A comparison of vehicle damage and longitudinal throwing distances when using biofidelic dummies, as opposed to conventional dummies

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Besides the vehicle damages, the longitudinal throwing distance is also a decisive indicator in pedestrian collisions in order to determine the collision velocity of the vehicle. Previous research has shown [1] that the construction of the biofidelic dummy leads to much more realistic vehicle damage in car-pedestrian collisions in comparison to those with conventional dummies. As to whether this also results in changes to the longitudinal throwing distance has so far only been tested with the first generation of biofidelic dummies[2]. In order to obtain a direct comparison of the damage differences and the longitudinal throwing distance, crash tests were carried out with the biofidelic dummy from crashtest-service.com GmbH using the same vehicle model with a velocity range from 28 kph to 80 kph and compared with existing crash tests with conventional dummies.

1 Introduction

A difficulty with the determination of collision velocity based on vehicle damage and the comparison of corresponding crash tests is that the vehicles compared may have a different construction. A longer bonnet, a lowered chassis or braking all lead to varying wrap-around lengths of the pedestrian[3], and are among other factors to be considered for the height of the head impact.

Similar problems arise when determining the collision velocity based on the longitudinal throw distance of the pedestrian. Furthermore, a none-braking or partially braked car, especially at lower collision speeds, can carry the dummy after the collision. This is followed by a long transport phase in which the dummy is first released from the vehicle when the car is rapidly decelerated. The subsequent occurring longitudinal throw distances in the crash tests can thereby be extended almost arbitrarily and is therefore no longer suitable for identifying the collision speed.

2 Crash series VW Polo 6R and Biofidelic dummies

A series of crash tests at different velocities was carried out, creating a form of EES-catalogue. The crash vehicles were several VW Polo 6Rs. The biofidelic dummies were laterally approached in most tests and impacted at the centre of the bonnet by the car, Figure 1. The VW Polo was not braked during the collision and was decelerated after a defined short period of time, which was almost the same in all crash tests, to prevent "carrying" with a subsequent transport phase. The controlling, that it did not come to a carrying phase, was done over the videos. The collision speeds in the crash tests were (rounded off) 28 kph, 47 kph, 68 kph and 80 kph. In all tests, the damage and the dummy throw distance was documented in detail. The new crash series with the biofidelic dummies built on the already existing crash test series carried out by crashtest-service.com GmbH, in which a VW Polo 6R was driven under the previously described impact configuration in six tests against a conventional dummy [4].

In the velocity range between 70 kph and 80 kph, the already existing crash tests were carried out again under the same conditions but with the biofidelic dummy, Figure 2. Thus, the study not only offers the possibility to investigate the increase in vehicle damage and longitudinal throw distance with increasing collision speed, but also to make a direct comparison between the biofidelic and conventional dummy.

3 Formation of vehicle damage

Table 1 shows an overview of the crash tests carried out. In order to later be able to carry out a complete comparison of damages, even in lower velocity ranges, an additional test with a conventional dummy at a velocity of approximately 30 kph has been recorded (see feature "Opel Astra G"). The dummies are all between 1.79 m and 1.83 m in height and weigh between 74 and 90 kg.

3.1 VW Polo 6R against Biofidelic dummy

Figure 3 documents the resulting damage incurred at increasing collision velocities in the range between 28 and 80 kph in a collision with a biofidelic dummy.

Both tests in the lower velocity range were carried out for financial reasons with the same vehicle, which is why the dummy was impacted in the first attempt at 27.5 kph left of the centre in thedirection of travel, and the second attempt with 46.7 kph to the right of the centre. In the crashattempts in the higher speed range, the biofidelic dummy was impacted in the centre of the vehicles front.

The collapsing of the front windshield at a collision speed of 46.7 kph results from the damage occurring in the first crash attempt at 27.5 kph, which was not replaced after the crash test.

Taking into account the damages of the front windshield in the two following crash attempts, it can be assumed that also at a collision speed of approximately 50 kph, the front windscreen would not have been penetrated. As the collision velocity increases, the damage to the bonnet and the windscreen also increase. By increasing the collision velocity, the head impact of the dummy also moves towards the edge of the roof. This is shown in the comparison of the motion sequences of each individual crash attempt in Figure 4. At a collision speed of approximately 70 kph, for the first time the head of the biofidelic dummy contacts the front roof edge. A significant damage to the roof occurs at a collision velocity of approximately 80 kph. At this collision speed, the bonnet of the vehicle is clearly crumpled.

3.2 Damage comparison after impact with biofidelic and conventional dummy

In Figure 5 and Figure 6 the damage to the crash vehicles at comparable collision velocities in the front and side view after an impact with a biofidelic (left) and a conventional dummy (right) are directly compared. It should be noted that the crash attempt with the biofidelic dummy at a collision velocity of around 50 kph was approximately 13 kph slower (46.7 kph biofidelic dummy, 59.4 kph conventional dummy).

From the damage comparison between the biofidelic and conventional dummy impact in the lower speed range, it is apparent that the impact of the biofidelic dummy produces a defined crack in the windscreen, with a deeper pushed-in centre but a smaller extension. The scratch marks and the slight deformation of the bonnet of the Opel (conventional dummy) does not occur to the VWPolo (biofidelic dummy). This can be explained by the wrap-around behaviour of the biofidelic dummy in contrast to the rigid physique of the conventional dummy, as earlier studies have alsodemonstrated [5].

In the transition range from medium to high collision velocities of 65 – 70 kph, the hard construction of the conventional dummy, in contrast to the biofidelic dummy, results in massive damages to the roof area when the conventional dummy contacts the rood edge area. The damage profile varies greatly. The susceptibility of the conventional dummy in the transition range from mid to high collision velocities will be discussed separately. If the collision speed is high, at approximately 80 kph, at first sight the vehicle damage from the impact of a biofidelic or conventional dummy appear similar. Merely the crumpled raised up positioning of the bonnet is lower when impacted by a conventional dummy.

Upon closer examination of the black VW Polo (impact against a conventional dummy) it presents more frontal damage. Due to the rebounding of the bumper covering after the collision, the high deformation of the cross-member is only apparent after disassembling the bumper cover. Figure 7 shows an example of the frontal damage to the crash vehicle with a disassembled bumper cover from a collision at approximately 70 kph. It can be seen, that the cross-member of the VW during the impact against a conventional dummy (Figure 7, right image, yellow framed) was more severely dented than in acollision against a biofidelic dummy (Figure 7, left image, yellow framed). From the deformation of the front cross-member of the VW Polo in an impact with a conventional dummy, even the stride position of the dummy at the point of the collision can be detected, see left and middle image in Figure 8. This results from the structurally rigid construction of the conventional dummy, which at this point hits the leg area. Since the feet are not pulled under in a collision with a conventional dummy, the front pedestrian under-run protection in the form of a bracket sitting just above the underbody remains completely intact (red arrows), whereas this bracket in a collision with a biofidelic dummy is severely pressed inwards, and therefore fulfilling its function (see also right image in Figure 8).

The crumpling of the bonnet of the VW Polo at a collision speed of 80 kph is a result of the wrap-around movement of the biofidelic dummy (comparison of motion sequences in Figure 4). Due to the rigid construction of the conventional dummy, the dummy rotates around its centre of gravity and collides then almost horizontally with the front windscreen. The bonnet remains mostly contact free so that less damage occurs to the bonnet (Figure 5 and Figure 6, bottom right images) incomparison to the impact with a biofidelic dummy colliding at the same velcoity.

3.3 Susceptibility of conventional dummies in the transition range from mid to high collisionvelocities

How susceptible the damage input on a vehicle in passenger car-pedestrian collisions with conventional dummies is, is shown in the compilation of damage pictures of the crash vehicles accordingly in Figure 9.

The impact configuration (laterally approached, centre of the bonnet) and the collision velocity (66 to

68 kph) were almost identical in all the crash test attempts shown. Only the weight and the height of the conventional dummies varied slightly. It emerges that the influence of the weight between 74 and 90 kg has no clearly visible changes in the vehicle damages occurred to the presented crash vehicles. A change in height from 1.79 m to 1.83 m, however, leads to a completelydifferent damage pattern, as in this crash test the roof edge of the vehicle was hit and massively compressed.

The energy absorption of the vehicle must be similar in all four crash test attempts. Three of the four attempts show very similar damages to the bonnet and the windshield. The energy was mainly absorbed by the windscreen, bonnet and the front cross-member. The windscreen has even been partially pierced by the conventional dummy. The slightly larger dummy in the fourth crash test (Figure 9 bottom right image) results in a higher contact point of the dummies head on the vehicle.

The dummy strikes almost horizontally against the roof edge, Figure 10 bottom images, so that the energy absorption mainly takes place through the compression of the roof. Simultaneously, in this position the conventional dummy has an unnaturally rigid structure. In the collision with the biofidelic dummy (Figure 10 top images), the described wrap around behaviour occurs, so that the energy absorption by the vehicle can evenly be distributed over the contact surfaces between the vehicle and the dummy.

4 Longitudinal throw distance

By Hartwiget. al. [2] investigations have been carried out on longitudinal throw distances in crash tests with biofidelic dummies. However, it refers to the first generation of the biofidelic dummy. It is possible that the modifications to the outer structure (silicon, neoprene etc.) lead to a different rebound behaviour and thus to a change in the throw distance.

The longitudinal throw distances determined from the investigated crash test attempts are listed in Table 2 and have been recorded in a graph, see Figure 11. In the case of specifics present in the crash tests, this has been noted in Table 2. Likewise, the throw distances from the investigations of Hartwiget. al. [2] were also added to the graph.

Although the collisions with the biofidelic and conventional dummies at the same velocity level show partially major differences in the damages, there is no deviating trend determined in the longitudinal throw distance of the biofidelic dummy compared to the conventional dummy. This is also shown by the added trend line of Focken [6]. The longitudinal throw distances of the biofidelic dummy all lay in the range of the throwing parabola determined by Focken. The throw distance of the biofidelic dummy therefore corresponds to that of the throw distance of the conventional dummy. The modified structure of the dummy therefore has no significant influence on the throw distance.

5 Conclusion

The comparison with the impact tests of conventional dummies has shown that the conventional dummy, especially in the transition range between mid to high collision velocities from 65 kph to 70 kph, has weaknesses due to its hard construction which can lead to significantly different vehicle damage caused because of the lack of the wrap-around behaviour during the course of a collision.

Through the crash series with the VW Polo 6R and the biofidelic dummy, it was possible to identify that the head impact of the dummy moves nearer towards the roof edge with increasing collision velocities, and at approx. 80 kph there is significant damage to the roof. The more realistic wrapping around of the biofidelic dummy during the collision results in extensive damage, while the conventional dummy causes punctual damage. With the biofidelic dummy, due to itsflexibility, it is also possible to demonstrate the functionality of the pedestrian underrun protection system designed by the automotive industry, which should reduce the possibility of the legs going under the vehicle.

When comparing the longitudinal throw distances of biofidelic and conventional dummies, no significant differences occurred, in contrast to the damage of the vehicle. The change in structure of the dummy has no significant influence on the throw distance.

6 Future work

In this article, vehicle damage and the throwing distance of the dummies were analysed. In the crash tests the biofidelic dummies, in contrast to the conventional dummies, were "injured" - resulting in fractures and joint injuries, see figure 12. A subsequent "autopsy" of the dummy can then also allow a statement to be made on the expected pedestrian injuries depending on the collision speed. This connection was also analysed by Appel et. al. [7] for accidents involving pedestrians, and can be used as a further verification of the collision velocity. At velocities of 90 kph, limb separation is to be expected.

As part of an expert seminar at crash test-service.com GmbH in September 2018, a high speed crashtest for a passenger car-pedestrian collision with a biofidelic dummy at over 100 kph was planned and carried out.

In a subsequent publication, not only can a connection between vehicle damages and the pedestrian injuries be made, but it is also possible to analyse whether the expected tears *(sic)* also occur with the biofidelic dummy.

We thank the company crashtest-service.com GmbH for the great co-operation and the extensive documentation of the crash test attempts.

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NOTE : All figures and tables referred to in this paper are shown at pages 8 -15

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Figure 1. : Crash test vehicle VW Polo 6R (left) and impact configuration with a biofidelic dummy (right) for the crash series performed

Figure 2. : Re-enactment (left – biofidelic) of the already available crash tests (right – conventional). Collision velocitiy here: v = 68 kph

Crash series	Collision velocity [kph]	Biofidelic	Nami	Weight [kg]	Height [m]	Features
new	27.5	yes		89	1.83	Collision centre of left half
new	46.7	yes		89	1.83	Collision centre of right half (vehicle pre-damaged)
new	68.2	yes		89	1.83	Vehicle only slightly decelerated, wet road surface
new	80.2	yes		90	1.83	
existing	59.4		yes	90	1.83	
existing	66.7		yes	90	1.83	Wet road surface
existing	67.8		yes	90	1.79	Lower crossmember missing
existing	66.1		yes	74	1.79	
existing	76.8		yes	74	1.79	
existing	66.7		yes	74	1.79	
existing	34		yes	74	1.79	Opel Astra G

Table 1 : Overview of the crash tests performed

Continued ....

Figure 3 : Frontal and side view of the change in the damage pattern (impact with biofidelic dummy) on the VW Polo 6R with increasing collision velocity from 27.5 to 80.2 kph

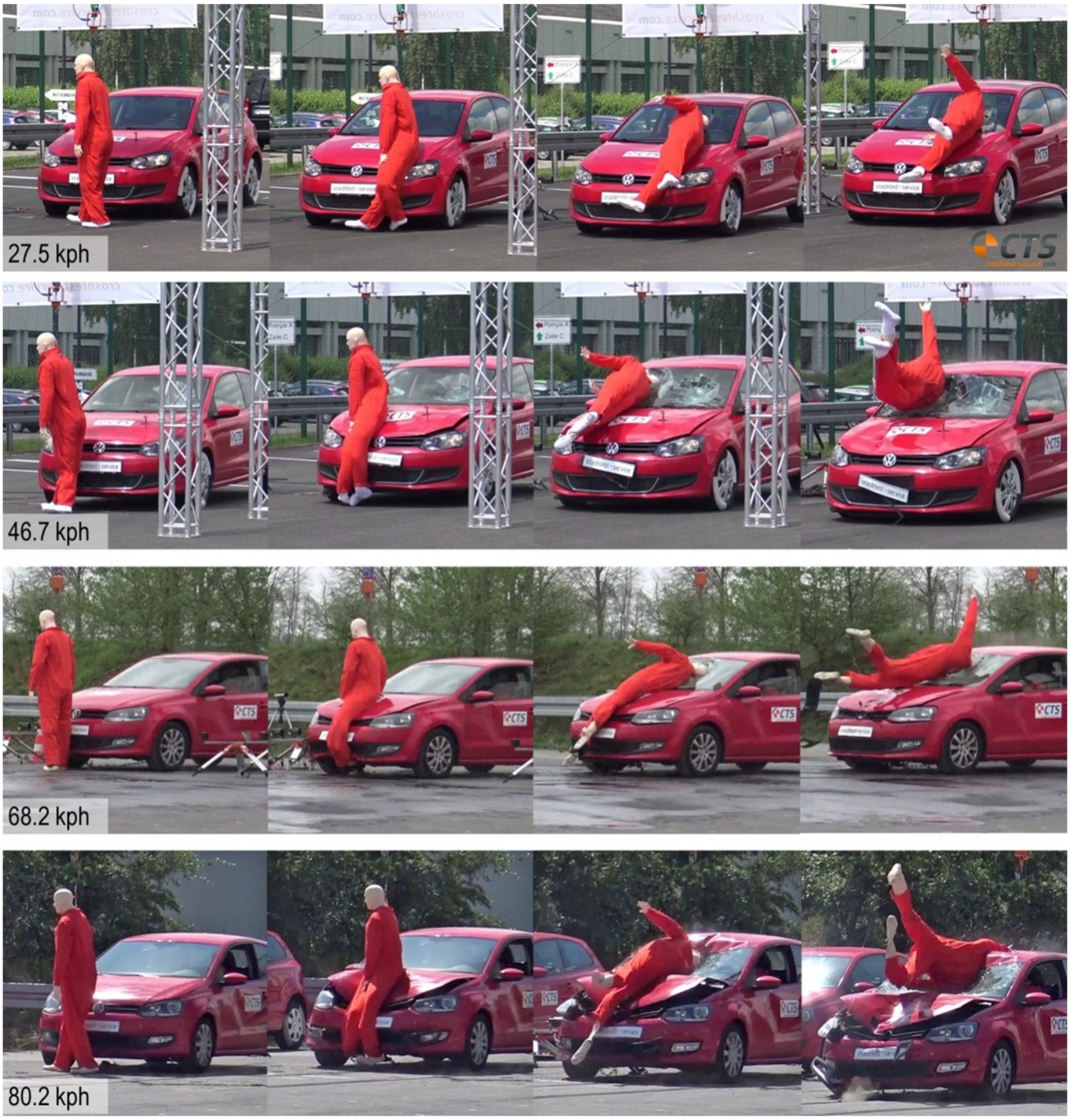

Figure 4 : Motion sequence of the biofidelic dummy and head impact height with increasing collision velocity

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Figure 5 : Comparison of the damage to the VW Polo 6R after an impact with the biofidelic dummy (left) and a conventional dummy (right) with increasing collision velocity (frontal view)

Figure 6 : Comparison of the damage to the VW Polo 6R after an impact with the biofidelic dummy (left) and a conventional dummy (right) with increasing collision velocity (side view)

Figure 7 : Comparison of the frontal damage to the crash vehicle (bumper removed) after a collision with the biofidelic dummy (left) and a conventional dummy (right) at v = 70 kph

Figure 8 : Step position for the impact with the conventional dummy (left) and the resulting cross-member deformation (centre) at v = 70 kph; comparison of the frontal damage after an impact with the biofidelic dummy(right)

Figure 9 : Comparison of the damage to the VW Polo 6R after an impact with a conventional dummy in the velocity range from 66 to 68 kph

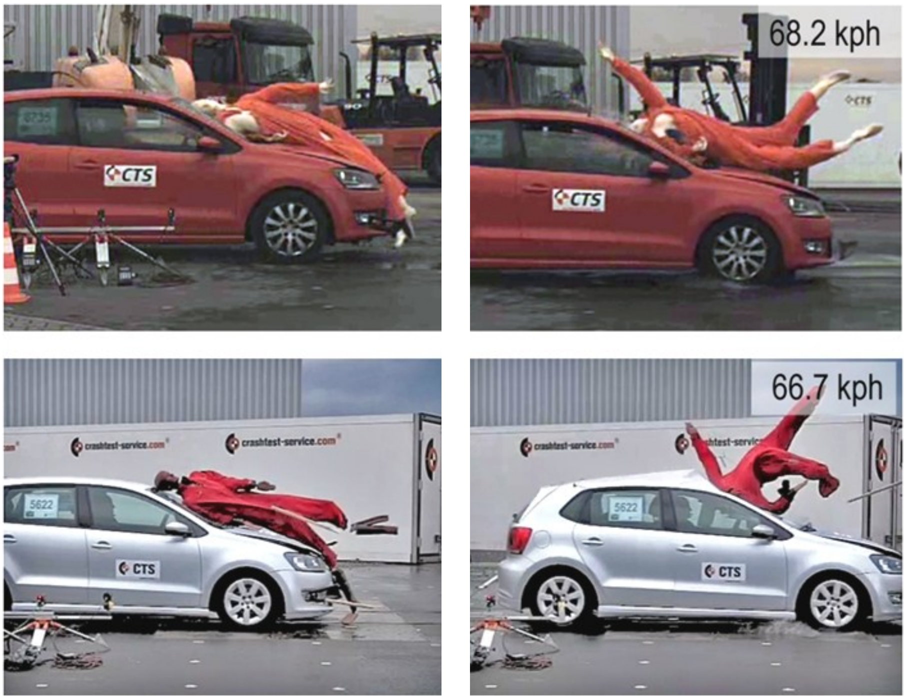

Figure 10 : Deformation of the roof edge after an impact with the biofidelic dummy (top), and a conventional dummy (bottom) at approx. 70 kph

Crash series	Collision velocity [kph]	Biofidelic	Nami	Throw distance [m] longitudinal	Throw distance [m] lateral	Features
new	27.5	yes		9.4	0.6	Collision centre of left half
new	46.7	yes		13.9	1.3	Collision centre of right half (vehicle pre-damaged)
new	68.2	yes		-	-	Vehicle only slightly decelerated, wet road surface
new	77.1	yes		39.4	1.9	Peugeot
new	80.2	yes		35.5	2.3	
existing	59.4		yes	29	0.1	
existing	66.7		yes	42.1	0.5	Wet road surface
existing	67.8		yes	30.9	2.1	Lower crossmember missing
existing	66.1		yes	30.2	1.6	
existing	76.8		yes	31.2	3.3	
existing	66.7		yes	30.3	1.2	
existing	34		yes	18.5		Opel Astra G

Table 2 : Longitudinal throw distances as a function of the collision velocity and dummy design

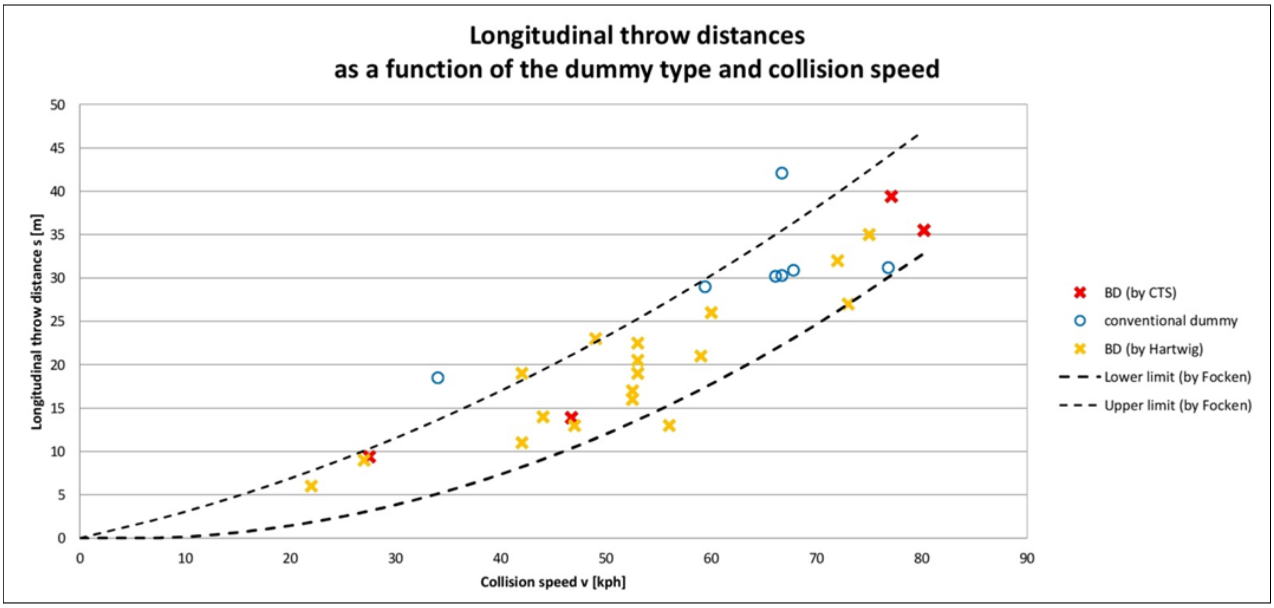

Figure 11 : Graph with throw distances of the different dummy types as a function of the collision velocity – trend line according to Focken [6]

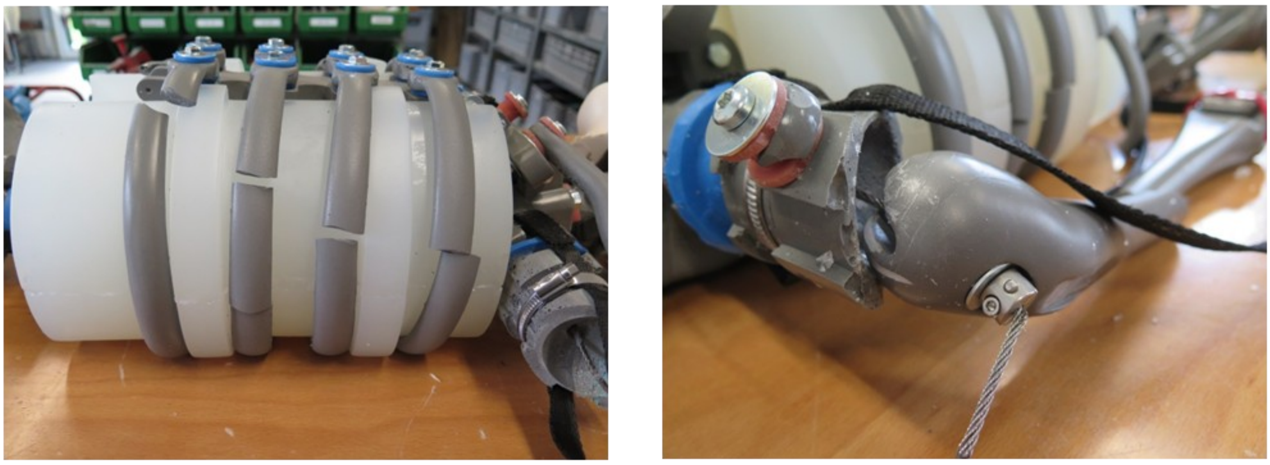

Figure 12 : Biofidelic dummy with serial rib fracture and shoulder joint injuries at a collision velocity of approx. 70kph