HIGH SPEED PEDESTRIAN COLLISION AND VERIFICATION OF CAR COLLISION SPEED IN PEDESTRIAN ACCIDENTS BASED ON BIOFIDELIC DUMMY INJURIES

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Recent studies have shown [1] that the construction and use of the biofidelic dummy leads to much more realistic vehicle damage in passenger car/pedestrian collisions than in collisions with conventional dummies. When comparing the longitudinal throwing distances of biofidelic and conventional dummies, no significant difference occurred in contrast to the damage caused to the passenger car. Often, when investigating pedestrian collisions with regard to the collision velocity, the pedestrian injuries remain disregarded. The relationship between collision speed and pedestrian injury characteristics was investigated on the basis of real accidents by Appel et. al. [2] Whether the biofidelic dummies present corresponding "injuries" in a collision as a function of the passenger car collision velocity can be checked by undergoing an "autopsy" on the dummy after the crash tests.

For this purpose, a series of crash tests were carried out with the biofidelic dummy from crashtest-service.com GmbH using the same vehicle model in the speed range from 28 to 109 kph. A collision speed of 109 kph represents the highest speed in currently available crash tests between passenger cars and pedestrians in relevant databases.

Introduction

Generally, the more indications available for resolving the course of events in car-pedestrian accidents, the more the results can be restricted. In accident reconstruction, the extent of the damage to the vehicle and, when present, the throwing distance of the pedestrian are used for determining the vehicle's collision speed. The injuries of the pedestrian are often only taken into account in regard to the impact direction, and where appropriate, in cooperation with forensic scientists. The relationship between collision speed and injury characteristics according to Appel et. al.[2] offers information on the injuries of the pedestrian which likewise provides the possibility to estimate the collision speed.

This is particularly interesting at lower vehicle velocities, since there is no or very little damage occurring to the vehicle, whereas the pedestrian can bear severe injuries as a result.

The crash test series with several VW Polo 6R and the biofidelic dummy [1] have shown that the conventional dummies presented weaknesses due to its hard construction and the restricted rigid mobility, also the damage caused to the vehicle and the movement sequence of the pedestrian during the collision was not realistically represented. Through the dynamic separation of the biofidelic dummy during the collision extensive damage occurred which can also be observed in real accidents.

Originally, the biofidelic dummy was developed as a pedestrian surrogate in order to realistically reconstruct the damage to the vehicle in a collision. Furthermore, the construction of the biofidelic dummies [3] (due to the achievable production accuracy) offers the possibility, for the first time, to reproduce the pedestrian injuries from a collision. Taking into account the damage to both vehicles, for example in a crash attempt recreating a passenger car versus passenger car collision, the solution of the road traffic accident appears to be obvious. This is now also possible for passenger car/pedestrian collisions by means of a subsequent examination of the biofidelic dummy.

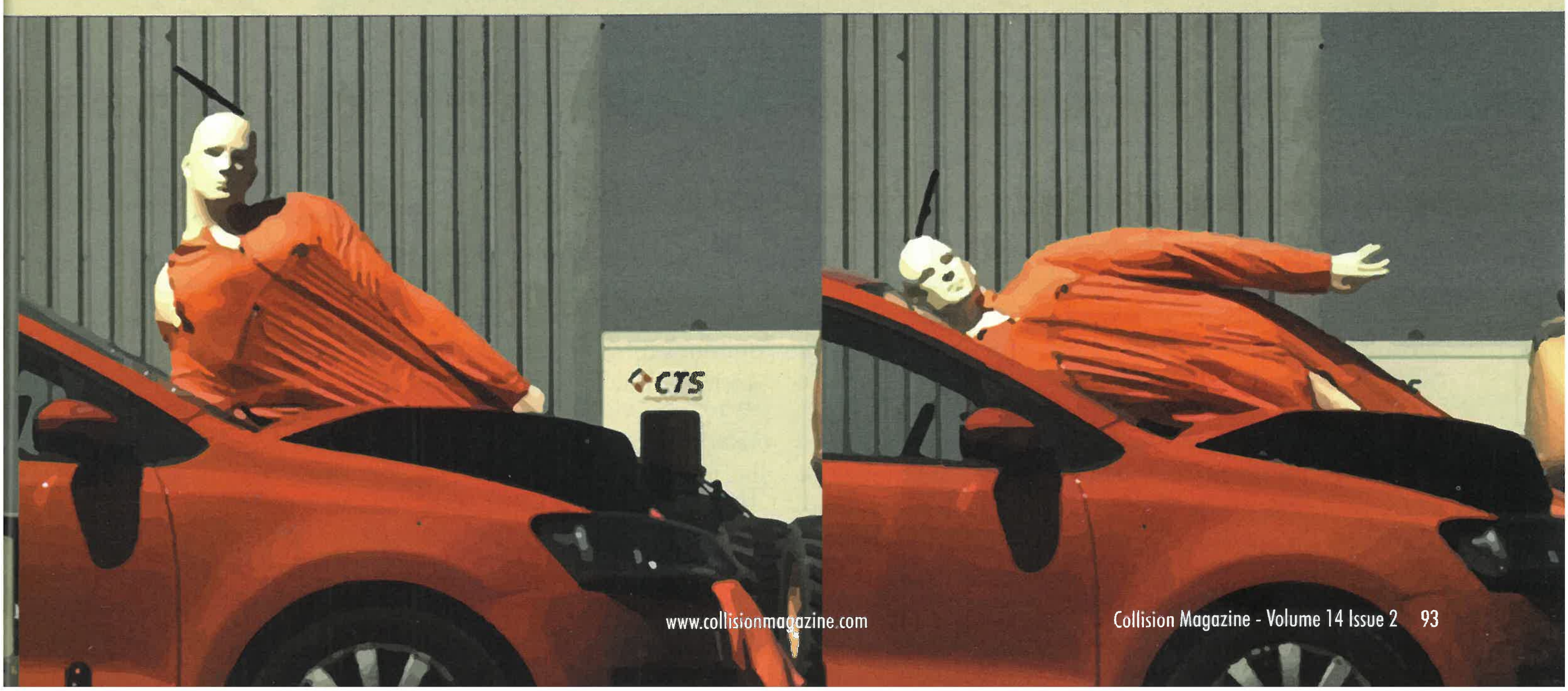
Supplement to the crash series VW Polo impacting a biofidelic dummy in the high speed range

The passenger car collision velocity could be further and more precisely restricted with the increasing amount of available crash tests. Up to a collision speed of about 80 kph, corresponding crash test attempts and the evaluation of throwing distance of pedestrians exist in relevant databases.

To also be able to provide information in the high speed range (v > 100 kph), as part of an expert seminar by crashtest-service.com GmbH, the crash test series with the VW Polo 6R and the biofidelic dummy was supplemented with a collision speed of 109 kph. Thus, the relationship between passenger car damages and pedestrian injuries be can extended. Additionally, it is possible to check whether at high collision speeds the postulate tears according to Appel et. al. [2] between the leg and torso also occurs to the biofidelic dummy. Similarly to the previous crash test series, the dummy was also impacted laterally in the high speed crash test. The point of impact on the passenger car was situated in the centre of the bonnet, figure 1.

Changes in the rolling behaviour of the pedestrian in high speed attempts

The rolling movement of a pedestrian in a collision with a passenger car is known, as shown in the side view in figure 2 in individual images. The crash attempt shows a biofidelic dummy, which was laterally impacted at a velocity of 80 kph. The rolling behaviour of the dummy begins when the dummy is positioned with the hips almost half way between the vehicle front and the lower edge of the windscreen. A typical lateral shearing movement of the head occurs in the direction of the windscreen.



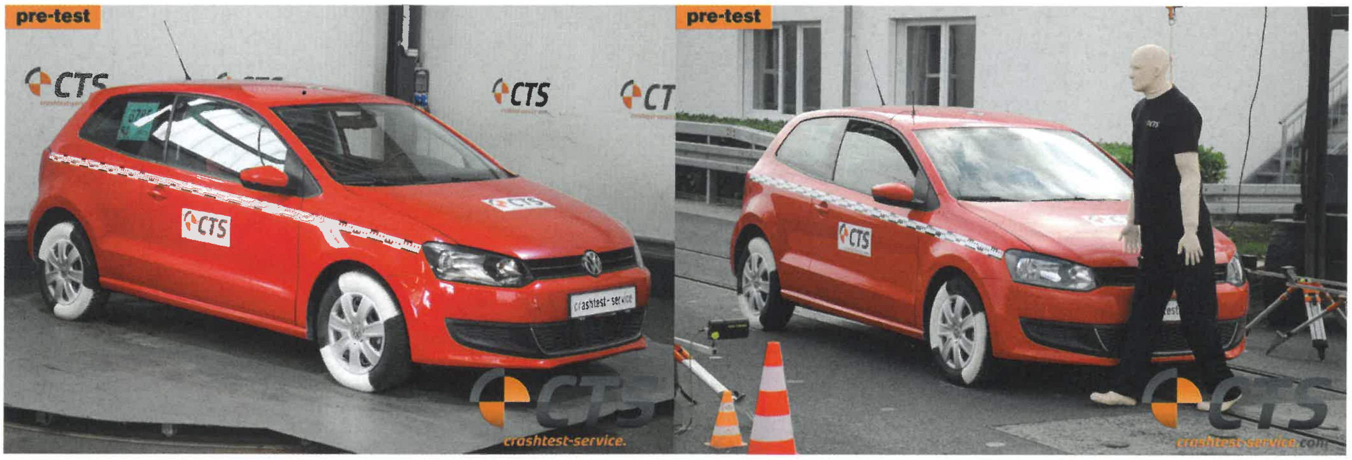


Figure 1: Crash vehicle VW Polo 6R (left) and impact situation with Biofidel dummy (right) for the high-speed test with v = 109 kph

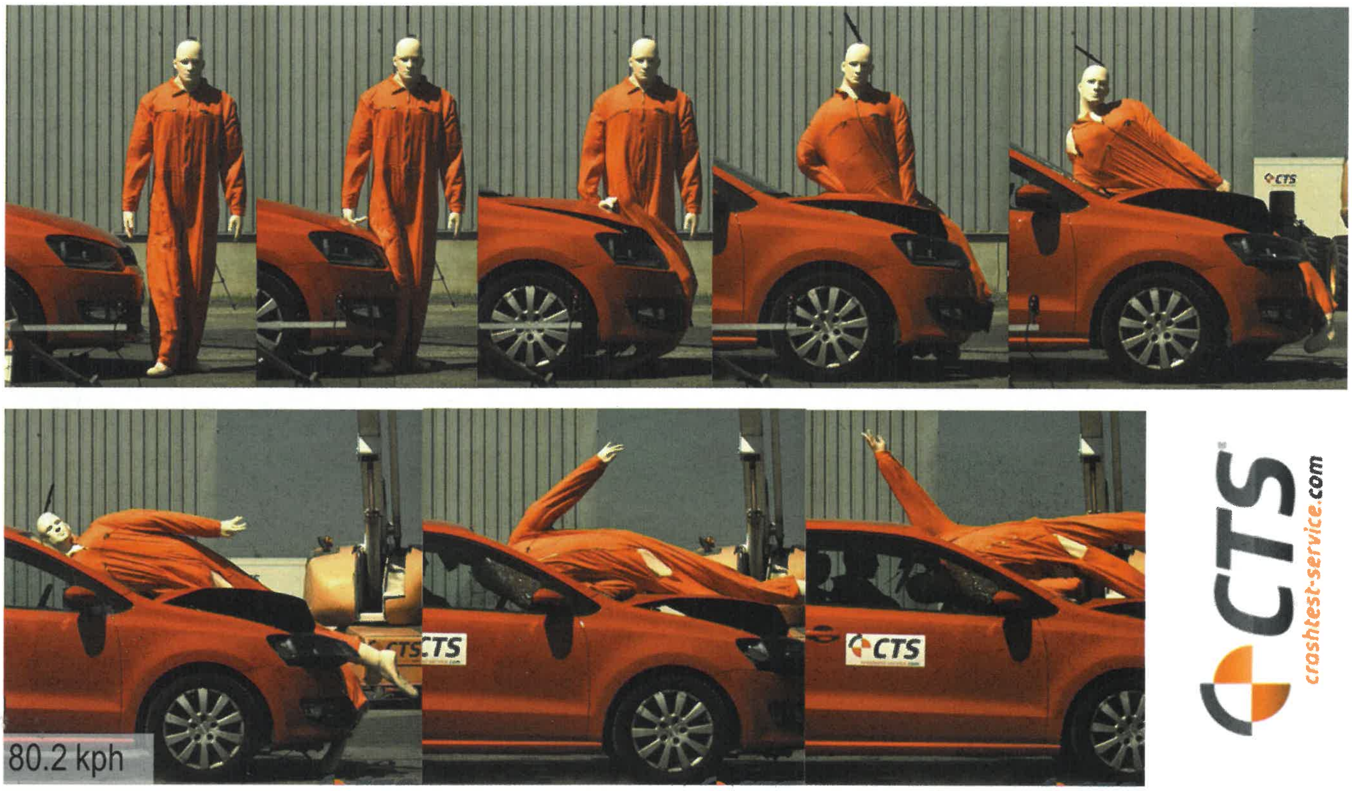


Figure 2: Motion sequence and rolling behavior of the Biofidel dummy at v = 80 kph.

For this purpose, a comparison is shown in figure 3 of the collision sequence under the same test conditions at a passenger car collision speed of 109 kph. In the top row of images, it is clearly recognizable that the typical rolling behaviour of the pedestrian does not take place due to the mass inertia of the dummy and the high collision speed.

After the undergoing of the feet, the torso remains almost upright during the first collision phase, until the hips of the dummy almost touch the front windshield. Only thereafter does the torso tilt towards the windshield, whereby the head impact occurs mainly on the roof of the vehicle. The roof is massively deformed and the dummy penetrates the vehicle interior with head and torso. During the collision phase, there is a notable elongation/stretching of the dummy's torso, which is particularly significant, evident in the lower row of movement sequence images.

Velocity dependant damage to the VW Polo 6R

The damage caused to the passenger car at a collision speed of 109 kph is exemplarily portrayed in the two images in

Figure 3: Motion sequence of the Biofidel dummy at v = 109 kph.

Figure 4: Hood and roof damage on the VW Polo at v = 109 kph.

figure 4. In the left image the hip impact of the dummy is visible, which ends just before the lower edge of the front windscreen. Up until this point, the upper body of the dummy tilted less than 5°, so almost upright.

The front bumper covering appears to be undamaged except for the missing grill and lighting units. The head impact on the roof can be retraced through the deep deformation as shown in the right image of figure 4.

Upon disassembly of the front bumper cover, the profound intrusion of the vehicle's crossmember is apparent, see figure 5. The lower crossmember, which should prevent the undergoing of the feet, was (in the direction of travel) bent inwards as far as the radiator at the right side. The left side of the lower crossmember remained fully intact, figure 6.

The exact stand position of the dummy at the first point of contact can also be seen through the deformation of the upper main front crossmember. The disassembly of the front bumper cover is therefore essential in order to identify the exact impact configuration. Figure 7 shows the damage incurred to the VW Polo of the

previous crash test series with increasing collision speed in the range between 28 and 80 kph, which is supplemented now by the high speed crash attempt at 108.7 kph.

As a result of the largely elastic deformation of the front bumper cover, the grill and the lighting units came off the vehicle's front. The higher speed results in a significant intensive deformation of the bonnet, a penetration of the front windshield and compression of the roof.

Figure 5: Damage of the VW Polo after dismantling the bumper cover

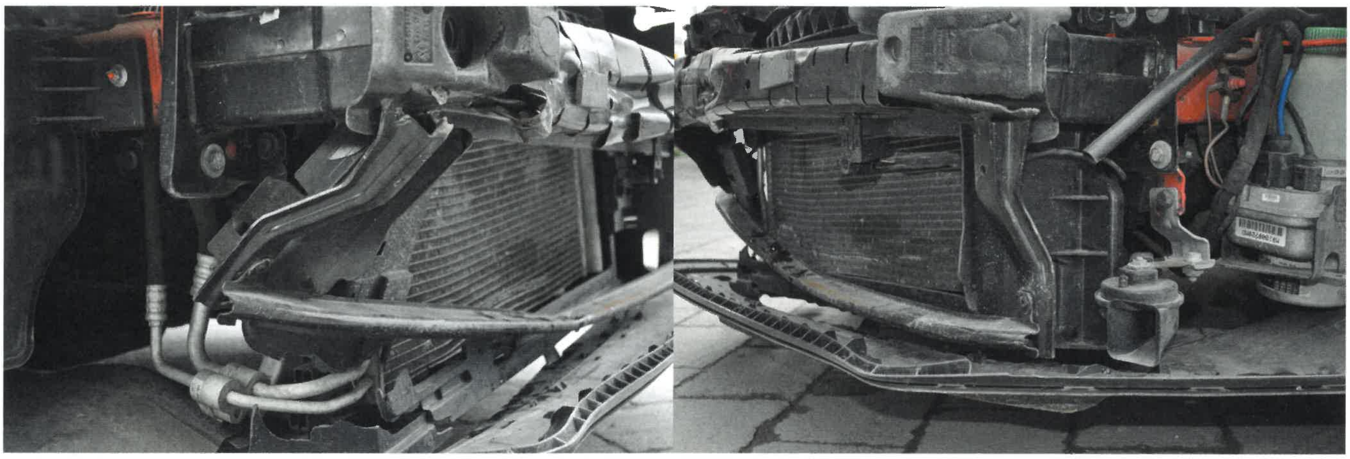


Figure 6: Side-dependent deformation of the bow to prevent the feet from being subjected to it

As previously discussed, at lower velocities of around 30 to 50 kph there is no visible damage to the front bumper.

Supplement to the longitudinal throwing distance diagram

In a high speed crash test attempt, a throwing distance of the biofidelic dummy of around 62 m longitudinally and 3.1 m laterally was reached. Accordingly in figure 8, the throwing distance diagram from [1] was supplemented with the high speed crash attempt.

The determined throwing distance range derived by Focken [4] as a function of the collision speed is also still valid even for high collision speeds. The crash test carried out at a collision speed of approximately 109 kph lies in the lower range of throwing distances according to Focken [4]. Whether the lower limit hereby is only to be clarified by the (usual) tolerances, or whether other effects due to the higher velocity occur, which lead to an actual smaller increase in the throwing distance with increasing velocities over 100 kph, needs to be further investigated.

Based on the motion sequences shown in figure 3, it becomes clear that at higher speeds different structures of the vehicle are affected, which may also have a different stiffness. Also, the angle upon impact of the dummy changes, since the dummy no longer collides exclusively with its upper body against the inclined surface of the windshield, but collides also almost horizontally on the vehicle roof. Whether the air resistance during the flight-phase of the dummy at a speed of over 100 kph is a relevant factor also needs to be investigated.

Injury characteristics of the biofidelic dummy in comparison to real accidents

When using a biofidelic dummy in crash tests it is possible to compare the "injuries" of the dummy with the collision speed, even though the dummy was only initially developed as a pedestrian surrogate for realistic damage generation on vehicles. After a collision the dummy undergoes an examination in the dummy laboratory at crashtestservice.com GmbH. The dummy is hereby disassembled, so that every component including soft tissue, tendon and liga-

Figure 7: Change in the damage pattern (impact against Biofidel) on the VW Polo 6R with increasing speed from 27.5 to 108.7 kph in the front and side view

ment injuries and also fractures of the bone can be documented. Photographic material of a typical dummy examination is shown in figure 9.

The detected damage to the dummy was detailed on to a drawing of a human skeleton, figure 10. Noted were cuts, fractures and torn ligaments. The illustration of the skeleton was compared with the construction of the biofidelic dummy (figure 10, centre). At a collision speed of approximately 70 kph (figure 10, left), damage identified on the dummy consisted primarily of multiple fractures to the ribs, a fractured pelvis, fracture of the femur and arm on the impact side and several torn ligaments. By increasing the collision speed of the passenger car to 109 kph, multiple fractures to the same bones occurred (figure 10, right). Additionally, fragmentation of the hip bone and a ripping out of the femur from the hip socket were recorded. In the hand area was such a deep incision that in a real accident a complete separation of the right hand could have occurred.

Analysing the movement sequences of the biofidelic dummy at a collision speed of approximately 109 kph in regard to the massive damage to the hips and femur, it becomes apparent in figure 11 that the hip area of the dummy is extremely elongated between torso and leg. Due to the high elasticity of the dummy's skin, the upper body had not been separated from the legs, although the hip bones were shattered and the femur bones placed out of the hip socket. In the case of real accidents, it can be assumed that with the same injuries it would have resulted in an amputation of the legs during the collision. There is still development potential in this area, so that a tearing of the dummy can also occur.

A likely amputation of limbs from the collision can currently only be concluded through a dummy examination and the identified bone injuries. Noticeable is that the biofidelic dummy did not sustain a fracture of the skull in any of the collisions, although the head collided partly at higher speeds with the roof or against the front windscreen. The cause of this is the (still) relatively rigid and massive head of the dummy.

Whether the "injuries" to the biofidelic dummies are equivalent to the injury characteristics of a human at similar collision speeds can be compared in the diagram according to Appel et. al. [2] (figure 12), which characterises the relationship between impact velocity and the degree of

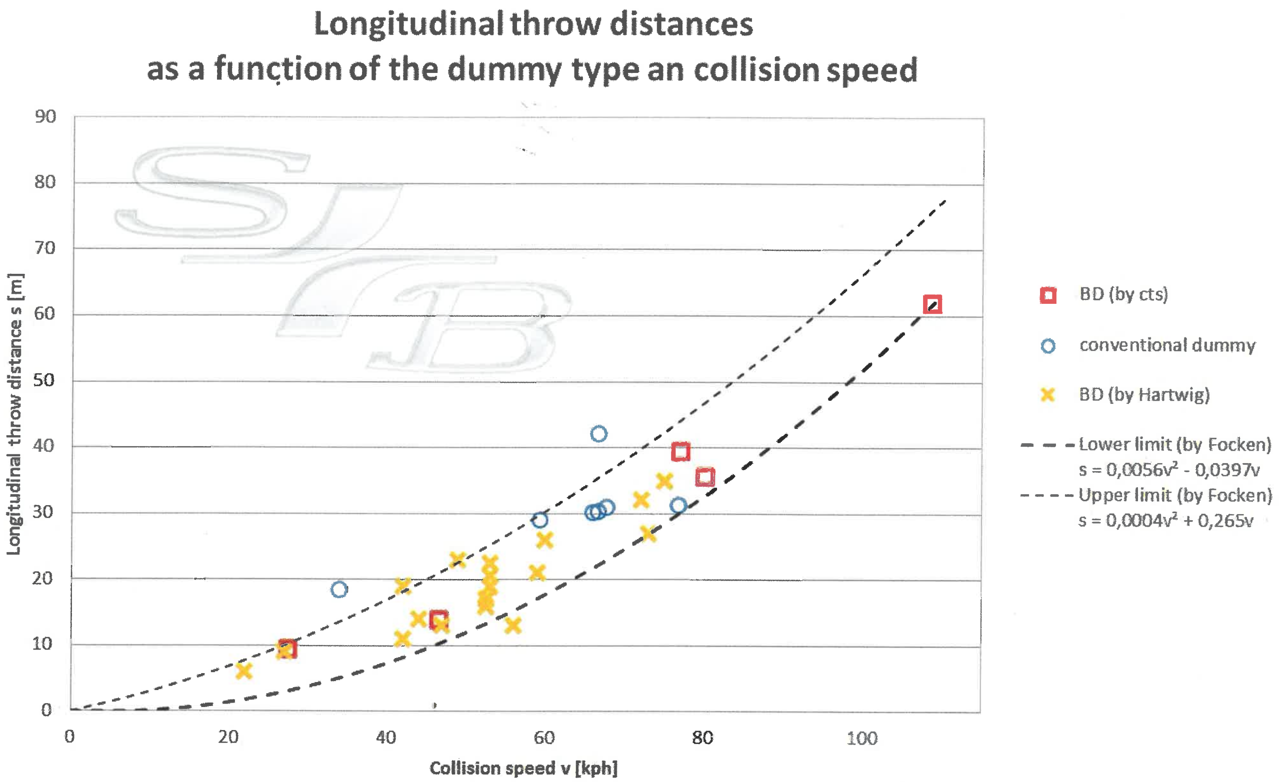


Figure 8: Diagram with longitudinal throw distance of the different dummy types as a function of collision speed-trend line after Focken [4]

injury of a pedestrian. For clarity, the identified injuries of dummy at a collision speed of 68 km/h (green) and at 109 kph (red) were supplemented in the diagram according to Appel et al.

This analysis has shown that the injuries sustained by the biofidelic dummies approximated those reported by Appel et al [2] with respect to pedestrians in real accidents. Rib and femur fractures and a fractured pelvis were identified on the dummy at a velocity of around 70 kph. A likely separation of the upper and lower body in the impact range of around 110 kph could be concluded by the analysis of the massively damaged bones in the pelvis area of the dummy. Injuries to the skull of the biofidelic dummy have not yet been present and are (so far) not expected due to the structure.

Conclusion

To expand the crash test database, a passenger car collision with a biofidelic dummy at a collision speed of 109 kph was carried out, which is currently the highest speed documented in relevant databases. The movement sequences and the damages can be well comprehended by using a biofidelic dummy.

The movement analysis of the biofidelic dummies at this speed has shown that the mass inertia of the dummy and the high velocity of the vehicle lead to a substantially delayed rotation of the dummy relative to the vehicle. Subsequently, a head impact occurs on the vehicles roof. During the collision, the dummy is significantly elongated in the torso area, without any separation.

The throwing distance of the dummy at a collision velocity of around 109 kph lies in the lower throwing distance range derived by Focken [4]. Whether it is a tolerance, or whether the higher speed causes other effects such as impact level, or the air resistance, or the structure rigidity of the passenger cars roof area take effect, which results in an actual smaller increase in the throwing distance with increasing velocities over 100 kph, needs further investigation.

Through an examination of the dummy (similar to an autopsy of humans) after the crash tests, the established relationship by Appel et. al. between impact velocity and the degree of injury in pedestrians can essentially be comprehended. The expected limb separation in the high speed range could not be reproduced using the biofidelic dum-

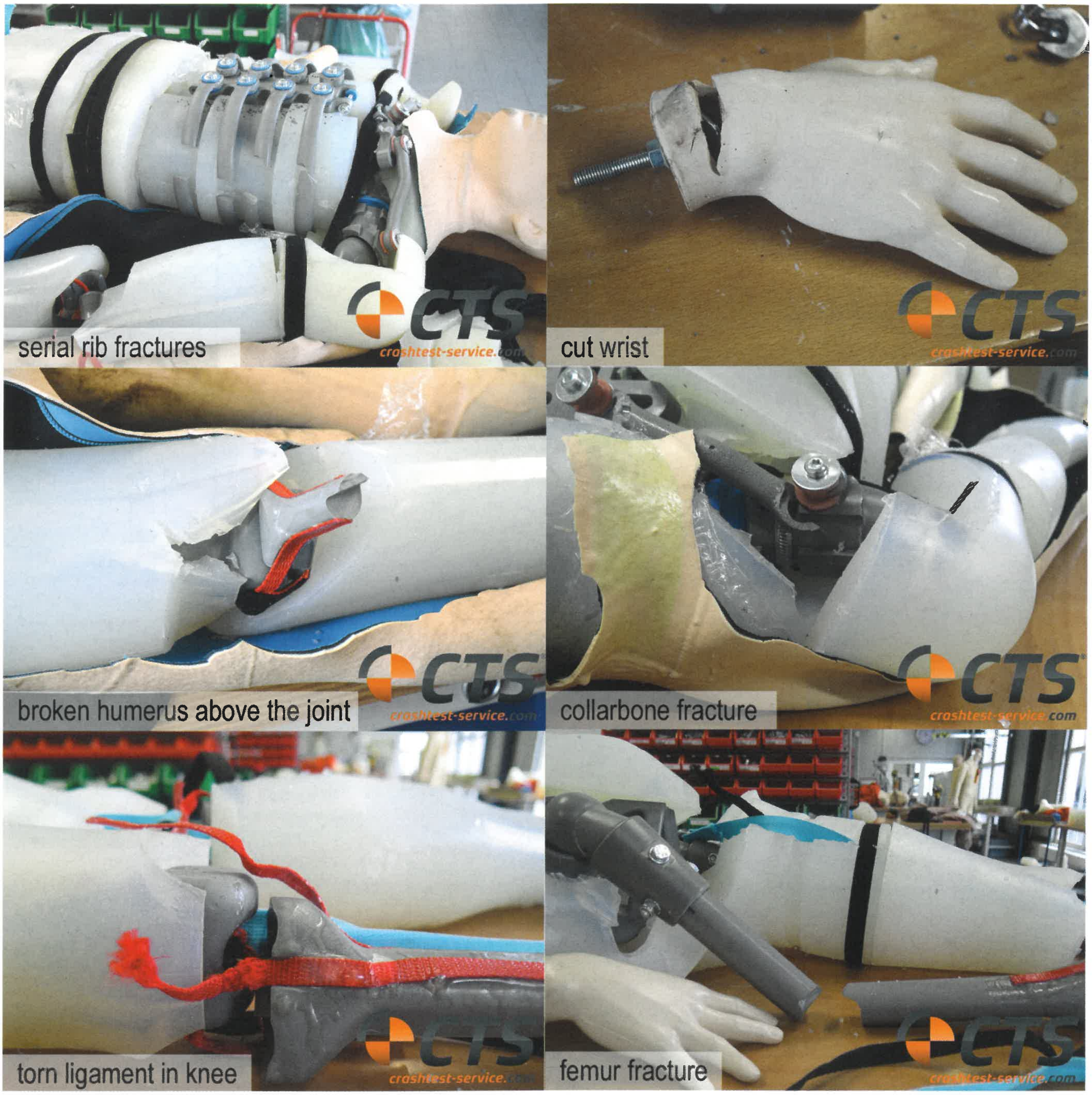


Figure 9: Investigation of a Biofidel dummy

mies due to the skin being too elastic, so there is also still a need here for further development.

An analysis of the bone injuries of the dummy allows us based on the shattered pelvis and the detachment of the femur from the hip joint to conclude an expected separation.

A head fragmentation could not be observed in any of the crash attempts, which due to the massive head structure, and is also not expected.

Future work

In this article, the application of the biofidelic dummies in pedestrian collisions was discussed. Currently, the company crashtest-service.com GmbH is developing in cooperation with the HTW Dresden and the TU Berlin, among other parts, a variable structure for the buttocks area of the dummy as well as an improved cervical spine and a new rib cage.

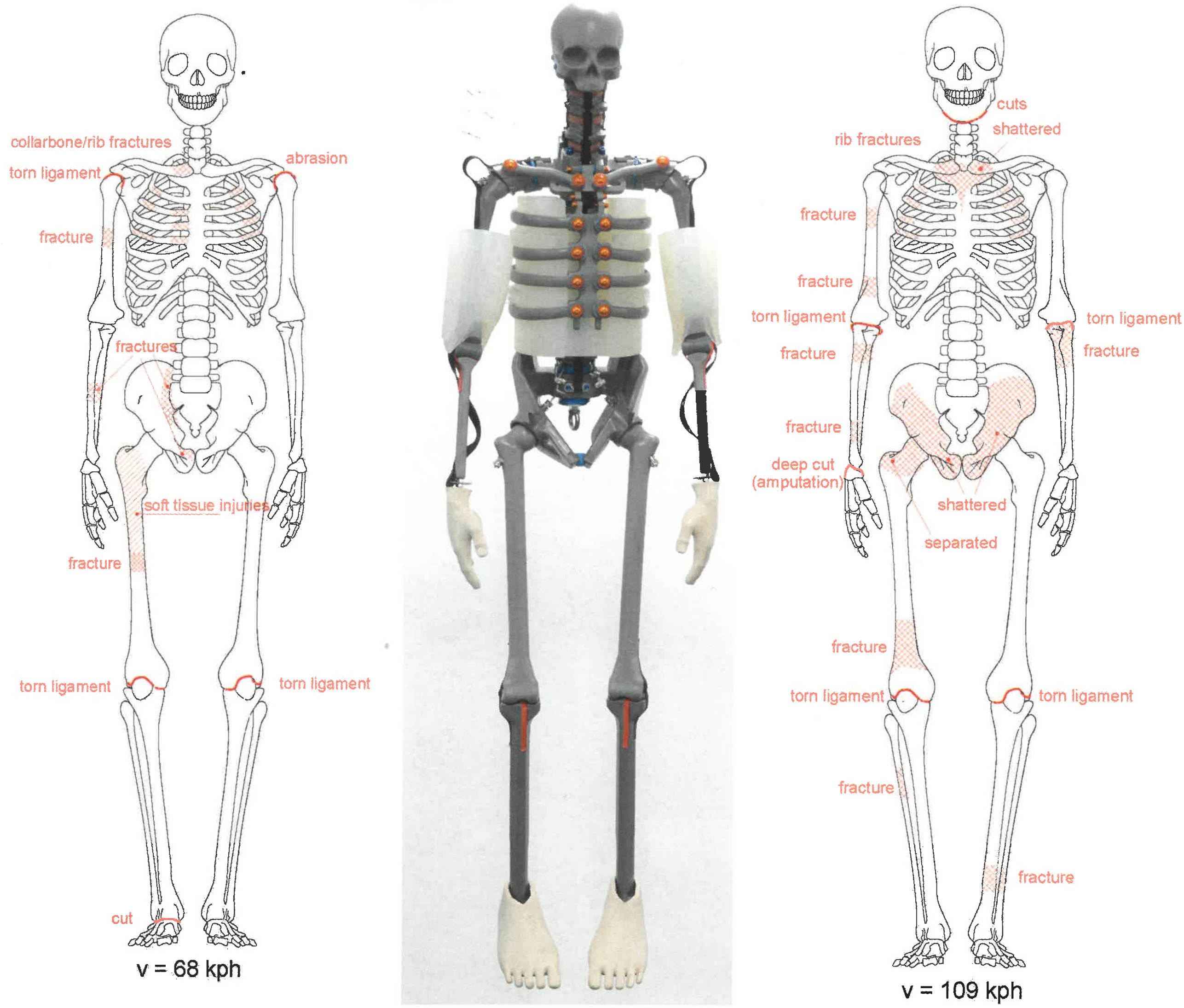


Figure 10: Injury image of the Biofidel dummy at a collision speed of 68 kph (left) and 109 kph (right) – design of the used Biofidel dummy

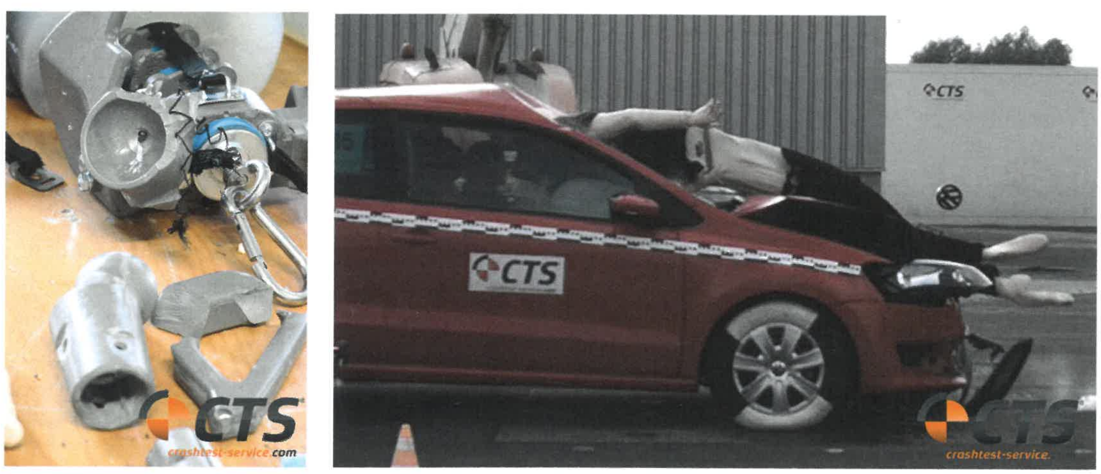


Figure 11: Massive hip damage (left) and severe dummy elongation during collision (right)

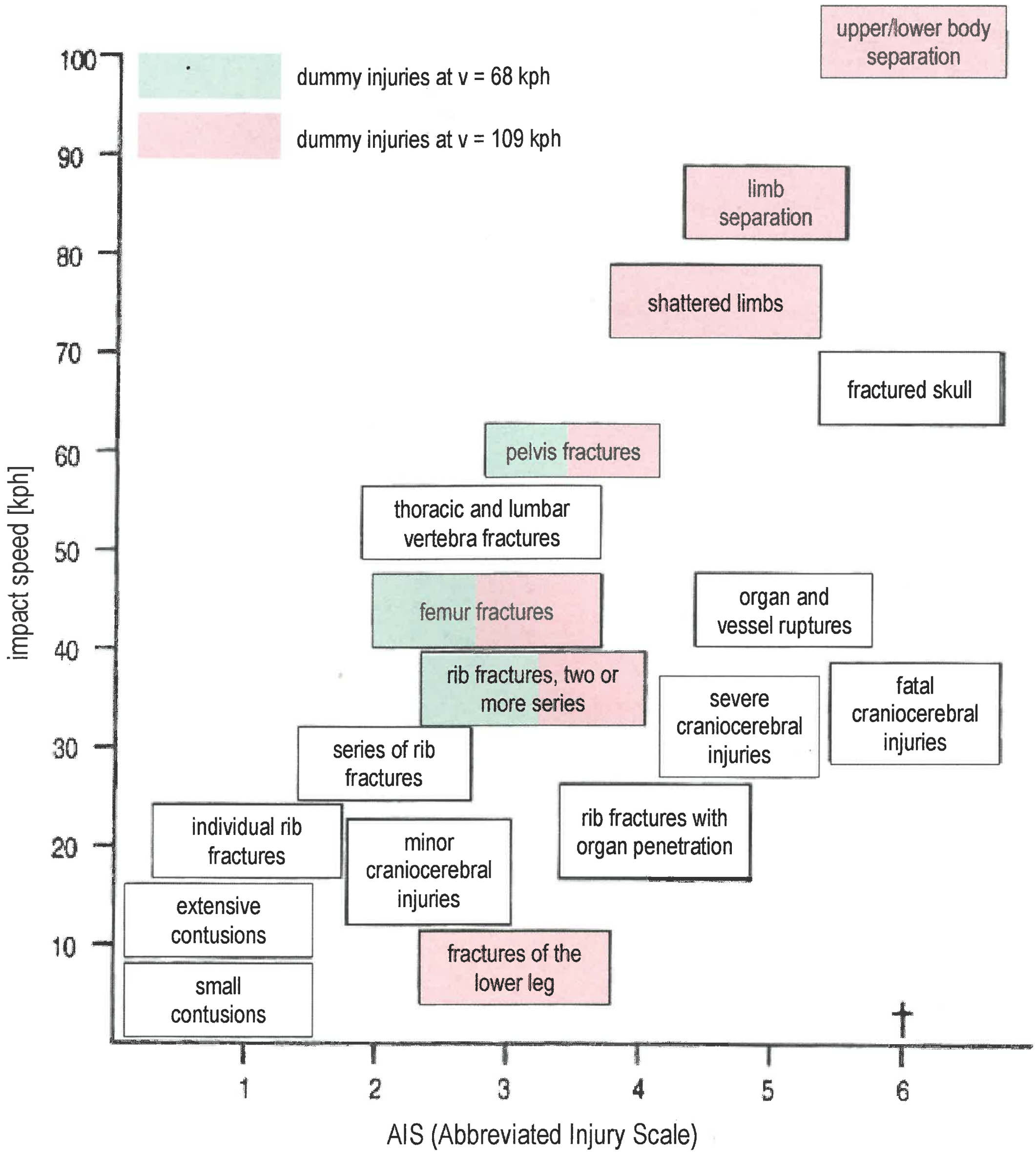


Figure 12: Relationship between impact velocity and degree of injury in pedestrians according to Appel et. al. [2] (translated into English)

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References

1. A. Kortmann, T. Hoger, Pkw-Beschädigungen und Längswurfweiten bei Verwendung von Biofidel-Dummys und konventionellen Dummys im Vergleich, VKU 10/2018.
2. H. Appel, U. Wanderer, S. Meißner, G. Schmidt, J. Barz, D. Kallieris, R. Mattern, F. Schüler, Mechanik und Biomechanik des Unfalls, H. J. Wagner (Hrsg.): Verkehrsmedizin, Springer-Verlag, Berlin 1984.
3. A. Kortmann, Crashverhalten im Crashvergleich: der neue Biofidel-Dummy bei unterschiedlichen Szenarien von Pkw-Fußgängerunfällen, VKU 03/2018.
4. U. Focken, Experimenteller Vergleich des gebremsten und ungebremsten Anstoßes bei der Kollision zwischen PKW und Fußgängern; Diplomarbeit, Fachhochschule Osnabrück, 1998.

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