

Results of NHTSA's Comparison of the Offset Deformable Barrier and the Progressive Deformable Barrier Test Procedures

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Paper Number 09-0549

ABSTRACT

Over the past several years, NHTSA has conducted testing to evaluate a high-speed fixed offset deformable barrier crash test. It was preliminarily determined that the benefits from such a crash test could lead to an annual reduction in approximately 1,300 to 8,000 MAIS 2+ lower extremity injuries. NHTSA also conducted vehicle-to-vehicle crash tests to investigate the potential for disbenefits from a fixed offset deformable barrier crash test. This testing demonstrated that, for some sport utility vehicles, structural changes that improved their performance in high-speed frontal offset crash tests may also result in adverse effects on the occupants of their collision partners.

The Directorate for Road Traffic and Safety (DSCR) of France developed and proposed a Progressive Deformable Barrier test procedure (PDB) to upgrade the current offset deformable barrier test procedure in the United Nations Economic Commission for Europe (UNECE) R.94 regulation. DSCR is proposing the PDB to potentially improve the barrier performance in testing of the current and future fleet. Therefore, NHTSA is investigating the use of the PDB in the offset test procedure by comparing the current offset deformable barrier test procedure specified in FMVSS No. 208 (ODB) to the PDB. This paper also investigates the performance of each barrier

to predict lower extremity injuries and the ability of the PDB to absorb more energy for heavy vehicles found in the United States (U.S.) fleet.

The PDB performed as designed for heavy vehicles and produced approximately the same occupant compartment intrusions. Both the ODB and PDB did not produce the same lower extremity injuries as seen in the real-world.

The general trend across each body region had a similar trend for each barrier. That is the magnitude of each IAV for each body region was approximately the same for each barrier, but one barrier is not always the maximum.

INTRODUCTION

In the U.S., driver and right front passenger air bags are required in all passenger cars and light trucks under FMVSS No. 208. However, NHTSA estimates that over 8,000 fatalities and 120,000 Abbreviated Injury Scale (AIS) 2+ injuries will continue to occur in frontal crashes even after all passenger cars and light trucks have frontal air bags (Docket number NHTSA-2003-15715). Therefore, NHTSA has focused on the development of performance tests not currently addressed by FMVSS No. 208, particularly a high severity frontal offset crash. These tests are intended to evaluate

occupant compartment intrusion that could compromise occupant survival space and thus increase the potential for lower leg injury. NHTSA is currently evaluating the potential for both the ODB and the PDB test procedures to predict lower leg injuries and to minimize the potential risk of increasing the aggressivity of heavier vehicles.

The EU Directive 96/79 for frontal crash protection went into effect in 1998. The Directive uses the R.94. The UNECE R.94 test procedure was developed to represent a vehicle-to-vehicle frontal offset crash and to generate occupant compartment intrusions similar to that seen in real world crashes of passenger cars. The deformable element of the R.94 barrier was designed to absorb energy and limit severe contact of the vehicle structure against the wall. The stiffness of the R.94 barrier represents the average stiffness of European passenger cars 15 years ago. The current R94 barrier has been shown to bottom out for European small cars, which is a possible concern for the larger-size U.S. fleet (Delannoy et al., 2005).

Many consumer rating programs have adopted the use of a fixed ODB crash test procedure to rate vehicle performance in a 64 kph frontal offset crash test (Euro NCAP (European New Car Assessment Program), Australian NCAP and Insurance Institute for Highway Safety (IIHS)). Some studies have suggested that using this test procedure to rate vehicles may increase their aggressivity, especially for heavier vehicles (Verma, et al., 2003 and Saunders, 2005).

The Directorate for Road Traffic and Safety (DSCR) of France developed and proposed a PDB to upgrade the current offset deformable barrier in the UNECE R.94 regulation to mitigate the potential for the offset test procedure to increase aggressivity

of larger vehicles. The PDB-XT progressively increases in stiffness as it is crushed, which contributes to its name. The barrier was designed to represent a vehicle structure with sufficient force level and energy absorption capacity to mitigate any occurrences of bottoming out. In doing so, the PDB may be able to better harmonize test severity among vehicles of different masses. The approach aims to encourage lighter vehicles to be stronger without increasing the force levels of large vehicles [Delannoy, 2005].

This paper investigates the performance of ODB and the PDB to predict lower extremity injuries and the ability of the PDB to absorb more energy for heavy vehicles.

TEST PROCEDURE

A “dummy-based” seating procedure was used for both the ODB and the PDB tests. This seating procedure uses a step-by-step process that mimics the procedure used by humans to position themselves in their vehicles. Basically the dummy is placed in the seat and the feet are in neutral position. The seat is moved forward until the right foot contacts the accelerator pedal. The left is placed symmetric to the right unless the left foot interacts with the pedal. If there is interaction with the pedal, the left foot is moved to avoid the pedal. A complete description of the “dummy-based” seating procedure can be found in Saunders et al., 2007.

All testing utilized the Hybrid III 50th percentile male dummy with Thor-Lx lower legs. Throughout the rest of the paper this dummy will be referred to as 50 HIII. The upper of the part 50 HIII was instrumented with three axis head and chest accelerometers, and a chest pot. The Thor-Lx was instrumented with upper and lower

tibia load cells and three ankle rotational potentiometers.

The ODB was conducted using the procedure defined in FMVSS No. 208 (S18) with two modifications. The test speed was increased to 56 kph, and the “dummy-based” seating procedure was used instead of the mid-track.

The PDB tests were conducted at 60 kph, overlap of 50 percent, and utilized the “dummy-based” seating procedure.

Figure 1 shows the properties and dimensions of the ODB barrier (Figure 1a) and PDB-XT barrier (Figure 1b). The PDB-XT is taller and thicker than the ODB barrier. The ODB barrier has two layers of honeycomb, both with constant stiffness. The PDB-XT has three layers: two layers with constant stiffness and a middle section that has four stiffness zones. The front two zones of this middle section get stiffer as the thickness increases and the back two sections have a constant stiffness. It should be noted that the PDB-XT height from the ground was 200 mm, for these tests, instead of 150 mm as specified in the PDB test procedure from UTAC.

TEST MATRIX

To compare the two test procedures paired vehicle tests were conducted. The vehicle selection tried to cover all classes of vehicles. Table 1 shows the final matrix.

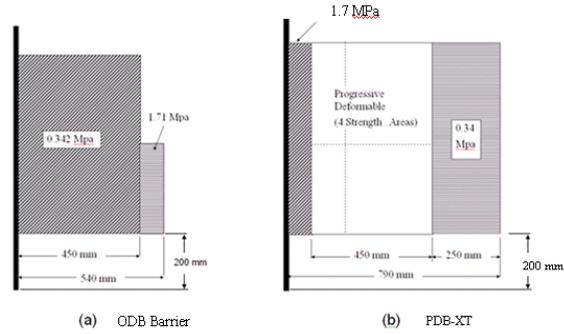


Figure 1. Properties and dimensions of the ODB barrier and PDB-XT barrier

Table 1. Vehicle test matrix for barrier comparison

Vehicle	Vehicle Class	Test Weight (kg)
2008 Chevrolet Aveo	Small passenger car	1,443
2008 Ford Escape	Small unibody SUV	1,781
2008 Saturn Outlook	Large unibody SUV	2,408
2007 Ford F-250	Heavy pickup	3,291

RESULTS

Occupant Compartment Intrusions

To evaluate intrusion the toepan points were measured pre- and post-test by using a 4 by 3 grid (Figure 2). Row 3 of the toepan grid is located at the intersection of the toepan and floorboard.

It can be seen from Figure 3 and Figure 4 that the PDB test procedure produced higher occupant compartment intrusions for the Aveo and Escape when compared with the ODB test procedure. The deformation pattern was similar for both test procedures. The Outlook had a small amount of intrusion for both procedures (Figure 5). For the F250 the ODB procedure pushed the toepan back in the x-direction, whereas, the PDB pushed the toepan up in the z-direction (Figure 6).

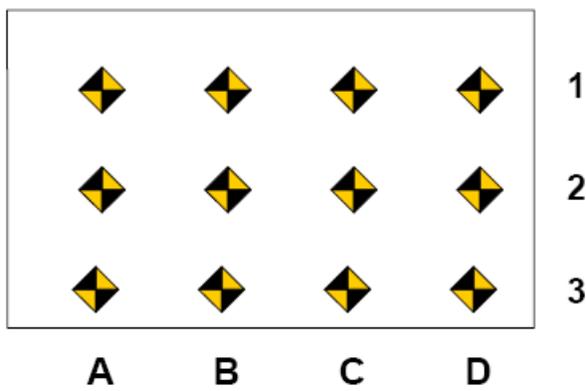


Figure 2. Toepan intrusion measurement points

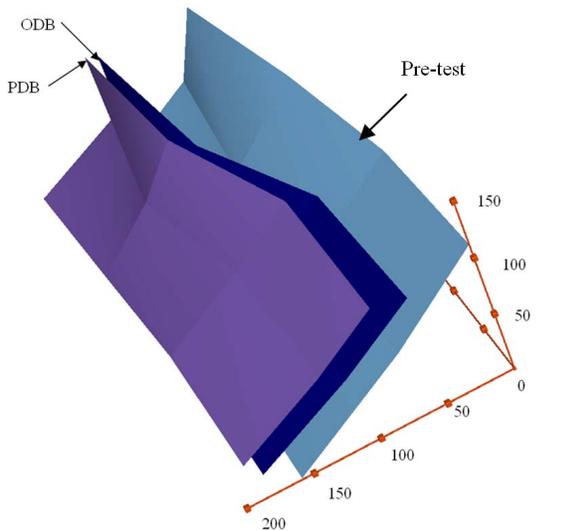


Figure 3. Aveo toepan intrusion mm

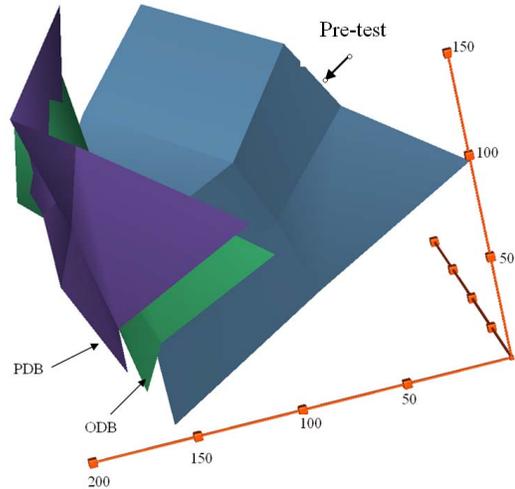


Figure 4. Escape toepan intrusion mm

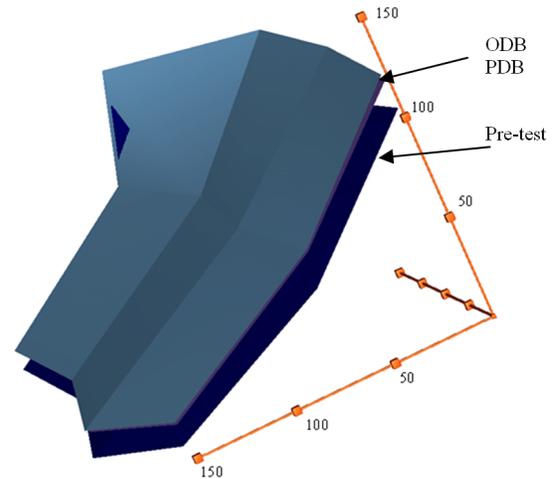


Figure 5. Outlook toepan intrusion (mm)

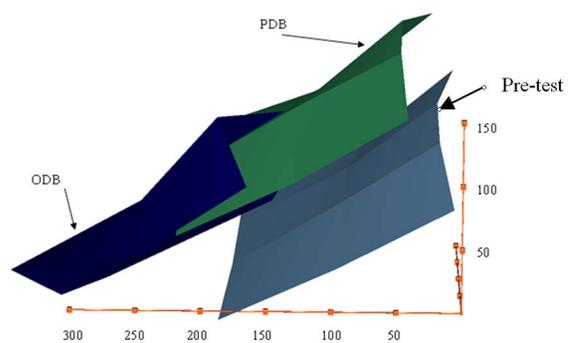


Figure 6. F250 toepan intrusion (mm)

Lower Extremity IAVs

This section compares the lower extremity (LE) Injury Assessment Values (IAVs) for the 50 HIII for each paired vehicle. The femur Injury Assessment Reference Values (IARV) for the 50 HIII are from the FMVSS No. 208 Advanced Air Bag Final Rule. The other IARVs were based upon Kuppa et al., (2001b). The IARVs used to assess LE injuries are presented in Table 2. The definitions for ankle rotations are as follows: Ankle Rot Y is the maximum positive y rotation and Ankle Rot X is the maximum of either the positive or negative x rotation. The highest value from the left or right legs IAV is presented in the following figures and tables.

The PDB procedure produced higher Injury Assessment Values (IAVs) for all body regions except for Ankle Rot Y for the Aveo (Figure 7). There is no comparable trend in the IAVs for both the Escape and Outlook (Figure 8 and Figure 9). The Outlook’s high Ankle Rotation X may be due to the geometry of the toepan. Using the “dummy based” seating procedure the left foot partially overlapped the footrest which may have contributed to the rotation. Finally, the trend for the F250 was that the ODB procedure produced higher IAVs for all regions except Upper Tibia Index (Figure 10).

The general trend across each body region had a similar trend for each barrier. That is the magnitude of each IAV for each body region was approximately the same for each barrier, but one barrier is not always the maximum.

The Aveo, Escape, and the Outlook had similar post-test toepan contours for both test procedures, but the trends in IAVs were not the same. The impact speed, overlap, and barrier were different for each paired

and may have affected the IAVs due to the vehicle interaction with the barrier during the test. The differences in the vehicle interaction with the barriers may have changed the rate of the toepan and therefore affecting the IAVs.

Table 2. Injury Assessment Reference Values for lower extremity injuries (Kuppa et al., 2001a, 2001b)

Injury Criteria	IARV for 50 HIII
Femur	10,000 N
Knee Shear	15 mm
Upper Tibia Force	5600 N
Lower Tibia Force	5200 N
Tibia Index	0.91
Ankle Rot Y	35 deg
Ankle Rot X	35 deg

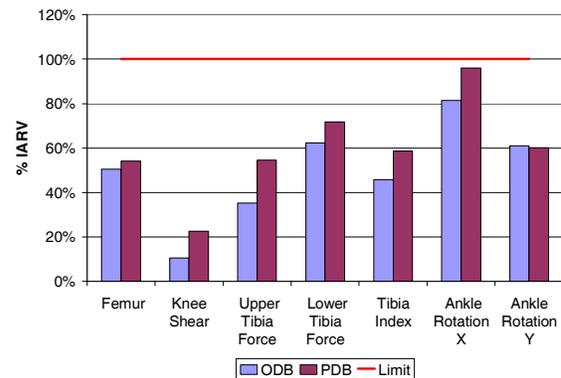


Figure 7. Lower extremity IAVs for the Chevrolet Aveo

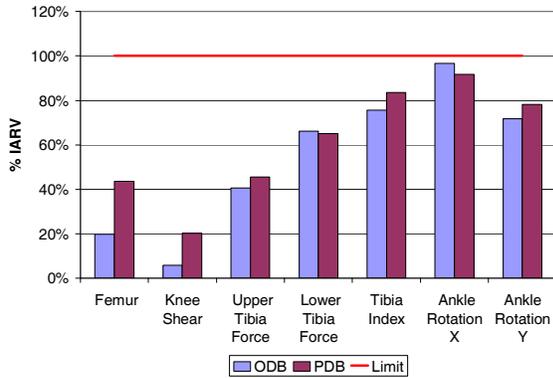


Figure 8. Lower extremity IAVs for the Ford Escape

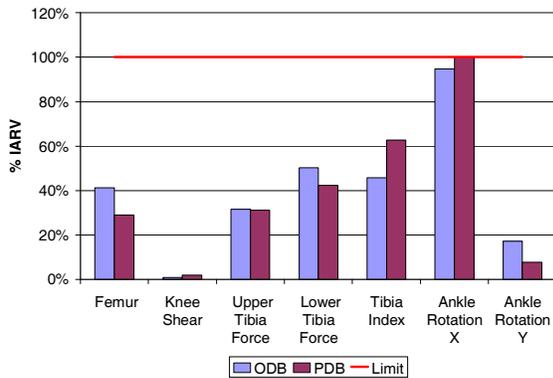


Figure 9. Lower extremity IAVs for the Saturn Outlook

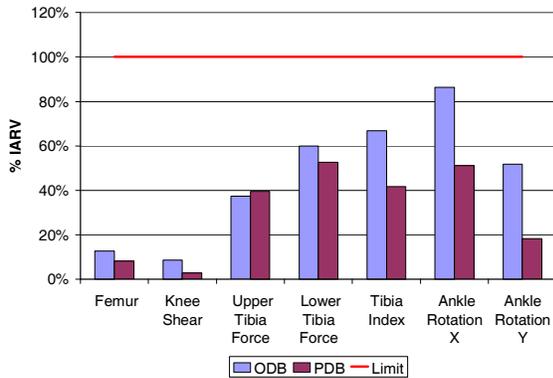


Figure 10. Lower extremity IAVs for the Ford F-250

Barrier Comparison

When comparing the crush of the ODB barrier and the PDB-XT, the ODB bottoms out even with a small car (Figure 11a), whereas the PDB-XT did not bottom out for the same small car (Figure 11b). Also, the ODB barrier bottomed out for the F250 (Figure 12a) and the PDB-XT stayed intact (Figure 12b). From Figure 13 it can be seen that the frame of the F250 punctured the PDB.



(a) ODB barrier



(b) PDB-XT barrier

Figure 11. Aveo barrier crush comparison



(a) ODB barrier



(b) PDB-XT barrier

Figure 12. Ford F-250 barrier crush comparison

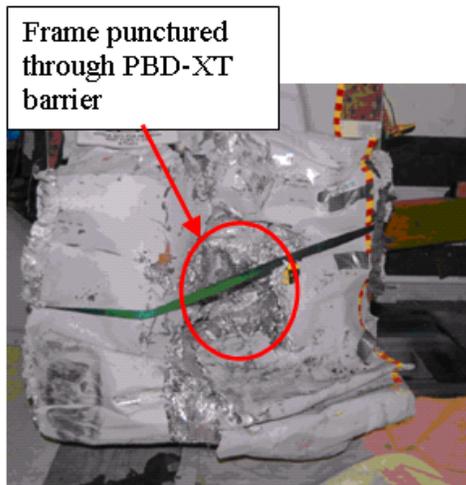


Figure 13. Front view of PDB-XT barrier for the F250

Crash Severity

Since both test procedures use a deformable element, the test speed is not a good indication of the test severity. A method for evaluating the test severity is with the Equivalent Energy Speed (EES). The EES is

the initial kinetic energy minus the energy absorbed by the barrier. Details of EES are explained in Pascal et al., 2005.

The EES for the paired vehicles were calculated and the results are shown in Figure 14. The lightest vehicle, Aveo, was the only vehicle tested with the PDB to have a higher EES than the paired vehicle tested with the ODB.

The Aveo tested with the PDB had a higher EES than the Aveo tested with the ODB implies that the Aveo had to absorb more of the crash energy. Which is opposite from the other vehicles tested. The PDB allows the heavier vehicles to absorb less energy when compared to the ODB, which may allow manufactures to soften the structures of heavier vehicles.

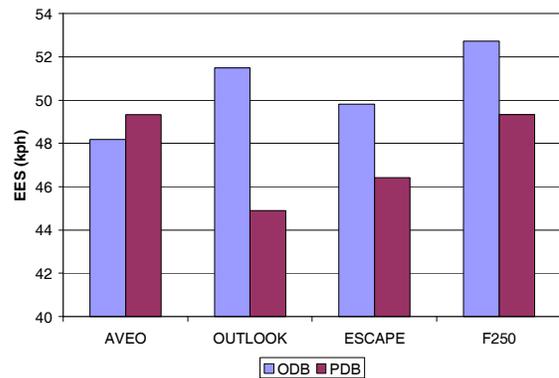


Figure 14. EES for the paired vehicles

DISCUSSION

Vehicle Severity

Pascal 2005 showed that the PDB is able to make the vehicle severity of the PDB procedure approximately equal for all vehicle weights. Figure 15 shows the EES for vehicles tested by NHTSA using the ODB and PDB. This plot includes all vehicles tested by NHTSA, not just the paired vehicles. It is seen from this figure

that the EES for the ODB test increases as the mass of the vehicle increases. For the PDB the EES is basically the same for all size vehicles when a linear fit is applied to the data.

The scatter in the data for the vehicles tested with the PDB is probably due to the vehicles being designed to the ODB test. The ODB barrier collapses during the test and it becomes like hitting a rigid wall. Therefore, these vehicles may not be fully optimized to a progressively deformable element.

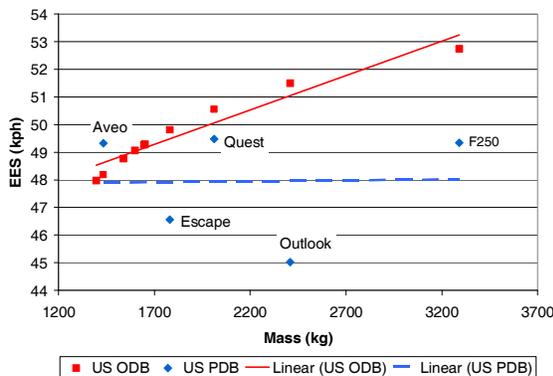


Figure 15. Theoretical EES for different test procedures and EES calculated for vehicles tested in US

Lower Extremity Injuries

Saunders, et al., 2004 showed that the ODB procedure reproduced real-world lower extremity injuries. But, the current ODB procedure and the PDB procedure did not show the same trend in lower extremity injuries as reported by Saunders (Table 3).

Some possible reasons for the difference between the tests conducted by Saunders, et al., 2004 and the current tests: 1) lower extremity injuries in the current fleet are different from the older fleet due to being designed to achieve a higher rating from the IIHS and 2) the use of a different seating procedure.

To determine if the trend of lower extremity injuries are different for current vehicles compared to older vehicles the NASS/CDS analysis performed by Saunders, et al., 2004 was reproduced. This analysis used NASS/CDS years 1995 through 2007 files for left offset crashes with DV over 48 kph. The model year cutoff was chosen at 2000 because most vehicles received a “good” or “acceptable” rating from IIHS after 2000. Figure 16 shows that the risk for LE injuries has increased for the newer vehicles for most of the LE body region injuries.

The dummy based seating procedure may have affected the results because it requires the ankles to be in neutral position, which prevents the ankle from being pre-loaded before the test (Saunders, et al., 2007). Also, the new seating procedure normally placed the seat behind mid-track and the left foot was not placed on the footrest. This seating procedure normally placed the feet away from the toepan and allowed the feet to slide forward before impacting the toepan (Figure 17).

The impact speed, overlap, and barrier were different for each paired may have affected the IAVs due to the vehicle interaction with the barrier during the test. The differences in the vehicle interaction with the barriers may have caused a different rate of the toepan and acceleration applied to the dummy.

CONCLUSIONS

The PDB performed as designed for heavy vehicles. It did not bottom out when impacted with a heavy vehicle (F250) and allowed the barrier to absorb more energy as demonstrated by the decrease in EES for heavier vehicles. It also produced approximately the same occupant compartment intrusion as the ODB procedure.

Both test procedures did not produce the same LE injury trend as previously reported (Saunders, et al.). The main reason for this could be due to the seating procedure used in the current testing. The “dummy based” seating procedure did not preload the ankle and normally placed the seat with the 50 HIII behind mid-track.

The general trend across each body region had a similar trend for each barrier. That is the magnitude of each IAV for each body region was approximately the same for each barrier, but one barrier is not always the maximum.

Table 3. Percent of vehicles tested that exceeded the IARV.

IAV	ODB mid-track	ODB “Dummy Based”	PDB “Dummy Based”
# Test	10	9	4
MY Range	96-03	06-07	07-08
Knee Shear	0%	20%	0%
Femur	0%	0%	0%
Tibia Index	40%	10%	0%
Upper Tibia Force	10%	0%	0%
Lower Tibia Force	30%	0%	0%
Ankle X Rot	20%	40%	0%
Ankle Y Rot	50%	0%	17%

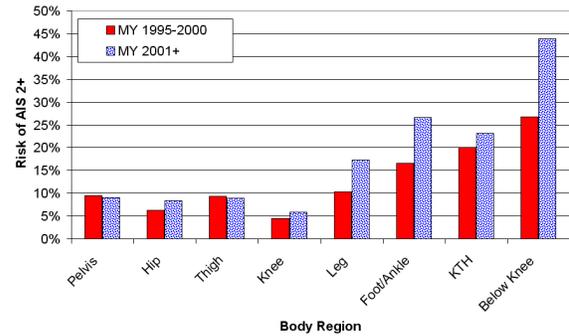


Figure 16. Risk of lower extremity injuries in offset crashes with DV greater than 48 kph

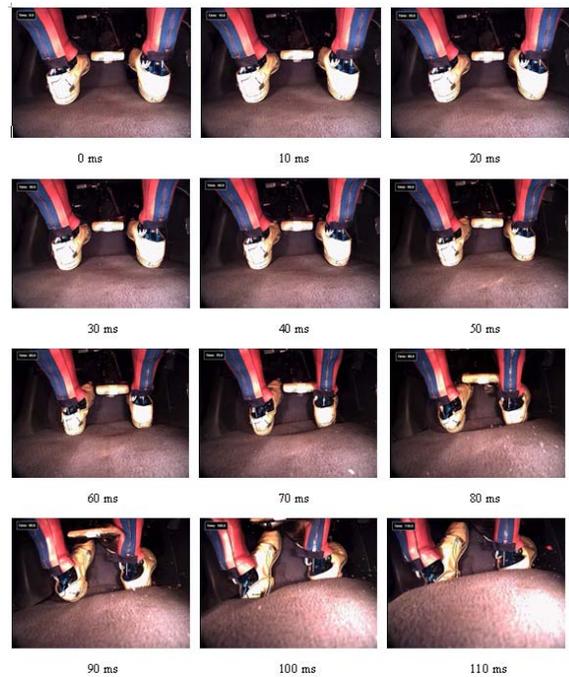


Figure 17. Feet kinematics for the Nissan Quest into the PDB

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