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CRASH BEHAVIOUR IN A CRASH COMPARISON

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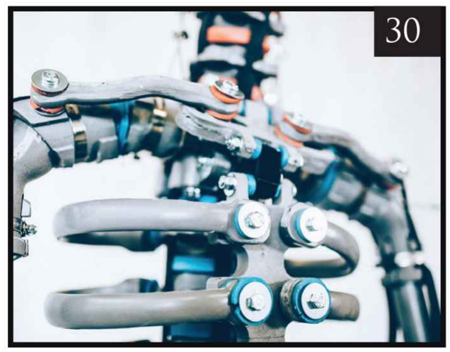
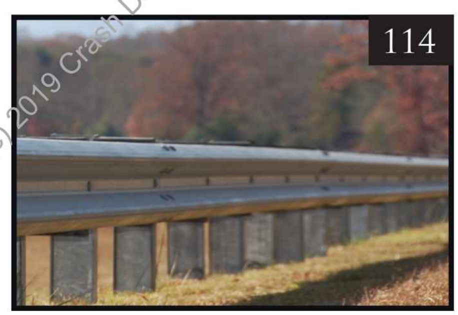




case problem

CRASH BEHAVIOUR IN A CRASH COMPARISON:

THE NEW BIOFIDELIC DUMMY IN DIFFERENT SCENARIOS OF ACCIDENTS INVOLVING PASSENGER CARS AND PEDESTRIANS

Annika Kortmann

In the reconstruction of passenger car-pedestrian accidents, the vehicle damages and the pedestrians injuries are important indications, which can now be realistically reproduced by means of the new biofidelic dummy. A series of selected crash tests clarifies the differences between the dummies including during the lateral impact with a normal passenger car front and an SUV. Also included in this article are collisions with the head-on impact of a dummy which is facing in the direction of the car, a grazing contact with the windows and the A-pillar.

Introduction

Pedestrian accidents require a detailed reconstruction of the accident happenings due to the severe injury consequences often caused to the unprotected road traffic user. For this reason, in modern accident reconstruction crash tests in which dummies are used are increasingly resorted to. In particularly important for limiting the collision velocity of the passenger car are, inter alia, the vehicle damages caused.

The dummies previously used for such crash tests usually have a "bone structure", which mainly consists of aluminium and steel, so that the extremely hard construction of the dummy causes much greater damages to the vehicle than in real pedestrian accidents at the same collision speed. The same damage characteristics caused by a conventional dummy suggests a lower collision speed as that in a real accident.

The biofidelic dummy as a real replacement

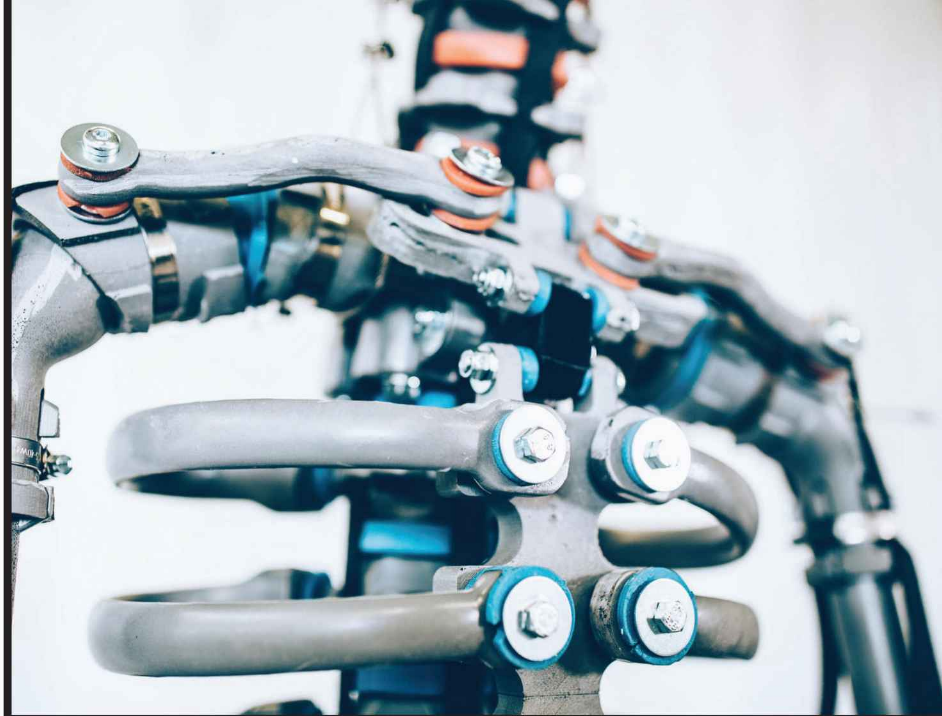
Since the beginning of 2017, the company crashtest-service.com GmbH (CTS) has, in cooperation with the HTW Dresden and the TU Berlin, taken over the construction and development of the so-called biofidelic dummy from Dr. Michael Weyde and have since July 2017 their own manufacturing laboratory. Due to the special construction, the biofidelic dummy has a very good comparability with the real human body. The used materials are selected according to their physical properties in order to reproduce the human "body parts" as precisely as possible. The "bones" of the dummy are, for example, made of epoxy resin and an admixture of aluminium powder in order to be able to reproduce the breaking resistance of human bones as realistically as possible. Also ligaments and tendons in the form of polypropylene straps form part of the biofidelic dummy. The reproduction of the soft tissues is accomplished by silicone and acrylic. Since every dummy is assembled by hand, step for step (see Figure 1 sidebar), it is also possible to deviate from the standard construction of the dummy with a height of 1,75 m and a weight of 79 kg to make custom-made models in terms of height and weight. The production time of a standard biofidelic dummy is approximately 2 weeks, custom-made products can be achieved in around 4 weeks. An example illustrating each stage of the production process is shown in Figure 2. Due to the in house production by CTS, the dummy can be equipped with measuring technology during the finishing procedure, so that collision induced accelerations and forces occurring in the area of the cervical spine can be measured. By installing special sensors, the pressure can be measured which impacts, inter alia, areas such as the chest or individual segments of the spine during the collision.

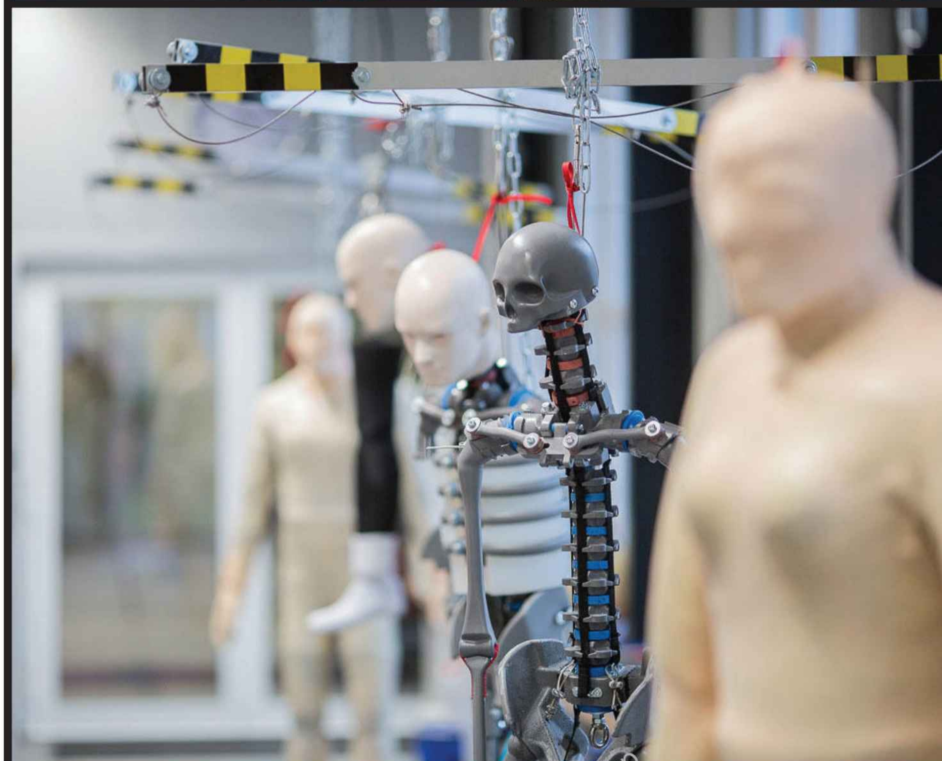
Crash behaviour in crash comparison

In order to make the differences in the crash behaviour of the conventional dummy in steel-construction compared with the biofidelic dummy visible, crash tests were carried out under different impact mechanisms of the vehicle against the dummy and then subsequently visually compared. Examined was, amongst others, a completely overlapped lateral impact of a pedestrian with a normal vehicle front (test vehicle: VW Golf III) and an SUV front facia (test vehicle: VW Touareg). For the comparability, the same test vehicle was used after relevant repairs under the same impact configuration impacting a biofidelic and a conventional dummy (in this case a so-called NAMI-dummy [1]).

Lateral impact of a normal passenger car front

The Federal Statistical Office prepared a statistic of collisions between vehicles and pedestrians from the year 2013 [2]. From a total of 28,805 accidents, 95 % of those accidents happened in urban areas and only 5 % in suburban areas. For this reason, for the first crash test comparison between a biofidelic and NAMI-dummy, a scenario was chosen in which a VW Golf III collided head on with an urban-usual speed of 50 km/h simultaneously with the two dummies. Figure 3 shows the impact configuration with a conventional (NAMI-) dummy in vehicle plan view on the left side. The biofidelic dummy is on the right side. The differences in the movement sequences of the dummies during the collision, in particularly in the carrying-phase, were filmed separately and are shown in Figure 4 and Figure 5. Figure 4 shows the movement sequences of the conventional dummy. Immediately after the impact, the legs of the dummy raise from the ground, a pedestrian accidents' typical "undergoing" of the legs does not take place. Due to the rigid construction of the NAMI-dummy, the dummy does not cling to the car bonnet and collides in an almost stretched out position with the head against the windshield. In the last sequence in Figure 4 it is clear to see that the body of the NAMI during the impact of the head has a significant clearance to the bonnet. The movement sequences of the biofidelic dummy by the impact of a passenger car (Figure 5) resembles the impact behaviour of a real pedestrian, by which the standing leg is pulled under the passenger car and the dummy clings to the bonnet during





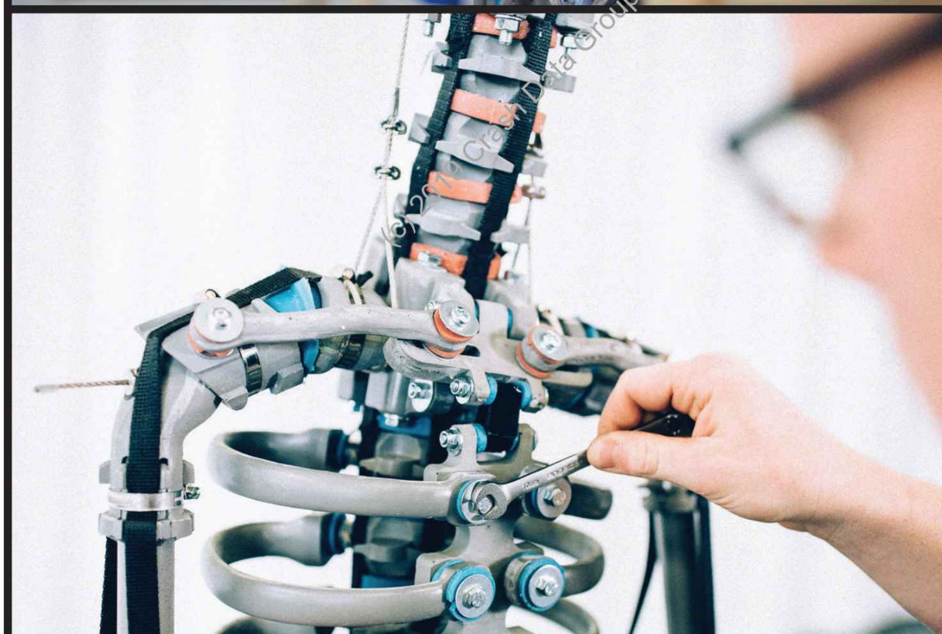


Figure 2: Each stage of the biofidelic dummy production process

Figure 3: The impact configuration with a conventional (NAMI-) dummy in vehicle plan view on the left side

the course of the collision. The head impact occurs with a movement from the top downwards whilst the body makes contact with the bonnet.

Also the comparison of the damages on the left and right side of the passenger car after the collision gives a much more realistic accident representation through the use of the biofidelic dummy. Figure 6 shows a top view of the vehicle front of the VW Golf III after the collision: left side; the damage pattern caused by the NAMI, right side; the damage pattern caused by the biofidelic dummy. It clearly shows that the passenger car in the contact area with the NAMI is much more severely damaged. Also the fracture pattern in the windscreen is diffused on the left side and the detail view in Figure 7 shows clearly that the NAMI, in comparison to the biofidelic dummy, actually penetrates the windscreen with its head. As a result of the clinging of the biofidelic dummies body during the collision, the contact of the hips and shoulder can be recognised afterwards in the damages caused to the bonnet, see Figure 8 (right image). During the impact of the NAMI on the car bonnet, the damages caused are extensive and also include several scratches, which would not occur in a real pedestrian accident (Figure 8, left image).

Lateral impact of an SUV-front

Since the SUV has seen an ever growing popularity in the last 10 years and this vehicle type has meanwhile become a city-car [3], the primary existing lateral impact of a pedestrian, the damages caused to the passenger car and the movement sequences of the dummy during and after the collision with such a vehicle type have likewise been investigated.

Figure 9 shows the test setup, where a biofidelic and a NAMI-dummy under identical conditions are impacted with a VW Touareg (Type 7L) at a velocity of just over 40 kph. Also the comparison of the impact configurations shown in Figure 10 validates the identical test setup. By means of the optical comparison of the impact configurations from Figure 3 and Figure 10 it becomes evident, that the lower edge of the bonnet of the VW Touareg around is 25 cm higher than the VW Golf III. In order to determine whether the previous rolling-off and clinging-on behaviour of the biofidelic dummy to the bonnet also takes place with an SUV front, the study of the movement sequences during the collision is of crucial importance.

As also previously in the crash test with the VW Golf III, a high-speed recording was made from the side view taken at the height of the collision, the movement sequences are correspondingly shown in Figure 11 and 12. In Figure 11 is becomes apparent that despite of the higher bonnet, as previously observed, the clinging of the biofidelic dummy on the SUV front and bonnet also takes place. The

Figure 4: The movement sequences of the conventional dummy

Figure 5: The movement sequences of the biofidelic dummy impacted by a passenger car (mirrored)

Figure 6: A top view of the vehicle front of the VW Golf III after the collision

Figure 7: Fracture pattern in the windscreen

Figure 8: Damages caused to the bonnet

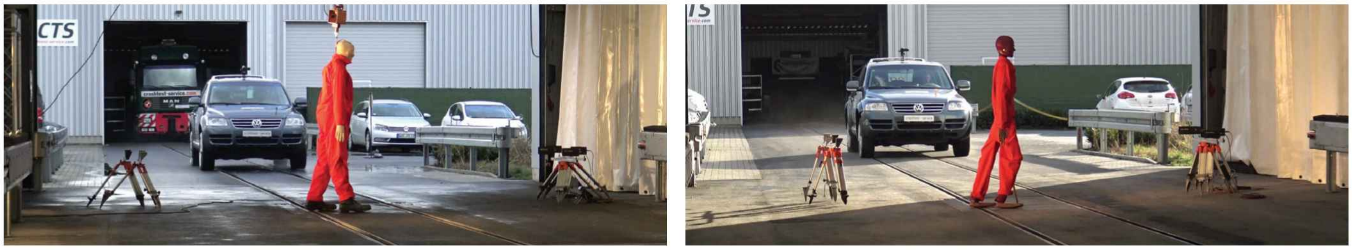


Figure 9: The test setup, where a biofidelic and a NAMI-dummy under identical conditions are impacted with a VW Touareg

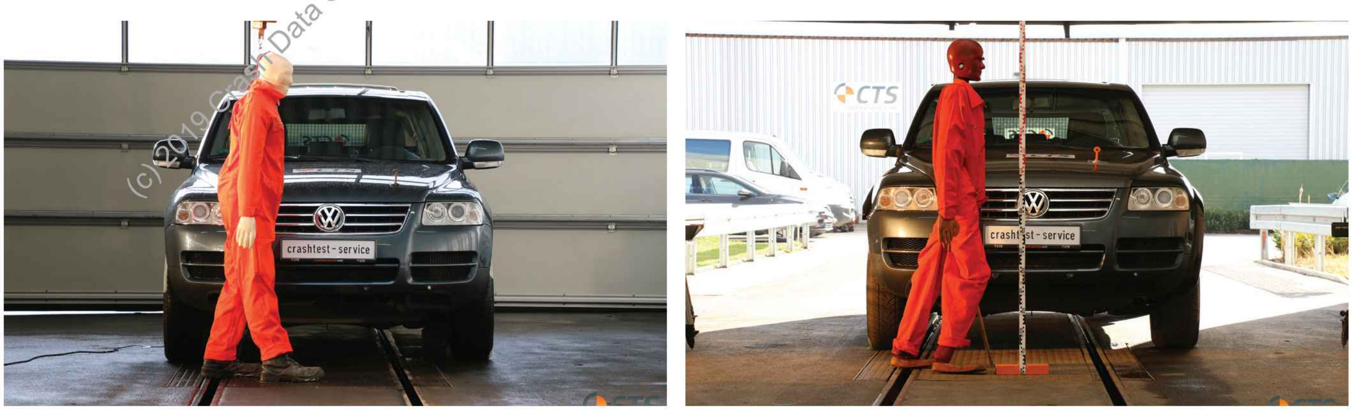


Figure 10: The test setup, where a biofidelic and a NAMI-dummy under identical conditions are impacted with a VW Touareg

Figure 11: Movement sequences during the test with the biofidelic dummy

Figure 12: Movement sequences during the test with the NAMI-dummy

Figure 13: End positions of the different dummy types

typical undergoing of the feet is also present in the crash with this vehicle type. During the course of the collision, the dummy adapts itself with the contour of the vehicle front,whereby the upper body presses from the top on the bonnet and the head impacts the bonnet with such a momentum in a sideways tilting movement. After the main exchange of force the movement of the dummy is opposed and it is then thrown off forwards in the SUVs direction of travel.

Comparing the previous movement sequences of the biofidelic dummy with the NAMI-dummy based on the images series in Figure 12, it becomes clear how immobile the conventional dummy is in comparison to the biofidelic dummy. The absent deformation behaviour of the NAMI-dummy means that the main force exchange is not on the top side of the bonnet but instead on the front edge. Thus, a head impact does not occur on the upper side of the bonnet. Rather, the rigid construction of the NAMI-dummy shows that it rotates on to its back during the collision and is therefore repulsed laterally from the vehicle after the main force exchange. An undergoing also does not occur, since the dummy takes on the speed of the SUV significantly quickly.

The end positions of the different dummy types reflect the significant deviation in the movement behaviour. Whilst the biofidelic dummy comes to rest after approximately 18 m almost straight in front of the SUV (Figure 13, right image), the NAMI-dummy rolled off the bonnet to the right during the collision due to the lack of deformation behaviour and reached a longitudinal throwing distance of only 14 m with a lateral offset of 2.5 m from the collision position (Figure 13, left image).

The comparison of the vehicle damages on the VW Touareg in both crash tests are shown in Figures 14 to 16. It becomes clear that the SUV during the crash with the biofidelic dummy has a deep extensive indent in the bonnet, which results on the bonnet from the impact of the upper body and the top of the head. The force exchange takes place essentially from the top. At the point of impact with the NAMI-dummy the bonnet was impacted from the front so that the bonnet at the first contact was significantly compressed backwards and the paintwork partially flaked. Additionally, the front grill and the bumper covering underneath the right headlight have been damaged by the impact with the NAMI-dummy, which do not occur when impacting the biofidelic dummy.

Head-on impact with a normal passenger car front

Usually in car-pedestrian collisions the pedestrian is impacting laterally, since the collision often occurs when crossing the road. From a summary of many accident reconstruction expert reports relating to passenger car-pedestrian collisions it becomes clear that there are also cases in which a pedestrian is impacted head-on, usually with the intention to stop the vehicle.

As shown in the comparison in the series of images in Figure 17 the carrying-characteristic of the pedestrian is dependant on the impact direction. A lateral impact impedes the bending movement of the upper body, a head-on impact causes the pedestrian to bend like a folding knife on the vehicles front, the forwards bending of the upper body is unrestrictedly possible.

So far there are only very few crash tests in order to judge the vehicle damages during a head-on impact with a pedestrian. For the purpose of the preparing an accident reconstruction expert report, a crash test at CTS was commissioned, where a biofidelic dummy should be impacted head on at a speed of almost 60 kph. The test vehicle used was a VW Bora. In order to also be able to make a comparison in head-on collisions between a biofidelic and a conventional dummy a crash test with a Fiat Bravo from the CTS-database was also used, where a conventional dummy was impacted head-on at the same velocity. The comparison of the impact configurations is presented in Figure 18.

The movement sequence of the biofidelic dummy in a head-on crash is indicated in Figure 19. The upper body tilts forwards whilst the legs are initially pulled under the car and then thrown back (from the perspective of the pedestrian) by the vehicles front. At the collision speed of the VW Bora at 62 kph the dummy does not hit the bonnet, which is the case when laterally impacted and the collision-related rolling off, but rather hits the front windscreen of the test vehicle directly with the head.

The comparison of the vehicle damages is shown in Figure 20. The bonnet of the Fiat Bravo is severely deformed and raised, since the rigid Winterthur-dummy [1] pushes the bonnet back and inwards at the point of contact. A similar behaviour shown by the NAMI-dummy due to its immobility when laterally impacted by a VW Touareg.

Besides the dent in the front edge of the bonnet which can be attributed to the knee impact of the biofidelic dummy, the bonnet of the VW Bora at the same collision speed was not damaged, Figure 21. The fracture caused by the impact of the head is situated at roughly the same height as on the Fiat Bravo and shows a lower intensity. The fact that the front windscreen of the VW Bora came around two thirds loose from the frame and was pushed inwards it is possible that it is not solely due to the high collision speed of 62 kph. Since the original windscreen of the VW Bora was

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Figures 14-16: Vehicle damages to the VW Touareg

slightly crasked before the crash test, it was replaced two days prior to the test. The unusual fracture pattern at the edges of the front windscreen is eventually due to the prior exchanging of the windscreen so that only the damages to the bonnet can be used to compare the crash behaviour of the biofidelic and conventional dummies. The unexpected minimal damages caused to the bonnet of the VW Bora in contrast to the severely deformed bonnet of the Fiat Bravo at the same velocity level rises the question whether in the past the collision speed of the accident vehicle in head-on collisions with pedestrians was partially underestimated based on the material provided and taking into account the damages of the vehicle.

Sliding collision of pedestrians with contact on the front windscreen and A-pillar

Due to the massive construction of the conventional dummy, collisions in particular with pedestrians are of great importance, in which the dummy impacts the A-Pillar or

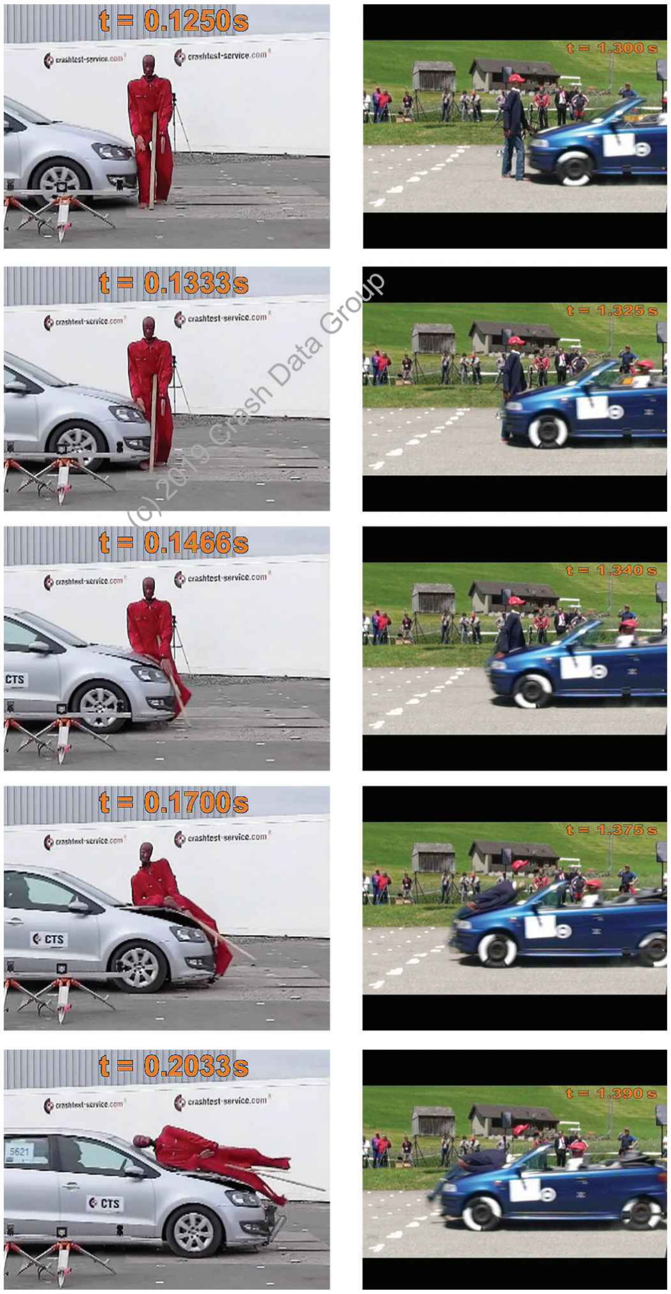

Figure 17: Carrying-characteristic of the pedestrian

Figure 18: The comparison of the impact configurations

Figure 19: The movement sequence of the biofidelic dummy in a head-on crash impact configurations

Figure 20: The comparison of the vehicle damages

Figure 21: The bonnet of the VW Bora

the rood edge of the passenger car during the course of the collision.

Figure 22 shows hereby a crash comparison of a biofidelic dummy and a conventional dummy in a grazing impact by which it came to an impact with the head on the front windshield and subsequently a contact with the A-pillar. On the left of Figure 22 shows a collision of an Audi Q7 at 57 kph with a biofidelic dummy. The right image shows a test by which a VW Golf III grazes a Hybrid-I dummy at 62 kph. The damage pattern comparison can be seen in Figure 23, which shows in both tests a significant damage to the front windscreen in the form of a fracture. The damage to the A-pillar fundamentally differentiates due to the vehicles and in particular the movement behaviour of the dummy.

Due to the mobility of the biofidelic dummy it hits the front windshield with the head in a nodding-movement and rolls then, initiated by the previous grazing impulse, over the A-pillar and the wing mirror. Due to the movement and therefore the change in contact points the A-pillar of the Audi does not appear to be deformed. In a collision with the VW Golf III, the dummy tilts over on to the vehicle. Because of the hard construction, the A-pillar is massively deformed.

Impact roof edge

In particular, at higher collision velocities, where the dummies contact the roof edge of the vehicle, the most commonly used NAMI- or Hybrid II-dummy cause significantly more damages in contrast to an impact in the same area with a human body. For this reason, the estimation of the collision speed in accident reconstruction is made difficult.

Injury characteristics of the pedestrian

Besides the damages caused to the passenger car, the use of the biofidelic dummy makes it now also possible to compare the injuries of the pedestrian in a real accident with those caused to the dummy. Through the addition of aluminium powder in the epoxy it is possible to x-ray the biofidelic dummy after the collision in order to see any

Figure 22: Collision between Audi Q7 and VW Golf III with a biofidelic dummy

Figure 23: Damage pattern comparison

fractures or breaks resulting from the crash test. This principal is presented in Figure 24 in form of a CT-scan of the predecessor model of the biofidelic dummy. In this case, the collision velocity at impact with the dummy was approximately 70 kph. The x-ray examination can be carried out after the crash test in cooperation with the veterinary clinic in Telgte, who obtained an official authorisation from the district government for undertaking such examinations. If required, an autopsy of the biofidelic dummy can also be done after the collision, an example is shown in the images of Figure 25. After carrying out crash tests for the reconstruction of passenger car-pedestrian accidents, it is possible for the biofidelic dummy to be repaired by CTS, so that the cost of the dummy for the crash test is only limited to the rental fee and therefore the dummy must not be completely charged for.

Conclusion

In modern accident reconstruction the biofidelic dummy is a great benefit in order to limit the collision speed based on the damage characteristics of the passenger car. With the construction design of the biofidelic dummy and the physical properties that resemble those of the human it is possible to also realistically recreate the injuries of a pedestrian.

By considering the available crash tests with biofidelic dummies it becomes in particularly clear in head-on pedestrian collisions that the damage extent caused to the crash vehicle at the same collision speed is much lower than in a collision with a conventional dummy. The question arises whether in the past the collision velocity of the accident vehicles based on the vehicle damages was partly underestimated.

The use of various types of measuring technology also offers extensive possibilities to record forces acting on the body, acceleration and pressures. The biofidelic dummy is constantly being further developed, so that, for example, the mobility is continuously improved and at the beginning of 2018 the dummy also received (among others) a new face with a bone structure made of epoxy. For accident reconstruction is it thus preferable that the biofidelic dummy be used in order to create sound expert reports based on comprehensive and visual documentation of damage patterns to the passenger car and the dummy as well as any measurement data obtained.

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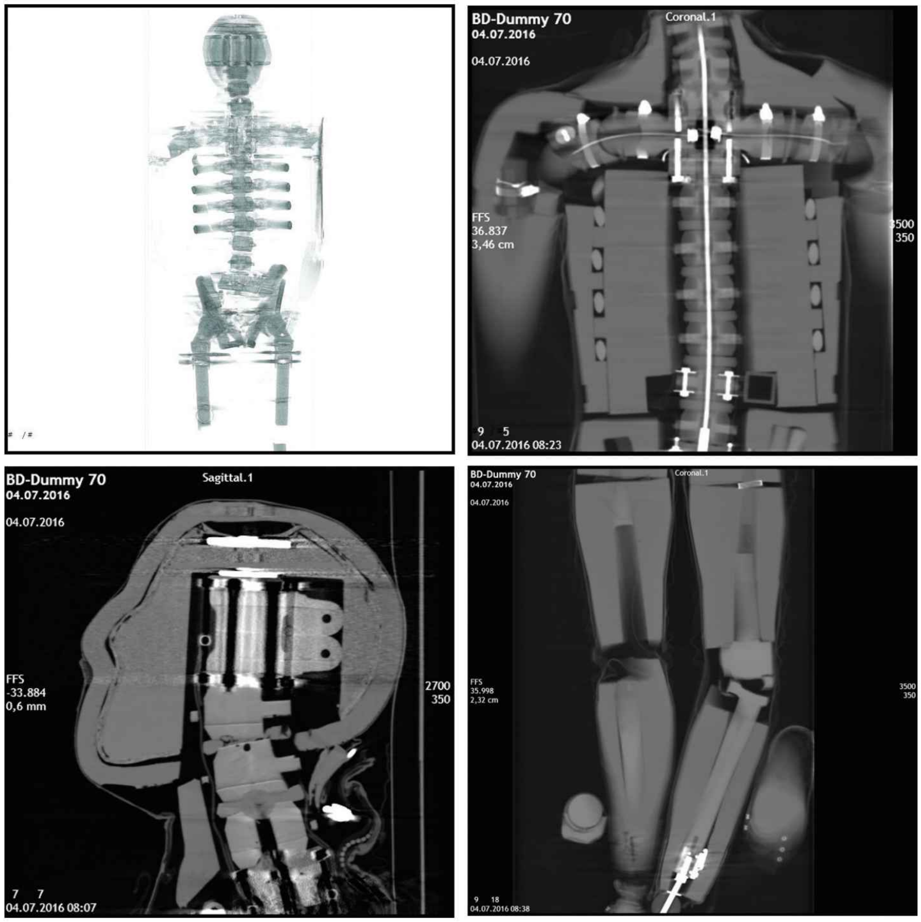

Figure 24: CT-scan of the predecessor model of the biofidelic dummy

Figure 25: An autopsy of the biofidelic dummy after a collision