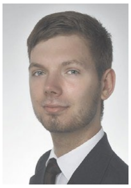

***Daniel Wdowicz***

# Impact tests employing pedestrian dummies. PRIMUS dummy – design and unique properties

**Abstract**

This article presents various models of pedestrian crash dummies, grouping them by their applicability: vehicle manufacture or road accident reconstruction. Selected experiments in the latter area using dummies of of pedestrian are presented. The second part of the article is devoted to a description of a PRIMUS dummy – a relatively new product on the market. The structure of the dummy presented, and studies verifying the dynamic response of the dummy in a collision with pedestrian are summarized. The application of the dummy in road accident reconstruction and R&D experiments are presented.

**Keywords**

Crash tests, biomechanics crash test, dummies, PRIMUS, pedestrians, passengers.

*Received: 25 July 2022, approved for publication: 28 November 2022.*

*DOI: 10.4467/15053520PnD.22.017.16987*

## *1. Introduction*

Advances in road accident reconstruction include not only new techniques for documenting the scene or analyzing post-accident data, but also the development of crash dummies used for reconstruction purposes. The purpose of this article is to introduce the reader to examples of pedestrian crash dummy designs and to describe a new development: the PRIMUS dummy from the German company crashtest-service.com GmbH (CTS).

The PRIMUS dummy was used in a pedestrian impact test during the "PIESZY – badania, dokumentacja, symulacje, bezpieczeństwo sp. k. and Politechnika

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Krakowska [Cracow University of Technology] on June 2 and 3, 2022. This was the first research experiment performed in Poland using such a dummy. This dummy will become part of the equipment of the CYBID research laboratory and is planned for use in subsequent crash tests and forensic experiments.

## *2. Pedestrian Dummies*

Pedestrian dummies can be divided into two groups: dummies typically used in industry and research to improve pedestrian passive safety, and dummies used in reconstruction and related research. This division is purely arbitrary and is introduced solely for the purposes of this article. However, it will provide an understanding of the differences between the two groups of applications.

The first group of dummies requires high biofidelity and the possibility to install sensors (usually accelerometers) inside the dummy. The information collected from the dummy is used to estimate the severity of the injury and, as a result, to evaluate the design in question, e.g. the effectiveness of the active engine cover system. Unfortunately, these requirements are also matched by the very high cost of a single test. As an aside, it is worth noting that pedestrian dummies, unlike passenger dummies, have not found their way into most protocols of official standards or even consumer testing. For example, crash tests performed within the framework of UN Regulation ECE R127/02 *Passenger Safety* [17] or test protocol EuroN-CAP *Assessment Protocol – Vulnerable Road User Protection*, version 10.0.5 [4], only require so-called *headforms, lower legforms* and *upper legforms*, i.e. devices that model individual body parts, respectively: the head, the shin (including the knee) and the thigh are used to test the passive safety of pedestrians.

The categories of dummies used in industry and scientific research include:

- Hybrid III Pedestrian dummy (in analogical versions for passenger dummies: 5-centile female, 50-centile male, 95-centile male)[1],
- Polar dummy developed by Honda [1],
- a dummy developed by Chalmers University of Technology in collaboration with Autoliv, among others, to test the effectiveness of the active engine cover [6].

[1] Distinguished from the *Hybrid III* passenger dummy by its pelvic design.

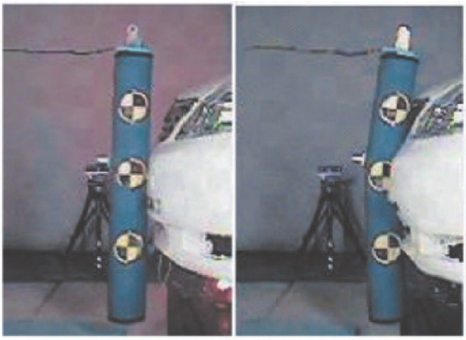

*Fig. 1. Crash test with* lower legform *[14].*

*Fig. 2. Hybrid III Pedestrian dummy. Source: humanetics.humaneticsgroup.com.*

*Fig. 3. Polar II dummy [1].*

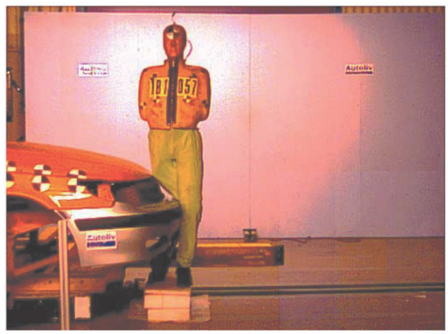


*Fig. 4. Dummy developed by Chalmers University of Technology [6].*

The main requirement of pedestrian dummies used in reconstruction is to be able to qualitatively reproduce the kinematics of a real body at the moment of impact in order, among other things, to compare the location of the damage sustained to vehicles in the incident and in the crash test. The longitudinal throw distance obtained from tests with dummies is also of interest, while the flight phase is less frequently analyzed in any detail. Another criterion is the reduction of the costs of conducting a single test, and thus the expected high durability of the dummy (no need for costly repairs/calibration). For reconstruction purposes, sensors mounted inside the dummy are relatively rarely used. Impact analysis is most often performed using time-lapse analysis of video recordings documenting the tests.

The dummies used so far in reconstruction are mainly older designs, such as:

- Hybrid II dummy developed by General Motors in 1972, used in aviation and automotive applications, the precursor to the Hybrid III[2] dummy,
- USI Žilina Dummy (USI, slov. Ústav súdneho inžinierstva, Institute of Forensic Engineering at the University of Žilina), also known as the *NAMI* dummy [9],
- ACTD-Series 2 dummy (*Automotive Crash Test Dummy*), a design developed in the United States by ARL and Sierra Engineering between 1950 and 1970.

Some of the experiments carried out by the researcher-reconstructors also used other, unnamed dummies, most likely of the researcher's own designs.

A selection of studies in the field of reconstruction that used different pedestrian crash dummies will be presented below. In most of these studies, the authors compared crash test results with simulation results using multi-body models in reconstruction programs: PC-Crash [11, 12] and Virtual CRASH [2, 3].

*Fig. 5. Unspecified dummy [11, 12].*

*Fig. 6. Unspecified dummy; most likely of the researcher's own design (body parts were sandbags taped together) [3].*

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[2] The Hybrid II dummy is also known from the popular science program "Mythbusters" (Adam Savage's "Tested", 2021).

*Fig. 7. US police research; unspecified plastic dummy, weight 22 kg, height 178 cm) [2].*

*Fig. 8. ACTD Series 2 dummy [13].*

*Fig. 9. Hybrid II dummy [13].*

*Fig. 10. USI Žilina Dummy [8].*

*Fig. 11. Construction of the USI Žilina Dummy [15].*

## *3. PRIMUS Dummy*

The PRIMUS dummy developed by the German company CTS could bridge the gap between R&D test requirements and road accident reconstruction practice.

### *3.1. Construction*

The PRIMUS dummy is a relatively new design, developed and researched since 2013. Referred to in many publications as the *biofidelic dummy*, it is distinguished by the design solutions it uses.

The height and weight of the dummy correspond to a 50-centile (average) male, at 175 cm tall and weighing 78 kg (however, it is also possible to adjust the proportions and dimensions to suit individuals).

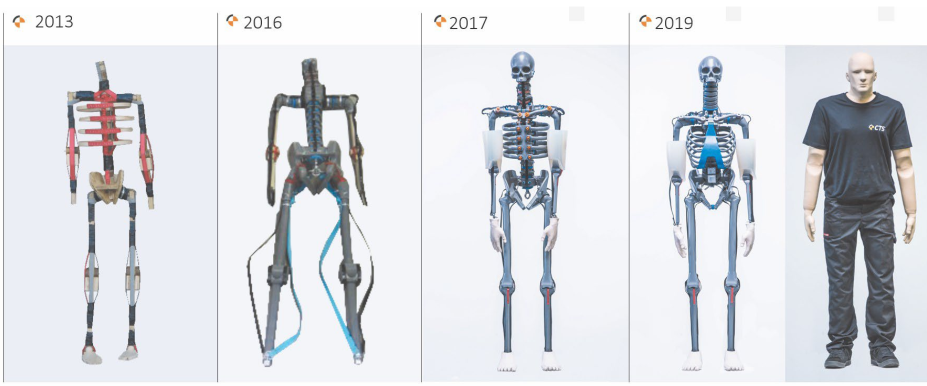



*Fig. 12. Evolution of the PRIMUS dummy design – from the wooden skeleton and simplified chest to the current version*[3].

PRIMUS has a realistically reproduced skeletal system, with a spine curved to mimic natural curves and artificial equivalents of ligaments and intervertebral discs. Three different types of ligaments can be found in the spine itself (made of steel cables, nylon bands and rubber bands). The density of the materials that make up elements such as bones and intervertebral discs is based on the human skeleton.

To model soft tissue, blends of silicone materials of different degrees of rigidity were used in the dummy. Depending on the body part in question, the materials used differ in stiffness and color.

[3] All illustrations for the PRIMUS dummy have been taken from CTS materials provided to the author, unless otherwise stated.


*Fig. 13. Cervical spine section of the PRIMUS dummy. Source: CYBID.*

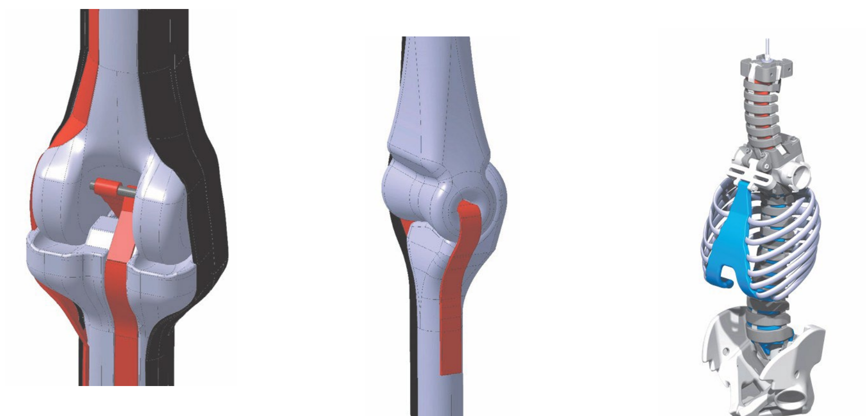


*Fig. 14. Selected elements of the skeletal system of the PRIMUS dummy: a) ligaments of the knee joint, b) elbow joint, c) thorax and vertebral column (sternum and intervertebral discs are made of a different material from the ribs/vertebrae).*

Unlike the Hybrid III dummy, the pelvis of the PRIMUS dummy allows it to be used in both sitting and standing positions, expanding its range of application. The hands of the PRIMUS dummy have the ability to grasp.

PRIMUS dummies currently come in two versions: *Unbreakable and Breakable*. The *Breakable* version uses biocompatible breakable elements, which extends the analyses and makes it possible to "dissect" the dummy and analyze injuries to the skeletal system. The comparison of injuries to victims in real accidents with dummy "injuries" remains the subject of various publications [7, 16].

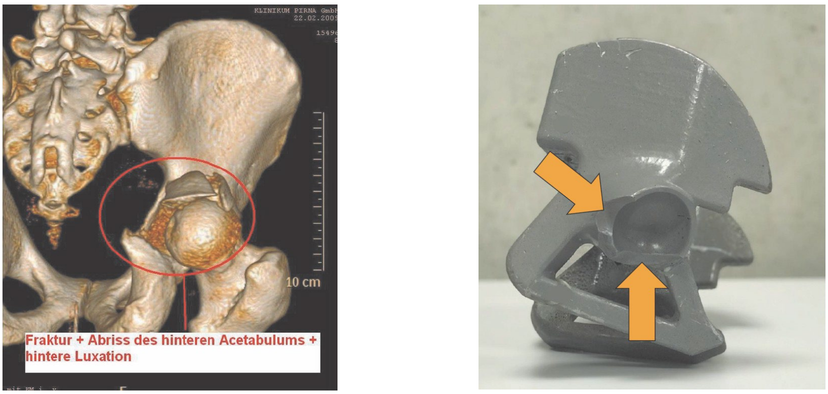
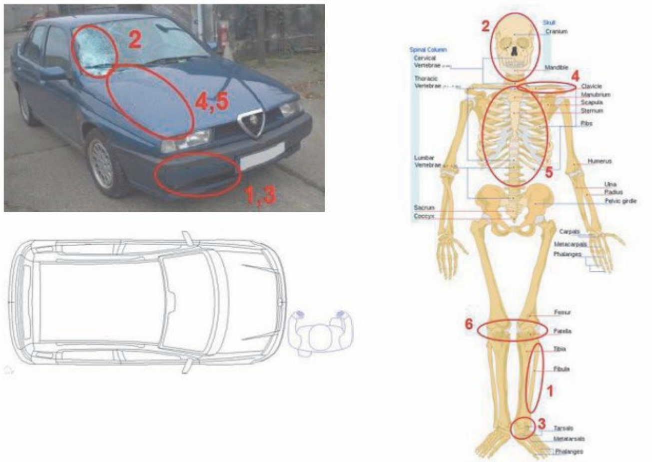



*Fig. 15. Comparison of the pedestrian's hip injuries with those of the PRIMUS dummy pelvis in a similar impact configuration.*

The PRIMUS dummy design provides locations for mounting sensors and an on-board recorder. The suggested instrumentation for the dummy is to equip it with acceleration sensors in the head, chest and on the pelvis.

### *3.2. Verification*

The performance of the dummy was verified by CTS in collaboration with DEKRA in 2019 [15]. The PRIMUS dummy was compared with the USI Žilina Dummy in terms of movement kinematics, among other things. The compatibility of the behavior of the dummies with real accidents was also checked using a database of information on victims' injuries and the recorded points of impact with vehicles.



| vehicle data | pedestrian data |
|---|---|
| Alfa Romeo 155 1995 | 67 years |
| trapezium | female |
| 1215 kg | 164 cm |
| 50 - 55 km/h | 78 kg |
| late or unbraked | survived |
| frontal | |
| complete | |

| no. | injury | injury caused by hit | injury caused by … |
|---|---|---|---|
| 1 | fracture of left fibula | primary | bumper |
| 2 | large occipital laceration | primary | windscreen |
| 3 | bimalleolar fracture of upper ankle joint | primary | bumper |
| 4 | fracture of left clavicle | primary | bonnet |
| 5 | multiple fractures of 3rd to 5th rib in axillary line with pneumothorax | primary | bonnet |
| 6 | haematomas on both knees | secondary | ground |

| injury | injury caused by hit | injury caused by … |
|---|---|---|
| traumatic subarachnoid haemmorhage | primary/secondary | windscreen/ground |

*Fig. 16. Example of a dataset used to verify the behavior of a PRIMUS dummy [15].*

Each dummy, USI Žilina Dummy and PRIMUS, was evaluated in each of the 6 categories:

- Biofidelity (whether the dummy reproduces the injuries suffered by the real pedestrian as a result of an impact),
- Realistic throw distances,
- Realistic vehicle damages (correspondence to real cases),
- Usability in a collision speed interval of 40 to 100 km/h,
- Cost,
- Durability (whether the dummy can be used several times in a row).

Compared to the USI Žilina Dummy, the PRIMUS dummy demonstrated high biofidelity of body damage and a realistic degree of impact damage to the vehicle. Both dummies showed good results in the longitudinal throw distance category and very good results in the usability category for a wide range of collision speeds.

The authors of the comparison noted that the durability of the PRIMUS dummy was low and, consequently, the cost of conducting the test with the PRIMUS dummy was higher than with the USI Žilina Dummy. This is understandable given that the comparison involved a PRIMUS *Breakable* dummy equipped with a skeleton that breaks realistically.

It should be added that the PRIMUS dummy witch the CYBID's laboratory is equipped with, and which was at the crash test during the conference mentioned in the introduction is an *Unbreakable* specimen. This allows multiple tests to be carried out without the need for a major repair of the dummy, thereby reducing the cost of a single test. It should be noted, of course, that for the *Unbreakable* version, biocompatible damage to the skeletal system of the dummy is less frequent. However, depending on the needs of a given experiment, individual dummy elements can be replaced with "breakable" ones.

### 3.3. Applications

The PRIMUS dummy can be used for various needs. The dummy is mainly used in impact tests against vulnerable road users: pedestrians, cyclists and those on individual means of transport (e.g. scooters). The dummy can also act as a passenger/driver of passenger vehicles.

A distinctive feature of the PRIMUS dummy is the possibility to mount internal sensors, mentioned above, which can allow studies comparing the estimated severity of injuries for several variations of the impact. In the past, this has allowed researchers to conduct studies comparing injuries in different configurations of seat belt buckling: correct, incorrect or no buckling [10].

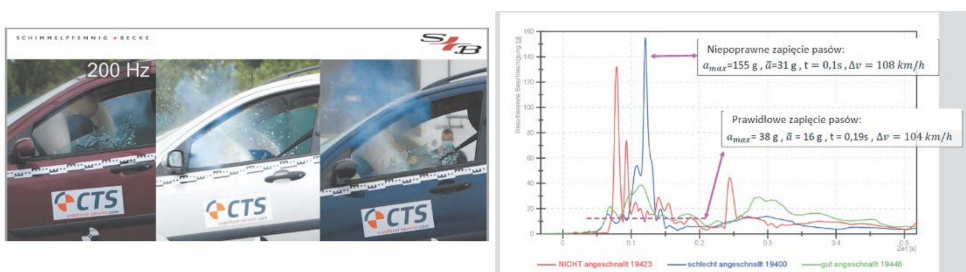



*Fig. 17. Example of the use of sensor readings from the PRIMUS dummy: comparison of the loads acting on the driver's body for different seat belt configurations [10].*

The PRIMUS dummy can also be used for industrial purposes, such as testing safety harnesses and for the military sector. Beschussamt Ulm's experiments (2021) with the PRIMUS dummy as a passenger can be cited as an example here. The research was designed to test the resistance of certain armored vehicles to fire and explosions by checking the damage to the dummy and the presence of shrapnel in its body[4]. Another example of research in a similar area of study used the sensor-equipped PRIMUS dummy for the US Armed Forces [5].

A less standard application of the PRIMUS dummy is the modelling of workplace accidents: e.g., falls from heights or falls into a swimming pool.

## *4. Conclusion*

Over the years, many dummies have been used to simulate pedestrians. Depending on the needs of a given experiment, the dummies have exhibited varying degrees of complexity in the solutions used.

The PRIMUS dummy is an alternative to older dummy designs, combining two aspects: advanced design solutions typical of dummies used in the automotive industry, and the ability to perform repeatable crash tests at a relatively low cost.

The first research test conducted in Poland with the PRIMUS dummy confirmed the feasibility of this type of crash test. This opens up new research perspectives in the field of accident research and reconstruction.

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