Upp Plan				334	162	25.5	14.6	10.1	5.8
2.5 mph	Front Bumper Centerline (L+1 in Flex test)	with U Plan				372	186	30.2	12.6	11.5	4.3
1.5 mph	Front Bumper Right Corner (L+5 in Flex test)	with U Plane				308	327	25.0	24.6	14.2	15.3

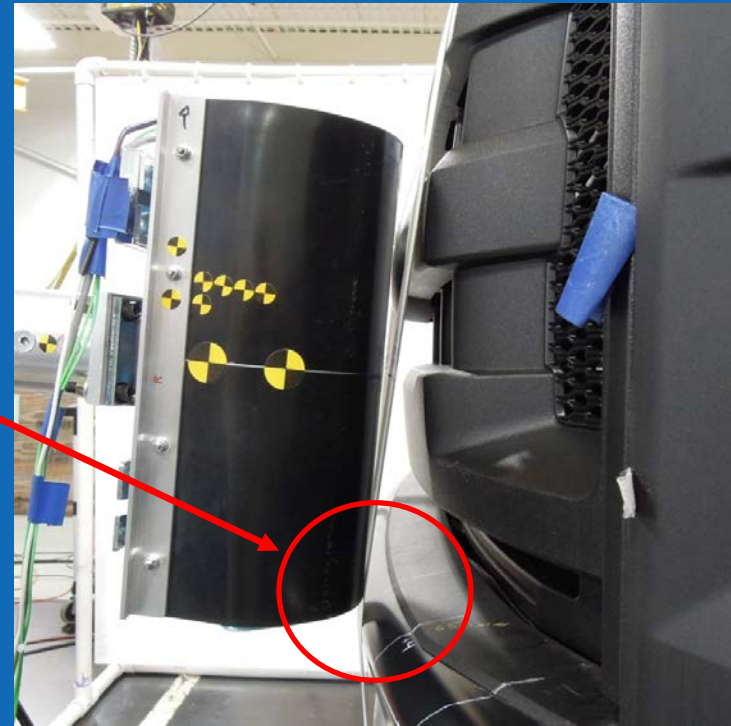
- 3 of 4 impact locations (inboard) showed much lower Flex measurements in the EU version
- The 4th (outboard) location showed similar results between EU and US versions

*Flex leg measurements shown are average of L+1 and L+5

Assessment of US Fleet Using EuroNCAP Procedures

Evaluation of EEVC/TRL Upper Legform

- Feasibility of testing US vehicles
 - Passenger vehicles - no issues
 - Pickups/SUVs - no issues for all but one
 - 2016 Ford F-150
 - Glancing impact between upper legform and top of bumper
 - Not a realistic impact scenario





Assessment of US Fleet Using EuroNCAP Procedures

Evaluation of EEVC/TRL Upper Legform

- Feasibility of testing US vehicles
- Repeatability / Reproducibility / Durability / Biofidelity



Assessment of US Fleet Using EuroNCAP Procedures

Evaluation of EEVC/TRL Upper Legform

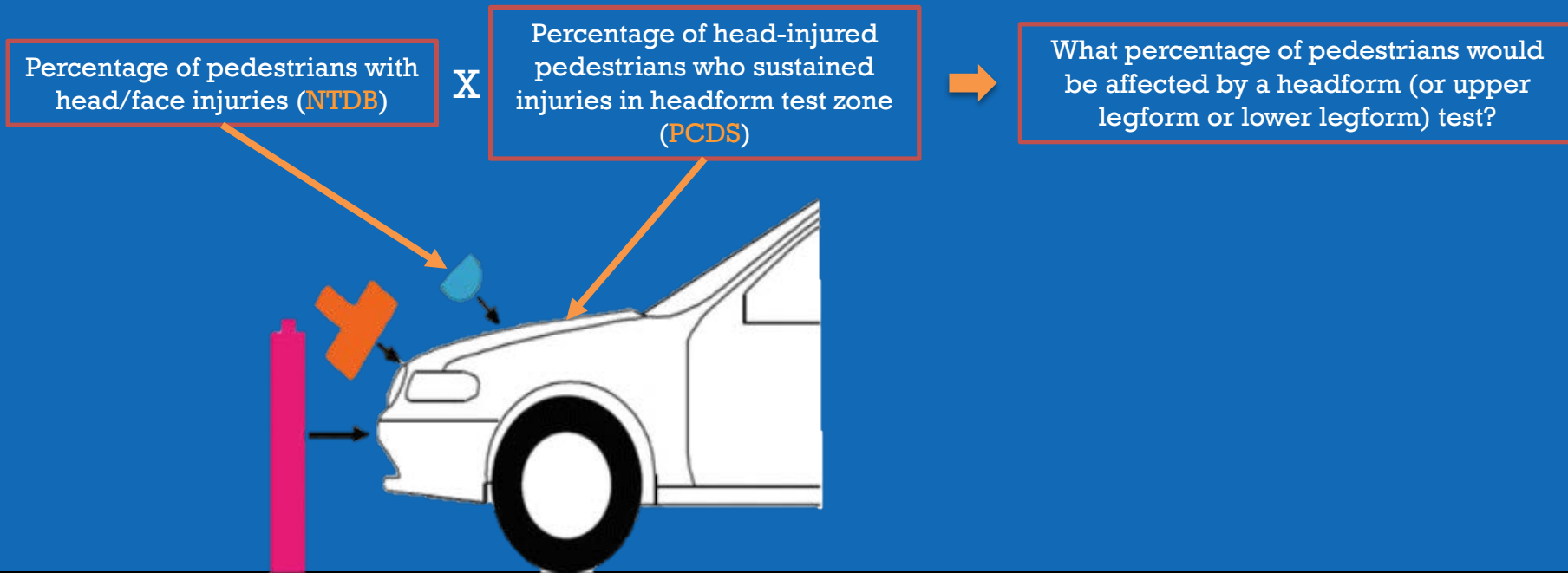
- Feasibility of testing US vehicles
- Repeatability / Reproducibility / Durability / Biofidelity
- Plan to evaluate the Advanced PLI (aPLI)



Isshiki et al.
2017

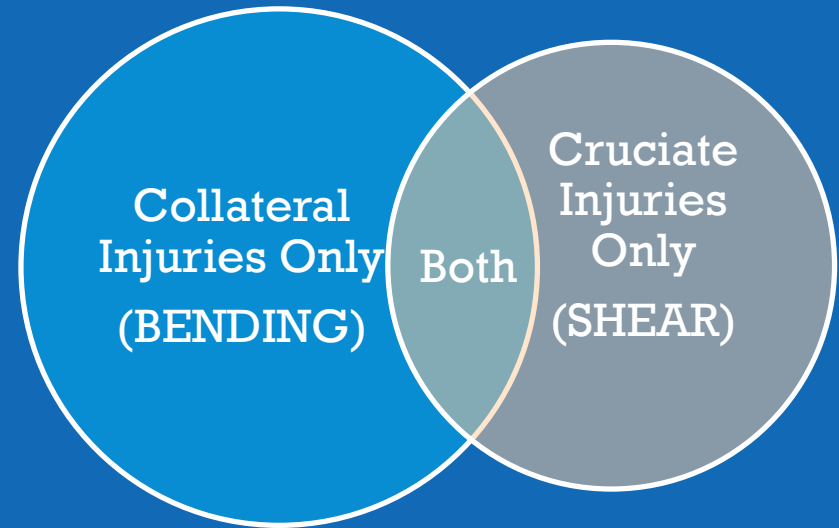
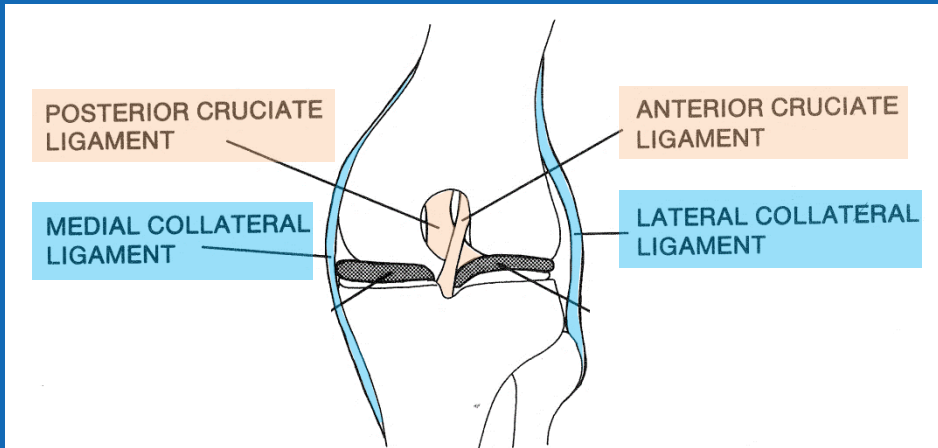
Pedestrian Crash Data Analysis

- Percentage of pedestrians affected by test procedures (NTDB & PCDS)



Pedestrian Crash Data Analysis

- Percentage of pedestrians affected by test procedure (NTDB & PCDS)
- Frequency of isolated cruciate injuries (NTDB)



What is the relative importance of measuring shear versus bending in a pedestrian legform?

Pedestrian Crash Data Analysis

- Percentage of pedestrians affected by test procedure (NTDB & PCDS)
- Frequency of isolated cruciate injuries (NTDB)
- Injury risk reduction with pedestrian protection (SDS)

18,000+ pedestrian cases from State Data System (SDS)



Is injury risk reduced with later-model vehicles that are more likely to contain pedestrian protection countermeasures?



Martin P & Pfeiffer M
SAE Government Industry Meeting 2017

Pedestrian Crash Data Analysis

- Percentage of pedestrians affected by test procedure (NTDB & PCDS)
- Frequency of isolated cruciate injuries (NTDB)
- Injury risk reduction with pedestrian protection (SDS)
- Thorax injury risk reduction with pedestrian protection (NTDB)

Distribution of injuries by body region in NTDB pedestrian cases (focus on thorax injury)



Is thorax injury risk reduced by head and upper leg/pelvis protection countermeasures?





Summary

- **Assessment of US fleet using EuroNCAP procedures**
 - Nine vehicles tested
 - Head: Scored well and similarly to EU vehicles
 - Lower Leg: 581 does not appear to be sole obstacle for good scores
 - Upper Leg: clear difference between passenger cars/small SUVs and trucks/large SUVs/minivans
 - Good VRTC-EuroNCAP lab consistency in head tests on global platform vehicles
 - Able to adapt EU-version active hood systems to US-version vehicles and test them
 - Part 581 tests on US & EU Focus
 - Pendulum forces: Both US & EU versions met the requirement
 - Damage: EU version had more damage than US version
 - Adjustments to EuroNCAP upper leg procedure may be necessary for pickup trucks
- **Pedestrian crash data analysis**
 - Ongoing studies investigating important elements of pedestrian protection



Thank You

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NHTSA

**OVERVIEW OF
NHTSA PEDESTRIAN
CRASHWORTHINESS
RESEARCH**

