Scientific Journals
Maritime University of Szczecin

Zeszyty Naukowe
Akademia Morska w Szczecinie

2013, 35(107) pp. 22–31
ISSN 1733-8670

2013, 35(107) s. 22–31

Overview and analysis of dummies used for crash tests

Marek Jaśkiewicz[1], Rafał Jurecki[1], Karolina Witaszek[1], Darek Więckowski[2]

[1] Kielce University of Technology, Faculty of Mechatronics and Machine Building
Department Vehicles and Transport
25-314 Kielce, aleja Tysiąclecia Państwa Polskiego 7,
e-mail: {m.jaskiewicz; rjurecki}@tu.kielce.pl, karolinawitaszek@wp.pl
[2] Automotive Industry Institute
03-301 Warszawa, ul. Jagiellońska 55, e-mail: d.wieckowski@pimot.org.pl

Key words: safety, anthropometric dummies, crashes

Abstract
This article is a description of the construction of dummies used in crash tests of vehicles. Dummies are classified according to their use in different types of crash tests. The noticeable improvement in the construction of dummies, their properties and similarity to humans man, is clearly visible referring to first dummies with modern ones.

Introduction

After World War II, biomechanical testing and crash tests were conducted on corpse or volunteers. However, the problem of finding dead bodies, which did not have any injuries on the bodies without internal damage was extensive. Similarly, the lack of volunteers has meant that engineers began to work on the construction of dummies that will copy a man.

The beginnings of the construction of dummies

In 1949, Samuel Alderson created a dummy named Sierra Sam. It was the first dummy that looked like a man. Dummy presented a 95-centile male. Sierra Sam dummy's task was to test the catapults on planes, flight helmets and pilot safety harnesses. Sierra Sam became the prototype, which was a model for later constructions – more anthropomorphic dummies. Muscles, joints, and other parts of the human body were specifically sought to be reflected in dummies [1, 2].

An example of this kind is a dummy designed in 1972 by Alderson Research Laboratories, and modified by General Motors and The National Highway Traffic – Hybrid version II. Knees, spine and shoulders were improved. The dummy was used by American car companies to test the effectiveness of seatbelts and knee injuries studies [1, 2, 3].

Fig. 1. Sierra Sam Dummy [2]

The skull of a dummy was made of vinyl leather and have a two-piece plate on the back, which allowed access to the entire dummy fixture. The rubber on the neck bracket was mounted cylindrically, with a fixed angle of 15 degrees towards the front. Dummy torso had a steel frame on the thoracic spine and steel ribs were mounted to the chest. Collarbone was cast aluminium with anatomically mapped blades. Front and rear of the dummy allowed access to accelerometers. A membrane was placed over the abdominal cavity. Six pairs of left and right ribs were combined with composite damping material. Ribs were mounted back to front-up to the thoracic spine. Leather breastbone was fixed to all that. The chest had sensors monitoring their movement. Stomach was also made with vinyl leather. The pelvis had a ball joint friction pistons serving to control the movement of the hip bone. The legs, like the rest of the body, were made of foam covered with vinyl. Knees and thighs may have been removed. Standard Hybrid II dummy was able to sit and stand. The lumbar spine had a power cable [4]. Thanks to all these improvements, Hybrid II dummy during tests provided more documentation than its predecessors.

Fig. 2. Hybrid II dummy of a 50 centile man [4]

In 1976, the family of Hybrid III dummies was created. It was intended primarily for testing head-on collisions [1]. It is a group of dummies with a very well mapped features of a human body and has good quality sensors. This kind of dummies was used as a model for such dummy structures as SID, EuroSIDA-I and-II BioRID.

Dummies for head-on crashes

Dummy of a 50-centile man

The primary dummy from Hybrid III “family” was a 50-centile man whose silhouette was created in the laboratory of General Motors in the United States. His first début took place in 1976 and is known as Crash Test Dummy. It is used in all tests conducted by the Insurance Institute for Road Safety. It was primarily created to measure the forces and accelerations during accidents and it is used for head-on collisions. 50-centile Hybrid III reflects an average male of 172 cm height and weight of 78.4 kg. Dummy was introduced by General Motors, and is now available at FTSS and the Society of Automotive Engineers, Biomechanices Committees and NHTSA [5, 6, 7, 8].

The dummy has been revised, with the aim of improving biomechanical capabilities of movement, as well as working to improve the ankle joint and foot.

Dummy head is made of aluminium and coated with rubber. In the interior of the head includes three sensors which measure the angular head displacement, the force of impact, and the acceleration to which the head is subjected during a collision with an obstacle [9].

The neck, which is shown in figure 3b. Includes a potentiometer, whose task is to measure the deflection of the spine against the chest. The purpose of the sensors in the neck is also measuring the force which causes deflection and stress values

a) b)

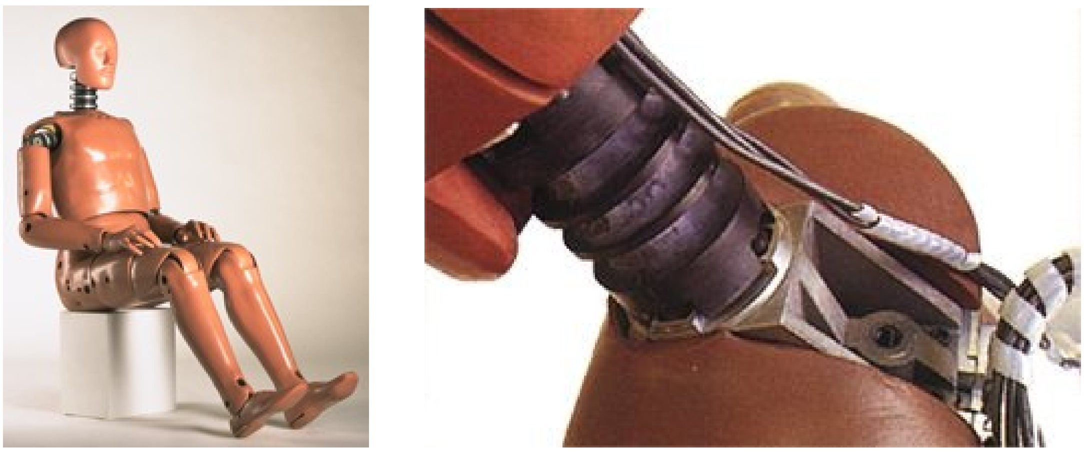
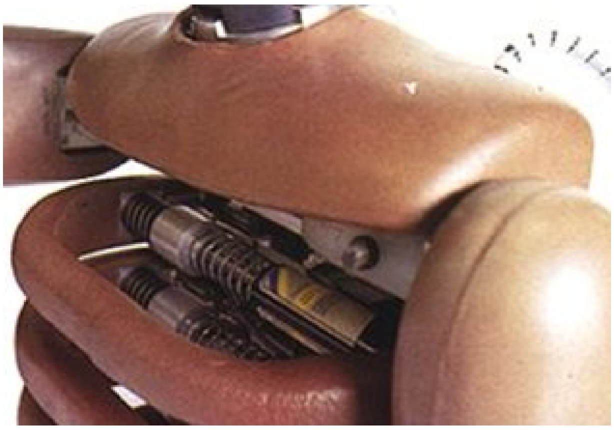


Fig. 3. Hybrid III Dummy: a) view of a 50 centile man, b) the neck of a dummy used for crash tests [9]

a)



b)

Fig. 4. Hybrid III Dummy: a) chest, b) view of a whole chest [9]

which occur during the movement backward or forward during an impact [9].

The chest is made up of six steel ribs of high strength (Fig. 4). The material has been selected to exhibit damping capabilities. The chest of Hybrid III dummy bends in a manner similar as in the case of humans. The ribs have also been made in accordance with the anatomy of a human body. The ribs are attached to the spine and breastbone [10]. Chest of the Hybrid III family dummies has fitted sensors whose task is to measure chest displacement during collisions. The design of the chest also allows injury analysis with fastened safety seatbelts and a head-on collision at high speed. These sensors also measure the acceleration, velocity and displacement of the chest [9]. Collarbone is a two-piece, made of aluminium. It has mounted set of sensors to collect information on the behaviour of shoulder belts during a collision [10].

In the case of Hybrid III dummies, whose stature can be seen in figure 3, pelvic is not treated in isolation but it is included into the upper parts of legs. This also includes thighbone, knee and hip joint. The use of the sensor in the thighs gives a picture of fractures or dislocation of the lower body in the event of a collision. The sensors that are placed in the knees measure the forces during knee impact against the dashboard.

The lower parts of the legs of dummies include mounted sensors that measure the deviation during the collision. Thanks to these sensors it is also known at what pressure and tension tibia and fibula bones have been damaged or broken [9].

Feet of dummies are not equipped with sensors. Their damage is determined by the destruction of the space in which they were placed during an accident [10].

Before testing, each of the Hybrid III dummy passed calibration. During sudden movements and stops the accuracy of bending the neck is verified. During the performance of tests, the dummy is equipped with dozens of sensors to record data at the time of an accident, and then the information is sent to a computer. The great advantage of these dummies is the interchangeability of parts in the case of damage.

Dummy of a 95-centile man

A 95-centile male stands out in the Hybrid III family of dummies, which was shown in figure 5. It is the biggest dummy used for crash tests. Its height in the upright position is 188 cm, while in a relaxed position equals 184 cm with weight of 100 kg [11]. Dummy has the characteristics of the largest American population that results from anthropometric surveys. Biomechanical reactions are similar to those of the dummy of a Hybrid III 50-centile male. A 95-centile male dummy is used to assess vehicles and the military safety, in particular, examine the integrity of the seats.

Fig. 5. A 95 centile man from Hybrid III family [12]

The skull is one piece of cast aluminium, coated with vinyl leather. Neck are segmented pieces of rubber, and its structure is made of aluminium. In the middle of the structure, as in all adult dummies Hybrid III, is located the centre cord. The result is an accurate reflection of the same movements as of man's neck [12, 13].

Chest also has six ribs, made of high-strength steel on the basis of damping material. The damping material allows for the development of accurate force-deflection characteristics of the chest, similar to the characteristics of a man. Breastbone includes potentiometer measuring rotary deviation. The lumbar spine of a dummy is specially shaped. There are no buckles, which allows the use of a dummy in an upright, as well as sitting position. The axis of the lumbar spine cord includes a cord that enhances durability and provides a wide range of spinal response to stimuli. The pelvis is cast aluminium and covered with polyurethane foam and vinyl leather. The thighbone and tibial bones include apparatus to predict bone fractures, and also to assess the injury of knee ligament, thighbone and tibia [12].

Dummy of a 5-centile woman

Another adult dummy in the Hybrid III family is a 5-centile female (Fig. 6). Dummy maps the woman of short height – 150 cm and weight of 50 kg. This dummy represents the smallest piece of adult women population. The woman dummy is of diminutive size, the width of shoulders is 39 cm, and hip width equals 30 cm. Knee height has the dimension of 39 cm [11]. Originally, the dummy was developed in 1988, and in 1991 was used to assess seats in cars. Then in 1997 it was used to improve the possibilities of the dummy to assess air-bags. A 5-centile woman dummy also offers the possibility to investigate the behaviour of the chest during an accident.

Fig. 6. Dummy of a 5 centile woman of Hybrib III [14]

The skull is made of cast aluminium pieces with removable vinyl leather. The neck is covered with rubber, and its centre includes aluminium construction with the central cable / cord. This allows for accurate simulation of the dynamic torque i.e. rotation, bending and straightening. Six ribs are made of a polymer-based damping material of high durability. The material is attached to the spine to simulate the human body. The dummy's body perfectly reflects the qualities of a human. Accelerometers are mounted on the breastbone and parallel on the spine. They allow accurate measurement even in high-compression state. Female 5-centile dummy is also equipped with a potentiometer and measuring equipment to measure the deflection between the spine and breastbone [14].

Lumbar spine provides straight and erect sitting position. The pelvis is cast aluminium and covered with vinyl leather. Thighs are designed to best capture the characteristics of the human body and behave quite naturally during an impact. They take a full range of displacement of the knee and tibia. Strength is processed by the transducers and thus it is known at which power the lower limb injury occurs [14].

Dummies of 3, 6 and 10-year-old children

Dummy figure representing a 3-year-old child (Fig. 7a) was created by the UAE in cooperation with NHTSA. The skull of such a dummy was made of fibreglass, and was coated with vinyl leather. This version of the dummy has a three-axis accelerometers which measure head injuries and one accelerometer to measure the rotation of the head. The neck is built in the same way as for other dummies from Hybrid III "family". It consists of flexible segments and in the middle there is a cable to prevent it moving and extending. The spine is made of steel, and the ribs are made of high-strength steel, however, have the ability to damp vibrations. Breastbone is made of aluminium and has accelerometers that record acceleration during head-on collision. Vertical movements of ribs have been reduced by the introduction of the ribs guides. The lumbar spine is made of cylindrical rubber. Hip bones are welded construction of aluminium axle with strain gauge sensors on each hip bone. The two hip acetabulums were placed uniaxial load cells. In the back of the pelvis there is a triaxial accelerometer. Bones of the dummy are urethane [15, 16].

Dummy was designed in 1993, but the finishing improvements were made in 1997. A 6-year-old child (Fig. 7b) is a dummy adapted to the latest head-on collisions. The construction of the dummy was modelled on adult Hybrid III dummies.

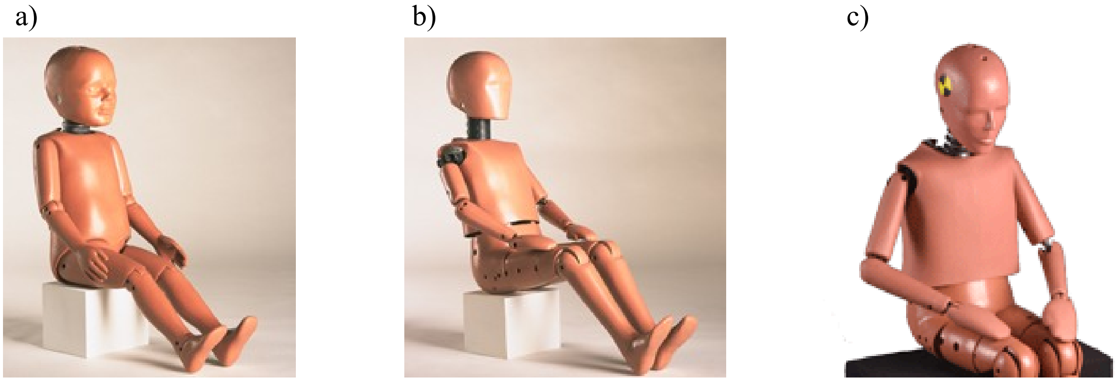


Fig. 7. Children dummies: a) 3-year-old, b) 6-year-old, c) 10-year-old [16]

The skull is composed of two aluminium cast parts, which have been coated with vinyl leather. Measuring mechanisms are arranged in the same way as in the case of a 3-year-old child. The neck is also identically constructed and has a cable limiting the movement. The ribs are made of high-strength steel. Breastbone is made of aluminium and the accelerometers connected to it. The ribs have the guides performing the same function as in the case of 3-year-old child dummy. Collarbone are two parts made of aluminium, which along with blades form an integral whole. Construction of the dummy is made of welded steel frame, covered with polyurethane foam and vinyl leather. The lumbar spine has load cells. The pelvis is formed in a sitting position. On each hip bone, made of aluminium, there are biaxial strain gauges. Triaxial accelerometer is located at the back of the pelvis [17].

A 10-year-old child version of a dummy figure 7c combines the features of a 5-centile Hybrid III woman and 6-year-old child Hybrid III. The skull is made of two aluminium parts. It is covered with vinyl leather. Accelerometers are placed in the same way as in the case of other Hybrid III children. The neck has a central cable inside. The neck has the ability to calibrate to bend or upright positions. The ribs are made in the same way as in the case of a 6-years-old child. Collarbone and bridgebone are constructed in the same way. The lumbar spine is made of rubber in the shape of cylinders. There is also an adjustable lumbar support which allows for positioning. The pelvis as in the case of Hybrid III is cast aluminium, and hip bones are biaxial strain gauges. Strain gauge is also located at the back of the pelvis [18].

Fig. 8. THOR dummy [20]

THOR dummy

THOR, which is shown in figure 8 as another dummy used for biomechanical testing. This advanced dummy is the successor to Hybrid III dummies. Its structure is more akin to the construction of a human body than other dummies. This can be seen mainly in the spine and pelvis areas [19]. THOR dummy was designed by NHTSA in 1995.

Dummy face includes a lot of sensors to enable a more detailed analysis of injury during a collision than for example in the case of Hybrid III dummies. The sensitivity of the sensors and recording capabilities are also higher than Hybrid III family dummies. Currently, this type of dummy is in a transition process from the English system to the metric system. The modernization of its components is also pending.

The pelvis and hips of these dummies more carefully reflect human traits. The same applies to the skull, and the upper arm elements and the lower abdomen. However, this is not a dummy used for tests in the same extent as Hybrid III family [20, 21].

Dummy neck has been improved in many directions of kinematic similarity to humans. In this way it is possible to accurately determine the trajectory of the head during a collision with a different speed and acceleration.

The ribs have been improved, have an elliptical shape and resemble human ribs. The torso has sensors which measure the deflection of the chest in four different points. The abdomen of THOR dummy is designed to measure compression of the belts in a number of points depending on the type of belts.

The pelvis consists of instrumentation, including three axle load bearings at each hip joint. The acetabulums contain strain gauges measuring the forces transmitted through the thighbones. There are also sensors monitoring the load of seatbelts. THOR dummy provides the accurate transmission of axial load forces through thighbones down to the pelvis. This type of dummy is able to obtain a measure for more than a hundred channels of different types of damage [13].

A great advantage of THOR dummy is good repeatability and ease of assembly and disassembly of particular segments [22].

TNO-10 dummy

TNO-10 dummy (Fig. 9) is mainly designed to test safety seatbelts in cars that stimulate a road accident. The dummy has features of 50% of the male population. A characteristic feature of the dummy is that it has only one leg and arms.

Fig. 9. TNO-10 dummy [23]

This type of dummy mainly consists of six parts, which are connected by connectors allowing movement in the sagittal plane.

The head is made of polyurethane reinforced with polyester. The head is able to rotate around the joint. However, the neck is made up of six high polyurethane concrete plates around the steel roller chain. The stiffness of the neck is adjusted by means of a tensioning device. The frame of torso consists primarily of a steel frame covered with polyurethane. The spine is a steel roll form and ribs are made with a steel structure attached to the breastbone. The upper part of the legs, that is thighs, is made of steel frame coated with polyurethane. Everything is made to be able to reproduce the human knee joint. Implementation of the hip joint and the proper design allows room for six steel weights. The shank is made of stainless steel and coated with polyurethane. Dummy uniform is made of cotton and reinforced by 200 mm wide belts around the hips. It is tailored in such a way as to hold only one leg. The dummy chest includes soft pillows that compensate for the rigidity of the chest [23].

THUMS 4 dummy

A very interesting version of the dummy, which is shown in figure 10 is THUMS 4 developed by Toyota Motor Corporation. Its body model is based on previous generation of dummies i.e. it has the same skeleton bones, sinews, ligaments, and brain (Fig. 11). However, the difference lies in the fact that this type of dummy is fine-tuned and reflected internal organs (heart, lungs, liver), similar to a human. This is an extremely important feature of the dummy because when it comes to an accident and injuries, we will be able to carry out a thorough analysis of the operation of the seatbelts and an air bag. THUMS 4 makes it possible to determine the place of organs damage, the degree of damage and determine whether there was internal bleeding [24, 25].

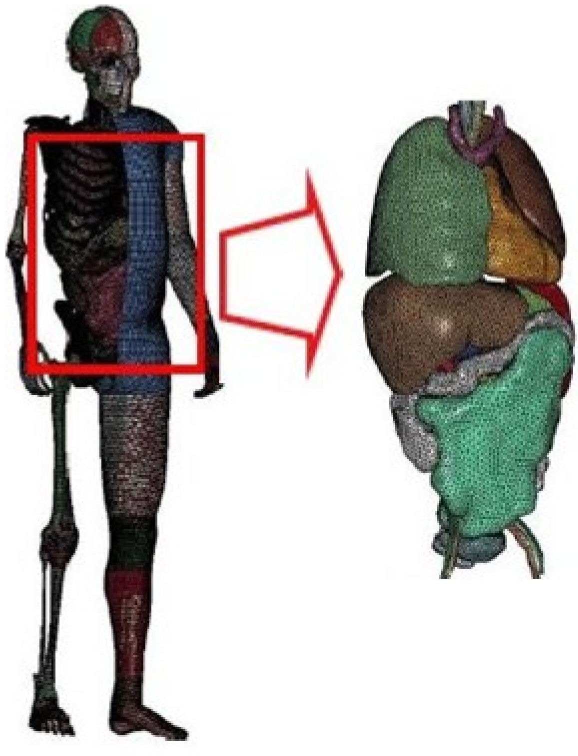


Fig. 10. THUMS 4 dummy [19]

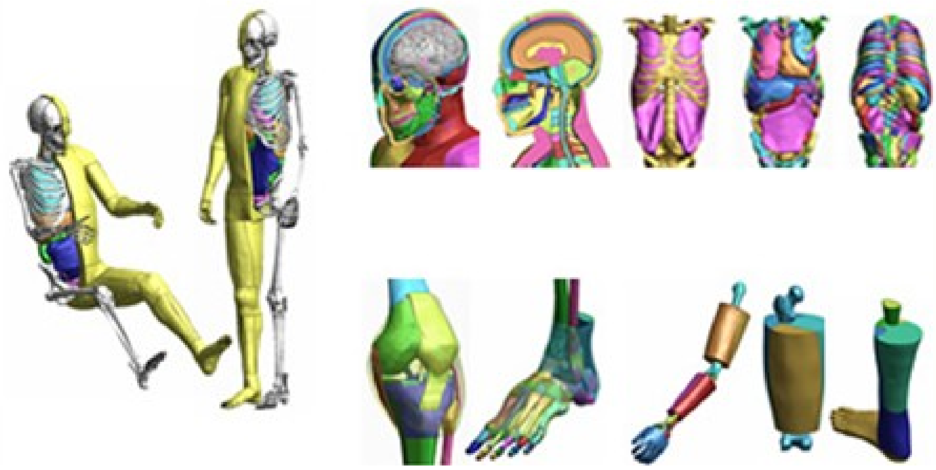


Fig. 11. THUMS 4 dummy body [25]

Toyota has developed this type of dummy with a computerized tomography scan (CT scan) that is very precise measurements of the depth of internal structures of the human body. So precisely constructed dummy allowed to obtain data and apply them to the development of side air bags, seats, which also helps to reduce carvical spine injuries [25].

Dummies for broadside crashes

SID AND EuroSID-1 dummies

Dummy used for broadside crashes is SID (Fig. 12b). There are two versions of the dummies. The first one is used by American engineers. Whereas, EuroSIDA-1 dummy, with the full name of European Side Impact Dummy (Fig. 12), created in accordance with European Directive 96/27/EC and ECE 95 Regulations represents a 50-centile male. The difference between SID and EuroSID-1 lies in the fact that the European version has no forearms, and SID version has only a torso. This is to expose the ribs to direct impact forces. However, despite of removed arms, dummy mass does not change, because the chest was additionally loaded. Due to the construction of these dummies, there is also variation in the results of research carried out by European and American engineers. The main

a) b)

Fig. 12. Dummy: a) EuroSID-1, b) SID [8, 26]

difference is that the European dummy is placed only on the front seat, and the impact is not absorbed directly through the chest, but also through half of the arm. The situation looks different in the case of the American dummy that can be placed on the back or front seat and the whole force of impact is absorbed through the chest. Thanks to these dummies it is also possible to assess spine and ribs slowdown [6].

EuroSIDA-1 dummy with its chest structure resembles Hybrid III dummy [1]. The difference between them lies in the fact that 5 pairs of ribs coated with a material whose function is to dampen vibrations. Three ribs have sensors that measure the pressure on the chest during the impact and the speed with which it occurs. Sensors are also located on the abdomen. Their main task is to measure the forces that can cause damage to internal abdominal organs. This type of dummy also has sensors in the pelvis, which measure the force with which it comes to pelvic fractures or dislocations.

The female equivalent of a SID dummy is SID-II which presents a 5-centile woman. SID dummy huge advantage is that it has been equipped with 212 sensors located throughout the body, which are able to collect 1000 pieces of information per second during the test [26]. SID dummy design is made to measure compression and shocks of chest, spine and internal organs [19].

EuroSID-2 dummy

EuroSIDA-2 dummies, which are shown in figure 13 is a new generation of EuroSIDA-1 dummies. They include a number of innovative improvements, and for this reason they are readily used for crash tests.

The construction of the head is based on the type of Hybrid III dummies. It is equipped with six-axis with upper neck load which allows the assessment of injury and head contacts. The neck is so developed that it performs lateral flexions in the same way as humans. The neck can be calibrated and you can easily replace worn parts [27, 28].

a) b)

Fig. 13. EuroSID-2 dummy: a) male, b) female dummy [27]

The abdomen consists of three modules of ribs with a hydraulic shock absorber which is mounted inside steel spring. The abdomen has linear potentiometers to measure deflection of ribs centre. EuroSIDA-2 chest is better than it was in with the older model. The rib module has linear guides that are modified to reduce friction at high loads. Collarbone and shoulder blade are more flexible and have special Teflon buttons whose purpose is to reduce friction. In this type of dummies the abdomen is more deformable with additional strain gauges to measure the loads onto the abdomen. The abdomen also has similar properties to human anatomy [27].

The pelvis consists of two deformable wings. Urethane hip bones are attached to the aitchbone. The lumbar spine and the pubic symphysis is a strain gauge. The pelvis is covered with vinyl leather, and underneath it there is urethane foam. Deflection angle of the pelvis during the impact is measured using the tilt sensor [27].

BioSID dummy

BioSID dummy was developed by General Motors and the Society of Automotive Engineers, and created by SAE figure 14. It is used in the study of crashworthiness during broadside impact and assess the damage that has arisen. With this type of dummy it may measure chest, ribs and pelvis deflection, as well as determine injuries during the accident [29].

Fig. 14. BioSID dummy [29]

The dummy with its dimensions and size is close to a 50-centile male Hybrid III. Ranges of motion, mass and gravity centres of particular parts of the body are very similar to those of 50% of the American population.

Dummy head is very similar to a 5-centile female Hybrid III, and its behaviour during impact resembles human behaviour. The head has a urethane shield whose task is to prevent interference from the chin. Cable located in the neck was insulated with plastic sleeves, which causes the elimination of mechanical noise. Special ground passing through the dummy's body minimizes electrical noise. Lower and upper parts of the neck contain sensors [29].

The upper part of the torso consists of six ribs mounted on one side transversely to the thoracic spine. Opposite the lowest rib on the collision side, are mounted side triaxial accelerometers. The ribs are made of high quality steel. The shape of the ribs resemble flat-sided ovals [29].

Neck and arm are mounted on a rubber pad which allows you to move the arm strength of influence and more accurate measurements of acceleration [29].

The lower part of the torso constitutes erect lumbar spine. The skeleton of this part was bent with bolts but it is possible to detach urethane iliac wings. Thighs are connected to ball-shaped bar joints. It is possible to remove the cover body from the pelvis with a zip on the back. It is also possible to mount sensors directly at the base of the spine.

Upper and lower limbs are the modification of limbs of Hybrid III dummies. Knees are made of steel blocks [29].

Dummies for rear crashes

BioRID-2 dummy

BioRID-2 (Fig. 15) is a dummy designed to assess injuries in rear collisions of vehicles [5]. It was designed by Chalmers University in Goeteborg in Sweden. BioRID-2 is primarily designed to check for cervical spine injury which occurs during a collision. The dummy is also used in assessing safety seatbelt tensioners. A characteristic feature of BioRID-2 dummy is its spine, which consists of 24 vertebrae: 7 cervical, 12 thoracic vertebrae and five lumbar vertebrae [3, 19]. This approach allows us to take a natural sitting position and more precise movements of the neck. The connection with torsion washers and urethane bumpers including stimulating muscles provides high performance. Inside the silicone shell, connected with the vertebrae by pins is the spine. The full picture of the spine has been in figure 15b and 15c.

Adequate space for cervical vertebra is ensured by modifying the leather on the neck. The back of the head is designed to accommodate output cables. The task of the head is to make room for measuring equipment, which includes a triaxial accelerometer blocks. BioRID-2, in addition to 7 cervical vertebrae, is also equipped with an occipital plate. The cervical vertebrae are of different hardnesses depending on the position. There are twelve thoracic vertebrae T1-T12. First vertebra is located in the traditional position, in the lower part of the neck and is made of aluminium. Further vertebrae from T2 to T12 are constructed of urethane bumpers. All vertebrae are connected to each other using stainless steel pins, which alternately block sets of torsional steel washers. This type of washers allow you to set the vertebra in a particular position. T4 washer is different from the others, because its function is to store the mounting of a fluid-filled damper. T4 vertebra can accommodate two muscles in the form of tubes, lying on opposite sides. The last part of the spine are five lumbar vertebrae. Upper and lower limbs in the BioRID-2 dummy are identically constructed as in the case of a 50-centile male of Hybrid III "family" [30].

Conclusions

The paper presented different versions of dummies which are selected depending on the realized collision. They very well reflect the characteristics of the human body. They are made of good quality materials and have dozens of sensors performing various measurements. This allows us to make a careful analysis of injury under certain delays. This gives a complete picture of the damage to the human body which occur during different types of accidents at given speeds. This kind of dummies are also used to reproduce complex road accidents.

Comparing anthropometric dummies with its predecessors, it may observe evident ability and ease to replace body parts and access to equipment. Modern dummies are designed for specific types of collisions. For this reason, their improvement is done in those parts that are most at risk of an accident and provide important information. Modern solutions make it possible to use a dummy in seated and standing positions. It was not possible to note that in the case of their predecessors.

a) b) c)

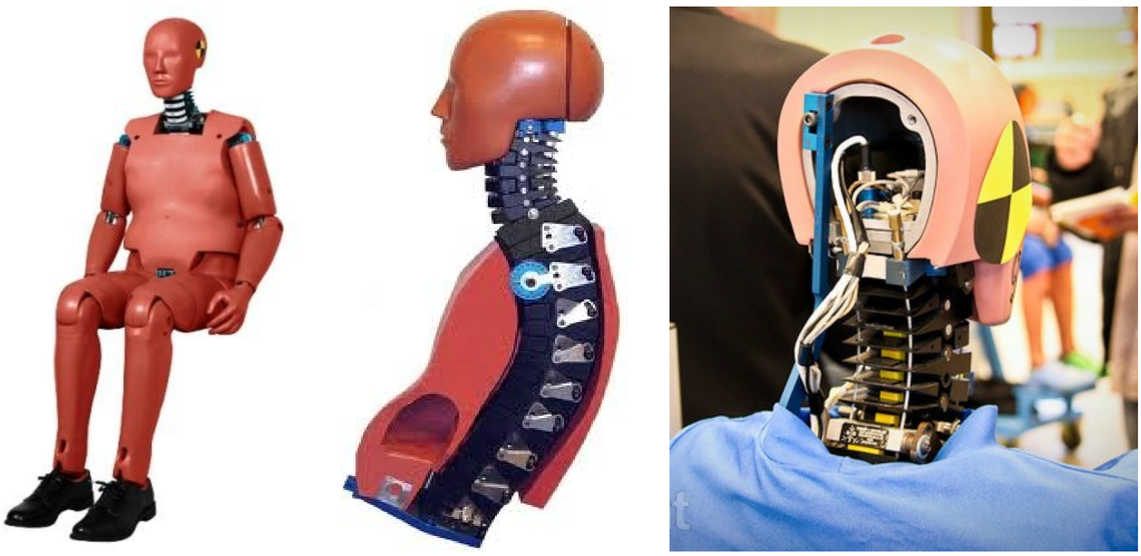


Fig. 15. BioRID-2 dummy: a) general view, b) BioRID-2 dummy spine – side view, c) BioRID dummy spine – rear view [31]

References

1. NAHUM A., MELVIN J.: Accidental Injury, biomechanics and prevention. Springer + Business Media, INC, New York, 2002.
2. http://translate.google.pl/translate?hl=pl&sl=en&tl=pl&u=http%3A%2F%2Fen.wikipedia.org%2Fwiki%2FCrash_test_dummy (access 07.05.2013)
3. DAVIDSSON J., SVENSSON M.Y., FLOGAARD A., HAALAND Y., JAKOBSSON L., LINDER A., LOEVSUND P., WIKLUND K.: BioRID I: a new biofidelic rear impact dummy. Conference: Preceedings of the 1998 International Ircobi Conference on the biomechanics of impact, Sweden, 1998.
4. http://www.humaneticsatd.com/crash-test-dummies/frontal-impact/hybrid-ii-50th (access 07.05.2013)
5. VIANO D.: Role of the seat in rear crash safety. SAE International, 2002.
6. WICHER J.: Bezpieczeństwo samochodów i ruchu drogowego. Wydawnictwo Komunikacji i Łączności, Warszawa 2002.
7. http://translate.google.pl/translate?hl=pl&sl=en&u=http://inventors.about.com/od/sstartinventions/a/SierraSam.htm&prev=/search%3Fq%3DSierra%2BSam%2Bbudowa%26hl%3Dpl%26client%3Dfirefoxa%26hs%3DE00%26rls%3Dorg.mozilla:pl:official%26prmd%3Dimvns&sa=X&ei=KaOGUJDvCYrStAauooGwCQ&ved=0CCUQ7gEwAA (access 12.05.2013)
8. http://www.autocentrum.pl/euroncap/opisy-testow/manekiny (access 07.05.2013)
9. http://www.nowe.mojeauto.pl/cms/?id=19 (access 07.05.2013)
10. http://www.humaneticsatd.com/crash-test-dummies/frontal-impact/hybrid-iii-50th (access 12.05.2013)
11. http://www.wfp.asp.krakow.pl/ergonomia2/pliki/Antropometria.pdf (access 07.05.2013)
12. http://www.humaneticsatd.com/crash-test-dummies/frontal-impact/hybrid-iii-95th (access 07.05.2013)
13. http://translate.google.pl/translate?hl=pl&sl=en&tl=pl&u=http%3A%2F%2Fwww.fire.tc.faa.gov%2F1998Conference%2Fpresentations%2FDBeach.pdf&anno=2 (access 11.05.2013)
14. http://www.humaneticsatd.com/crash-test-dummies/frontal-impact/hybrid-iii-5th (access 12.05.2013)
15. www.humaneticsatd.com/crash-test-dummies/pedestrian/hybrid-iii-5th (access 07.05.2013)
16. http://www.humaneticsatd.com/crash-test-dummies/children/hybrid-iii-3-year-old (access 12.05.2013)
17. http://www.humaneticsatd.com/crash-test-dummies/children/hybrid-iii-6-year-old (access 11.05.2013)
18. http://www.humaneticsatd.com/crash-test-dummies/children/hybrid-iii-10-year-old (access 11.05.2013)
19. ALEXANDRU R.C.: The Evolution of the Crash Test Dummy. Autoevolution, 2010, 06.
20. http://pl.wikipedia.org/wiki/Wstrz%C4%85%C5%9Bnienie_m%C3%B3zgu (access 07.05.2013)
21. http://www.humaneticsatd.com/crash-test-dummies/pedestrian/hybrid-iii-50th (access 12.05.2013)
22. JAŚKIEWICZ M.: Symulacyjne badania działania ochronnego zagłówków aktywnych. Rozprawa doktorska, Politechnika Świętokrzyska, Kielce 2007.
23. http://www.humaneticsatd.com/crash-test-dummies/frontal-impact/tno-10 (access 12.05.2013)
24. http://www.humaneticsatd.com/crash-test-dummies/pedestrian/hybrid-iii-95th (access 07.05.2013)
25. http://www.toyotaglobal.com/innovation/safety_technology/safety_measurements/thums.html (access 07.05.2013)
26. http://www.motogazeta.mojeauto.pl/Aktualnosci/Wspolny_manekin_do_testow,a,3214.html (access 07.05.2013)
27. http://www.humaneticsatd.com/crash-test-dummies/side-impact/es-2 (access 12.05.2013)
28. http://www.anatomia.webd.pl/szkieletowy.html (access 07.05.2013)
29. http://www.humaneticsatd.com/crash-test-dummies/side-impact/biosid (access 11.05.2013)
30. http://www.humaneticsatd.com/crash-test-dummies/rear-impact/biorid-ii (access 11.05.2013)
31. http://www.e-autonaprawa.pl/encyklopedia/biorid-ang-biofidelic-rear-impact-dummy-i/1971/ (access 07.05.2013)

Others

32. MILES S.: A day in the life of a crash test dummy at the Volvo Car Safety Centre. Poceket-lint, May 2010.
33. http://www.humaneticsatd.com/crash-test-dummies/side-impact/sid-iis (access 07.05.2013)