4
Anthropomorphic Test Devices

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Anthropomorphic test devices (ATDs), commonly referred to as dummies, are mechanical surrogates of the human that are used by the automotive industry to evaluate the occupant protection potential of various types of restraint systems in simulated collisions of new vehicle designs. Current ATDs are designed to be biofidelic; that is, they mimic pertinent human physical characteristics such as size, shape, mass, stiffness, and energy absorption and dissipation, so that their mechanical responses simulate corresponding human responses of trajectory, velocity, acceleration, deformation, and articulation when the dummies are exposed to prescribed simulated collision conditions. They are instrumented with transducers that measure accelerations, deformations, and loading of various body parts. Analyses of these measurements are used to assess the efficacy of restraint system designs.

Dummies are classified according to size, age, sex, and impact direction. There are adult male and female dummies of different sizes, and child dummies that represent different ages. There are dummies that are used to assess frontal collision protection and dummies for side impact collision evaluations. The most current frontal impact dummies have sufficient biofidelity to be used to evaluate rear-end collision protection. However, neither the current frontal nor side impact dummies have the necessary biofidelity, measurement capacity, or durability to evaluate the other's impact direction. The midsize adult male dummy is the most utilized size in automotive restraint testing. It approximates the median height and weight of the 50th percentile adult male population. The heights and weights of the small female and large male adult dummies are approximately those of the 5th percentile female and the 95th percentile male, respectively. Child dummies have the median heights and weights of children of the specific age groups that they represent without regard to sex. Key dimensions and weights for various sizes of dummies are given in Table 4.1.

The history of dummy development is summarized elsewhere.[1–3] Table 4.2 gives a chronology of the dummies that have been used in restraint system testing by the United States automobile industry. The first crash test dummy used by the domestic automobile industry for restraint system testing was Sierra Sam, a 95th percentile adult male dummy that was developed by Sierra Engineering in 1949 for ejection seat testing by the U.S. Air Force. The early versions of dummies were used to assess the integrity of restraint systems during simulated frontal collisions. These dummies mimicked human shape and weight and were quite durable. However, they lacked human-like stiffness in the important areas such as the head, neck, thorax, and knee, and they were not extensively instrumented to measure responses that could be associated with all the pertinent injury concerns. Current dummies have been designed to be biofidelic in their impact responses and are extensively instrumented. This chapter discusses the pertinent

A. M. Nahum et al. (eds.), *Accidental Injury*

TABLE 4.1. Key dimensions and weights for various sizes of dummies.

Key dimensions and weights	Infants			Children		Adults (percentile)		
	6 mo	12 mo	18 mo	3 yr	6 yr	5th female	50th male	95th male
Dimensions (mm)								
Erect sitting ht.	439	480	505	546	635	812	907	970
Buttocks to knee	170	198	221	284	381	521	589	638
Knee to floor	125	155	173	221	358	464	544	594
Shoulder to elbow	130	150	160	193	234	305	366	381
Elbow to fingertip	175	198	213	254	310	399	465	503
Standing ht.	671	747	813	953	1,168	1,510	1,751	1,873
Weights (kg)								
Head	2.11	2.49	2.72	3.05	3.48	3.68	4.54	4.96
Neck	0.29	0.34	0.35	0.43	0.41	0.81	1.54	2.04
Torso	3.04	4.38	5.22	6.61	10.76	24.14	40.23	53.00
Upper extremity	0.85	1.18	1.31	1.79	1.98	4.67	8.53	10.94
Lower extremity	1.53	1.31	1.60	2.63	4.28	13.52	23.36	31.79
Total wt.	7.82	9.70	11.20	14.51	20.91	46.82	78.20	102.73

TABLE 4.2. Chronology of notable dummies used by domestic auto industry.

Year	Dummy	Key features	Deficiencies	Current usage
1949	Sierra Sam, 95th male (frontal impacts)	Human-like exterior shape and body weight; articulated limb joints; durable	Stiffness not biofidelic; limited instrumentation; poor reproducibility	None
1966	VIP series (very important people), 5th female, 50th and 95th male (frontal impacts)	Human-like shape and body weight; articulated limb joints; rubber neck; human shaped pelvis; instrumented to measure head and thoracic spine accelerations and femur loads	Stiffness not biofidelic; limited instrumentation; poor repeatability and reproducibility	None
1967	Sierra Stan, 50th male (frontal impacts)	Human-like shape and body weight; articulated limb joints; segmented neck; plastic shell for rib cage; instrumented to measure head and thoracic spine accelerations and femur loads	Stiffness not biofidelic; limited instrumentation; poor neck bending response	None
1968	Sophisticated Sam, 50th male (frontal impacts)	Frangible clavicles, humeri, radii, ulnas, femurs, tibias, fibulas, and patellas	Fracture levels of bones poorly controlled	None
1970	Sierra Susie, 5th female	Same features as Sierra Stan from which it was scaled	Same as Sierra Stan	None
1972	GM Hybrid II, 50th male (frontal impacts)	Uses parts from VIP-50 and Sierra Stan; human-like shape, body weight, and ranges of motion of some articulated joints; repeatable, durable, and reproducible; specified for use in FMVSS 208 until 9/97	Stiffness not biofidelic; limited instrumentation	None
1976	GM Hybrid III, 50th male (frontal and rear impacts)	Based on GM ATD-502, which was developed under a NHTSA contract; human-like shape and weight; biofidelic response for head, neck, chest, knee; extensively instrumented; human-like automotive seated posture; excellent biofidelity, repeatability, reproducibility, and durability	Not appropriate for side impact studies	worldwide reg.

TABLE 4.2. *Continued*

Year	Dummy	Key features	Deficiencies	Current usage
1979	NHTSA/SID, 50th male (side impact)	Modified Hybrid II with chest design for side impact loading	No shoulder or arm; not biofidelic in response; limited instrumentation; not recommended by ISO for side impact testing	None
1982	GM 3-year-old air-bag dummy	Modified ARL VIP-3C dummy with foam-filled rib cage and segmented neck structure tuned to give human-like response; instrumented to measure loads associated with airbag deployment injuries	Not designed to interface with child belt restraints	None
1985	Hybrid II–type 3- and 6-year-old dummies	Modified ARL—3 and 6 child dummies; specified by NHTSA in Part 572 for child restraint testing	Not biofidelic in impact response; limited instrumentation	USA reg.
1987	Hybrid III–type small female (5th), large male (95th), and 6-year-old (frontal and rear impacts)	Scaled from Hybrid III midsize male with same level of biofidelity and measurements capacity; incorporated into Part 572 by NHTSA	Not appropriate for side impact tests	Worldwide USA reg.
1989	EUROSID-1, 50th male (European side impact dummy)	Hybrid III dummy modified for side impact testing; unique neck, chest, abdomen, and pelvis	Marginal biofidelity; shoulder design and back plate imped rib deflection; limited instrumentation	Europe, Australia, Japan reg.
1989	BIOSID, 50th male (side impact)	Hybrid III dummy modified for side impact testing; "far side" mounted rib concept used for shoulder, thorax, and abdomen design; pelvis is modified EUROSID-1 design; extensively instrumented; acceptable biofidelity	Biofidelity could be improved; side impact testing only	Exp., worldwide
1990	CRABI, 6, 12, and 18 month	Designed to evaluate airbag interactions with rearward-facing infant restraints; biofidelic neck; incorporated into Part 572 by NHTSA	Head impact response may not be biofidelic	Worldwide USA reg.
1992	Hybrid III–type 3-year-old (frontal and rear impacts)	Designed to evaluate airbags and child restraints; scaled from Hybrid III 6-year old; incorporates pertinent features of GM 3-year-old airbag dummy; incorporated into Part 572 by NHTSA	Not instrumented nor durable enough for side impacts	Worldwide USA reg.
1997	TNO-Q3 (3-year-old child dummy for frontal and side impacts)	Replacement for TNO-P3; improved biofidelity and instrumentation; designed for frontal and side impacts; developed to replace TNO-P3 in European reg.	Not designed for air-bag interaction testing	Exp, worldwide

CRABI, child restraint air-bag interaction; Exp., experimental; FMVSS, Federal Motor Vehicle Safety Standard; GM, General Motors; NHTSA, National Highway Traffic Safety Administration; Reg., Regulation; SID, side impact dummy; TNO, Netherlands Organization for Applied Technical Research; ARL, Alderson Research Laboratory.

characteristics of the more notable frontal impact dummies (the Hybrid II and III families and the CRABI infant dummies) and side impact dummies (SID, EUROSID-1, BIOSID, and SID-IIs).

Hybrid II Dummy Family

The most used of the early frontal impact dummies was the Hybrid II midsize adult male dummy, which was developed by General Motors (GM) in 1972 to assess the integrity of lap/shoulder belt systems.[1,2] This dummy mimicked the size, shape, mass, and ranges of arm and leg motion of the 50th percentile adult male. It was instrumented to measured the orthogonal linear accelerations of the center of gravity of its head and a point prescribed in its "thoracic spine." Its femurs were instrumented to measure axial-shaft loading. The dummy was quite durable and gave repeatable responses (coefficient of variations of 10% or less) when subjected to repeat tests. Reproducibility was acceptable; that is, the design of the dummy was sufficiently defined by engineering drawings so that dummies manufactured to the specifications would give similar results under similar test conditions. In 1973, the GM Hybrid II was specified in the Federal Motor Vehicle Safety Standard 208 (FMVSS 208) as the dummy to be used for compliance testing of vehicles equipped with passive restraints.[4] It remained as a compliance dummy until September 1997.

In addition to the midsize male, Humanoid Systems developed Hybrid II–type small adult female and large adult male dummies by scaling the shapes and features of the midsize male.[1,2] These dummies had instrumentation capabilities similar to those of the Hybrid II midsize adult male. Also, a 3-year-old and a 6-year-old child dummy were developed. These two child dummies, along with the three sizes of adult dummies, became known as the Hybrid II Dummy Family. This family of dummies had two major deficiencies that limited their usefulness in assessing the efficacy of restraint systems: they lacked human-like response stiffness for their heads, necks, thoraxes, and knees, and they were sparsely instrumented.

Hybrid III Dummy Family

The Hybrid III Dummy Family consists of a small adult (5th percentile) female dummy, a midsize adult (50th percentile) male dummy, and a large adult (95th percentile) male dummy (Fig. 4.1), and a 3-year-old and a 6-year-old child dummy (Fig. 4.2). These dummies were developed to addressed the biofidelity and instrumentation deficiencies of the Hybrid II family. Because their necks mimic human bending response in flexion and extension, these dummies can be used in rear as well as frontal collision evaluations. The following is a discussion of the development of the Hybrid III Dummy Family.

In 1972, GM initiated a research program to define and develop a biofidelic midsize adult male dummy, called Hybrid III, to replace the GM Hybrid II dummy. The Hybrid III[5,6] was designed to mimic human responses for forehead impacts, fore and aft neck bending,

FIGURE 4.1. Hybrid III family of adult dummies. The midsize male shown without its torso jacket exposing rib construction.

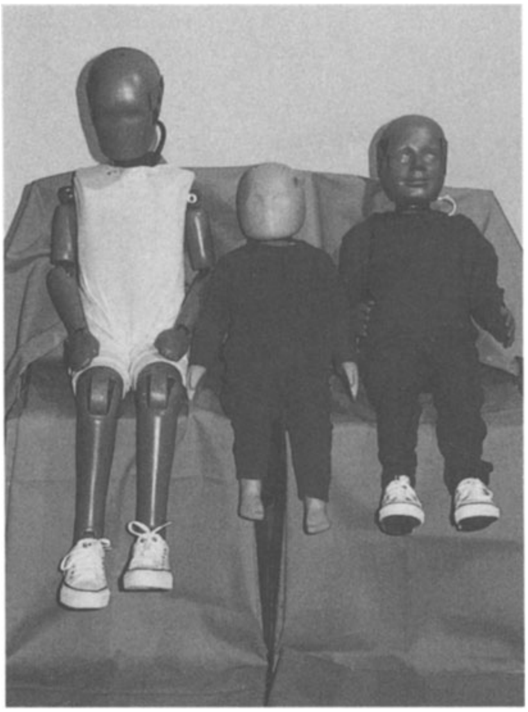

FIGURE 4.2. Child restraint airbag interaction (CRABI) 12-month-old infant dummy and Hybrid III 3- and 6-year old child dummies.

distributed sternal impacts, and knee impacts. Its head consists of an aluminum shell covered by vinyl skin having constant thickness over the cranium. The thickness of the skin was chosen to give human-like head accelerations when the forehead is impacted. The neck is made up of asymmetric rubber segments bonded to aluminum disks. A braided wire cable attached to end plates passes through the neck center. The top end plate is linked to the head with a single pivot joint to represent the atlanto-occipital joint of the human. This construction allows the neck to mimic human neck bending responses for flexion, extension, and lateral bending. The chest is composed of six steel ribs linked on one end to a leather part representing the sternum and on the other end to a rigid spine. Damping material is bonded to the inside of each rib to mimic the energy dissipation of the human thorax. The size of the ribs was chosen to mimic the dynamic sternal force-deflection response of the human thorax. The shoulder structure was designed to provide an appropriate interface with the shoulder belt. The abdominal part is a molded piece consisting of closed-cell foam with a solid vinyl skin. The lumbar spine is represented by a cylindrical curved rubber piece with two braided steel cables running through the center and attached to end plates. The curvature was chosen to give the dummy a human-like automotive seated posture. The pelvis consists of an aluminum casting of a human pelvic bone that is encased in vinyl molding to give the external shape of the pelvic region. Femurs and legs are made of steel shafts covered with a vinyl skin. Rubber pads are inserted in both knee areas under the skin to give human-like impact response. Ball joints are used for the hip and ankle joints. Other joints are constant-torque pin joints.

The instrumentation of the dummy is quite extensive and is noted in Table 4.3. Additionally, a deformable face[7] and a deformable abdomen[8] are available that can be used to assess the risk of facial bone fracture and abdominal injury due to lap belt submarining, respectively.

Because of its excellent biofidelity and measurement capability, GM petitioned the National Highway Traffic Safety Administration (NHTSA) in 1983 to allow the use of the Hybrid III midsize adult male dummy as an alternative test device to the Hybrid II for FMVSS 208 compliance testing of passive restraints. Its use was allowed in 1986. In 1990, GM filed a second petition requesting that the Hybrid II dummy be deleted from FMVSS 208 compliance testing. NHTSA deleted the Hybrid II in September 1997, making the Hybrid III midsize adult male dummy the only dummy allowed for FMVSS 208 testing and the only dummy specified for frontal restraint evaluation thoughout the world.

Since its creation in 1976, the Hybrid III midsize male dummy has undergone design changes to improve the biofidelity of its hips and ankle joints[9] and to increase its measurement capacity.[6] Because the Hybrid III is specified in worldwide regulations, all design

TABLE 4.3. Instrumentation for Hybrid III (HIII) family of dummies.

Dummy instrumentation	HIII-5 female	HIII-50 male	HIII-95 male	HIII-3-yr child	HIII-6-yr child
Head					
Accelerations (A_x, A_y, A_z)	Yes	Yes	Yes	Yes	Yes
Neck					
Head/C1 (F_x, F_y, F_z, M_x, M_y, M_z)	Yes	Yes	Yes	Yes	Yes
C7/T1 (F_x, F_y, F_z, M_x, M_y, M_z)	Yes	Yes	Yes	Yes	Yes
Shoulder					
Loads (F_x, F_z)	Yes	Yes	Yes	No	Yes
Thorax					
Spine acceleration (A_x, A_y, A_z)	Yes	Yes	Yes	Yes	Yes
Sternal deflection (δ_x)	Yes	Yes	Yes	Yes	Yes
Sternal acceleration (A_x)	Yes	Yes	No	Yes	Yes
Abdomen					
Lumbar (F_x, F_y, F_z, M_x, M_y)	Yes	Yes	Yes	Yes	Yes
Pelvis					
Acceleration (A_x, A_y, A_z)	Yes	Yes	Yes	No	No
Ilium (F_y)	Yes	Yes	No	No	Yes
Lower extremities					
Femur (F_x, F_y, F_z, M_x, M_y, M_z)	Yes	Yes	Yes	No	Yes
Tibia/femur displacement (δ_x)	Yes	Yes	Yes	No	No
Knee clevis (F_z)	Yes	Yes	Yes	No	No
Tibia loads and moments (F_x, F_y, F_z, M_x, M_y, M_z)	Yes	Yes	Yes	No	No

changes have to be approved by the various regulatory bodies.

In 1987, the Centers for Disease Control (CDC) awarded a grant to Ohio State University (OSU) to develop a multisized Hybrid III–based dummy family. To support this effort, the Mechanical Human Simulation Subcommittee of the Human Biomechanics and Simulation Standards Committee of the Society of Automotive Engineers (SAE) formed a task group of biomechanics, test dummy, transducer, and restraint-system experts. They defined the specifications for a small adult (5th percentile) female dummy, a large adult (95th percentile) male dummy, and a 6-year-old child dummy having the same level of biofidelity and measurement capacity as the Hybrid III midsize adult male dummy. Key body segment lengths and weights were defined based on anthropometry data for the U.S. population. Biofidelity response requirements for the head, neck, thorax, and knee of each size of dummy were scaled from the respective biofidelity requirements of the Hybrid III, midsize adult male dummy.[10,11] The dummies became commercially available in 1991.

In 1992, the SAE Hybrid III Dummy Family Task Group initiated a program to develop a Hybrid III 3-year-old child dummy. Again, this dummy was designed to have the same level of biofidelity and measurement capacity as the other Hybrid III–type dummies, except for the knee impact requirement and the leg instrumentation.[10] These items were omitted from the design requirements since knee impact is an unlikely event for a properly restrained 3-year-old. Since this dummy was to be designed to replace the GM 3-year-old airbag dummy[12] for evaluating unrestrained child interactions with deploying passenger airbags as well as to be used to assess the efficacy of child restraints, its sternum was instrumented to measure its response to the punch-out forces of deploying passenger airbags. Its instrumentation is summarized in Table 4.3. The dummy became commercially available in 1997.

The SAE Hybrid III Dummy Task Group has documented the designs of the Hybrid III

TABLE 4.4. Instrumentation for CRABI dummies.

Dummy instrumentation	CRABI—6 mo	CRABI—12 mo	CRABI—18 mo
Head			
Acceleration (A_x, A_y, A_z)	Yes	Yes	Yes
Neck			
Head/neck interface (F_x, F_y, F_z, M_x, M_y, M_z)	Yes	Yes	Yes
Neck/T. spine interface (F_x, F_y, F_z, M_x, M_y, M_z)	Yes	Yes	Yes
Shoulder (F_x, F_y)	No	Yes	Yes
Thorax			
Spine (A_x, A_x, A_x)	Yes	Yes	Yes
Abdomen			
Lumbar/pelvis interface (F_x, F_y, F_z, M_X, M_y, M_z)	Yes	Yes	Yes
Pelvis			
Acceleration (A_x, A_x, A_x)	Yes	Yes	Yes
Pubic loads (F_x, F_x)	No	Yes	Yes

small female, large male, 3-year-old child, and 6-year-old child dummies so that they can be incorporated into Part 572 of the U.S. Transportation Regulations, replacing their respective Hybrid II dummies. The dummies are well defined, durable and give highly repeatable and reproducible results. To date, all but the large male dummy have been incorporated into Part 572.

CRABI Infant Dummies

In 1990, a second SAE task group of the Human Mechanical Simulation Subcommittee was convened with the specific purpose of developing instrumented 6-month-old, 12-month-old, and 18-month-old infant and child dummies to be used to assess the injury potential associated with the interactions of deploying passenger airbags and rearward-facing child restraints if they are placed in the front seat of vehicles. The 12-month-old dummy is shown in Fig. 4.2. They are called child restraint airbag interaction (CRABI) dummies. Prototypes of these dummies were available in 1991. The size and weights of the dummies were based on anthropometry studies of the U.S. child population. Biofidelity response requirements were defined for the head and neck.[11] The instrumentation used with the dummies is given in Table 4.4. The designs of these dummies have been documented by the SAE so that they can be incorporated into Part 572 of the U.S. Transportation Regulations. To date, only the 12-month-old has been incorporated into Part 572.

Side Impact Dummies

There are four side impact dummies (SIDs) that are commercially available: SID, SID-HIII, EUROSID-1, and BIOSID. All four dummies were designed to be representative of the size and weight of the midsize adult (50th percentile) male. A fifth side impact dummy, SID IIs, has been developed under the Occupant Safety Research Partnership (OSRP) of the U.S. Council on Automotive Research (USCAR). This dummy is representative of the size and weight of a small adult (5th percentile) female or a 12- to 13-year-old adolescent.

SID was developed in 1979 by the University of Michigan Transportation Research Institute (UMTRI) under contract with NHTSA.[13–16] The SID is a Hybrid II dummy modified for side impact testing. It features a unique chest structure including a hydraulic shock absorber that links five interconnected steel ribs to the spine. The SID has no arm or shoulder structure. The chest is covered with vinyl flesh. The other body segments are those of the Hybrid II. Exterior size and shape are those of a 50th percentile adult male. Its instrumentation is given in Table 4.5 and includes measurement of linear

TABLE 4.5. Instrumentation for side impact dummies.

Dummy instrumentation	SID	SID-HIII	EUROSID-1	BIOSID	SID-IIs
Head					
Accelerations (A_x, A_y, A_z)	No	Yes	Yes	Yes	Yes
Neck					
Head/C1 (F_x, F_y, F_z, M_X, M_y, M_z)	No	Yes	No	Yes	Yes
C7/T1 (F_x, F_y, F_z, M_x, M_y, M_z)	No	No	Yes	Yes	Yes
Shoulder					
Loads (F_x, F_y, F_z)	No	No	Yes	Yes	Yes
Deflection (δ_y)	No	No	No	Yes	Yes
Arm (A_x, A_Y, A_z, M_Y, M_z)	No	No	No	No	Yes
Thorax					
Spine acceleration (A_x, A_Y, A_z)	Yes	Yes	Yes	Yes	Yes
Rib deflection (δ_y)	No	No	Yes	Yes	Yes
Rib acceleration (A_y)	Yes	Yes	Yes	Yes	Yes
Abdomen					
Force (F_y)	No	No	Yes	No	No
Deflection (δ_y)	No	No	No	Yes	Yes
Lumbar (F_x, F_y, F_z, M_X, M_y)	No	No	F_y, F_z, M_x	Yes	Yes
Pelvis					
Acceleration (A_x, A_y, A_z)	Yes	Yes	Yes	Yes	Yes
Ilium (F_y)	No	No	No	Yes	Yes
Acetabulum (F_y)	No	No	No	No	Yes
Pubic (F_y)	No	No	Yes	Yes	Yes
Lower extremities					
Femur (F_x, F_y, F_z, M_X, M_y, M_z)	No	No	F_z	Yes	Yes
Knee clevis (F_z)	No	No	No	Yes	Yes
Tibia loads and moments (F_x, F_y, F_z, M_x, M_y, M_z)	No	No	No	Yes	Yes

accelerations of the head, thoracic spine, ribs, and pelvis.

Major biofidelic deficiencies of the SID are the lack of a shoulder load path, no elasticity in the thoracic compliance, and a very heavy rib mass. Major instrumentation deficiencies are no measurement of neck, shoulder, and abdominal loads and no measurement of rib deflection.[17] The dummy does not provide sufficient biofidelity or measurement capacity to be used to either design or assess side impact protection.[17–25] Despite these deficiencies, the SID was specified by NHTSA as the only dummy to be used to evaluate side impact protection compliance under FMVSS 214. Its use is also allowed in the Australian Side-Impact Regulation. SID-HIII is the SID dummy with its head and neck replaced with the Hybrid III head and neck. This improves the biofidelity of its head and neck response and provides for measurement of neck loads as indicated in Table 4.5. The dummy is specified by NHTSA to evaluate side impact head airbags in the side impact pole test of FMVSS 201.

EUROSID-1 (European Side Impact Dummy, version 1) was developed in 1986 by several European laboratories working together as an ad-hoc group under the auspices of the European Experimental Vehicle Committee (EEVC). Extensive development of EUROSID was performed by the Association Peugeot-Renault (APR) and the French National Institute for Research in Transportation and Safety (INRETS), the Netherlands Organization for Applied Technical Research (TNO), and Transport Research Laboratory (TRL) in the United Kingdom. Four prototypes were built and evaluated in 1986. This version, known as the EUROSID production prototype,[26–28] was evaluated worldwide between 1987 and 1989 by governments, the car industry, the International Standards Organization

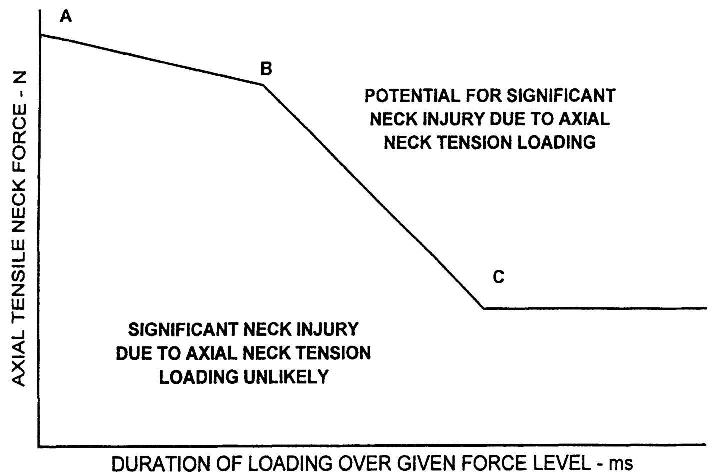

FIGURE 4.3. Injury assessment reference curve for axial neck tension loading for the Hybrid III and side impact dummy families.

	3 Year Old		6 Year Old		Small Female	
Point	Time ms	Force N	Time Ms	Force N	Time ms	Force N
A	0	(1130) / 1480	0	(1490) / 1910	0	(2070) / 2620
B	21	(993) / 1300	25	(1309) / 1678	31	(1819) / 2302
C	36	(377) / 493	42	(497) / 637	54	(690) / 873

	Mid-Male		Large Male	
Point	Time ms	Force N	Time ms	Force N
A	0	(3290) / 4170	0	(3970) / 5030
B	35	(2815) / 3665	37	(3489) / 4420
C	60	(1097) / 1390	64	(1323) / 1677

Note: (Minimum Muscle Tone) / 80 Percent Muscle Tone.

(ISO), and the SAE.[18–20,25] Based on this international evaluation, the dummy's biofidelity, durability, and instrumentation were improved and its named was changed to EUROSID-1.[29]

The EUROSID-1 consists of a metal and plastic skeleton covered by foam and rubber flesh simulants. The head is that of the Hybrid III. The neck is a composition of metal disks and rubber elements with special joints to the head and the thoracic spine that allow a human-like head-to-chest motion. The thorax consists of three separate, identical ribs covered with flesh-simulating foam, attached to a rigid steel spine box by a piston-cylinder assembly and a spring-damper system. The shoulder is designed to rotate forward, allowing a direct impact exposure of the chest. The abdomen is a lead-impregnated, skinned foam. A solid rubber cylinder with a steel cable inside simulates the lumbar spine. The pelvis consists of two plastic iliac wings linked by a metal sacrum and covered with a foam and polyvinylchloride skin. The arms are represented by upper arms (plastic skeleton and flesh) only, and the legs are those of the Hybrid III. The EUROSID-1 instrumentation is given in Table 4.5 and includes linear accelerometers in the head, spine, ribs, and pelvis. Rib-to-spine displacement can be measured for each rib. Loads to the abdomen and pelvis are measured by means of transducers. The dummy represents a

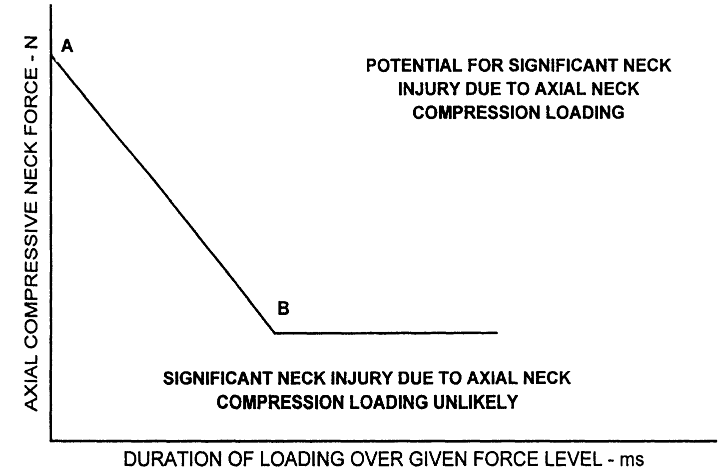

FIGURE 4.4. Injury assessment reference curve for axial neck compression loading for the Hybrid III and side impact dummy families.

	3 Year Old		6 Year Old		Small Female	
Point	Time ms	Force N	Time Ms	Force N	Time ms	Force N
A	0	1380	0	1820	0	2520
B	18	380	21	500	27	693

	Mid-Male		Large Male	
Point	Time ms	Force N	Time ms	Force N
A	0	4000	0	4830
B	30	1100	32	1328

50th-percentile adult male, and its final specification was established by EEVC in April 1989. The EUROSID-1 is the only dummy allowed for compliance testing by the European Side Impact Regulation ECE 48. Its use is also allowed in the Australian and Japanese Side Impact Regulations.

Major deficiencies of the dummy are its marginal biofidelity,[24] the flat-topping that can occur on its rib deflection measurements due to the interaction of the arm/and shoulder structure with its ribs,[30] and the lack of neck, iliac, and acetabulum load measurements.[17]

BIOSID (Biofidelic Side Impact Dummy) was developed by SAE for side impact testing in 1989 following international evaluations of SID and EUROSID, which indicated the need for a more biofidelic dummy with additional measurement capability. The dummy was designed to have impact response biofidelity for the head, neck, shoulder, thorax, abdomen, and pelvis.[31,32] The BIOSID uses the Hybrid III head, neck, and legs. The chest consists of three steel ribs with damping material glued to their inside surfaces similar to the Hybrid III rib construction. The ribs are mounted to a steel spine box that is located laterally on the nonimpacted side of the chest. This "far side" mounted rib concept allows 75 mm of rib deflection without permanent rib deformation.[33] The shoulder and abdominal constructions are also made using this concept. Only the upper arm is simulated on BIOSID. The pelvis is a modification of the EUROSID pelvis, but made of metal with a crushable block in the H-point area. BIOSID instrumentation is given in Table 4.5 and

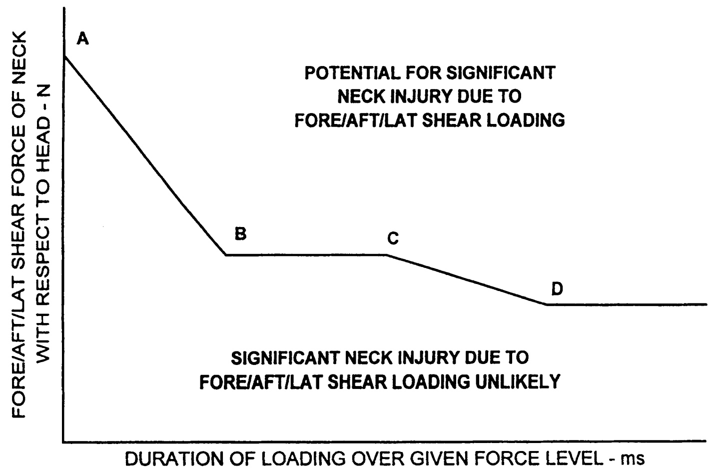

FIGURE 4.5. Injury assessment reference curve for fore/aft/lateral shear force acting on the head for the Hybrid III and side impact dummy families.

	3 Year Old		6 Year Old		Small Female	
Point	Time ms	Force N	Time Ms	Force N	Time ms	Force N
A	0	1070	0	1410	0	1953
B	14	518	15	683	20	945
C	19	518	22	683	29	945
D	25	380	28	500	37	693

	Mid-Male		Large Male	
Point	Time ms	Force N	Time ms	Force N
A	0	3100	0	3743
B	25	1500	28	1811
C	35	1500	39	1811
D	45	1100	50	1328

includes measuring linear acceleration of the head, shoulder, spine, thoracic and abdominal ribs, and pelvis; neck forces and moments; shoulder force and deflection; rib deflection in the chest and abdominal areas; iliac, sacrum and public symphysis forces; and the same lower extremity loads as that of the Hybrid III. The design of the dummy is well documented and quite durable, resulting in excellent repeatability and reproducibility. BIOSID has been commercially available since 1990. It is an acceptable test device for assessing side impact protection.[17,24,25]

SID-IIs is a small (s), second-generation (II) SID that has the anthropometry of a 5th percentile adult female, and thereby it is also representative of a 12- to 13-year-old adolescent. The dummy was developed to fill the need for a small-size test device to evaluate side impact protection countermeasures, notably airbags.[34,35] The Small Size Advanced Side Impact Dummy Task Group of OSRP first met in January 1994 to define the general characteristics of the SID-IIs. The biofidelity response targets were scaled from ISO targets[34,36] that were defined for the midsize adult (50th percentile) male. Since the SID-IIs was to have the anthropometry of the small adult female, many of the parts from the Hybrid III small adult female were incorporated into the design. The thorax, abdomen, and pelvis structures are scaled versions of the BIOSID design. The SID-IIs is extensively instrumented, as noted in Table 4.5, with a total measurement capacity of 148

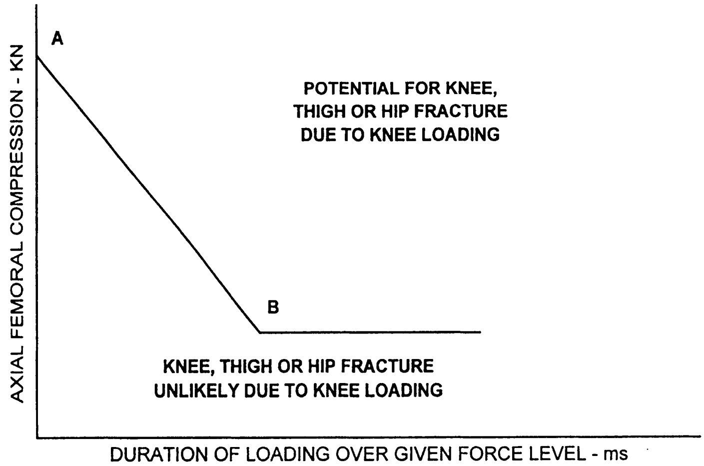

FIGURE 4.6. Injury assessment reference curve for distributed knee loading for Hybrid III dummy family.

	6 Year Old		SMALL FEMALE		MID-MALE	
Point	Time ms	Force N	Time Ms	Force N	Time ms	Force N
A	0	2310	0	6186	0	9070
B	6	1930	9	5156	10	7560

	LARGE MALE	
Point	Time ms	Force N
A	0	11537
B	11	9616

data channels. This includes the use of an instrumented arm[37] that has been incorporated into the design. Using the ISO rating scheme,[17,21–23] the SID-IIs biofidelity rating is good and its instrumentation rating is excellent. The dummy became available commercially in 2000.

Current Dummy Development Programs

Many organizations are involved in developing either entirely different dummies or entirely different replacement parts for existing dummies. NHTSA has a research program to develop an advanced frontal, 50th percentile adult male crash dummy called THOR (Test Device for Human Occupant Restraint).[38] The distinguishing features of this dummy are a two-segment thoracic spine, a rib cage shaped like a human's, and passive muscle force simulation for the neck and leg/foot structures. TNO has been funded by the European Union (EU) to develop a new family of omnidirectional child dummies called the Q-series.[39] These dummies are to replace the TNO P-series, which are currently specified in the European regulation. The SAE Human Biomechanics and Simulation Standards Committee has initiated a program to develop 3- and 6-year-old side impact child dummies for evaluating child interactions with deploying side airbags. They are also considering developing a Hybrid III 10-year-old child dummy for child restraint evaluation. Two rear impact dummies (RIDs), the TRID, developed by TNO[40] and the BIORID[41] developed by Chalmers University,

TABLE 4.6. Injury assessment reference values for measurements made with Hybrid III family of dummies.

Injury assessment criteria	Child dummies		Adult dummies		
	3-yr-old	6-yr-old	Small female	Midsize male	Large male
Head					
15-ms HIC	570	723	779	700	670
Peak acceleration (G)	175	189	193	180	175
Head—neck junction (Minimum)/80% muscle tone					
Flexion moment (Nm)	42	60	95	190	250
Extension moment (Nm)	(17)/22	(24)/30	(39)/49	(77)/96	(102)/127
Axial tension (N): see Fig. 4.3					
Axial compression (N): see Fig. 4.4					
Fore/aft shear (N): see Fig. 4.5					
Neck—thorax junction (Minimum)/80% muscle tone					
Flexion moment (Nm)	100	144	228	461	600
Extension moment (Nm)	(41)/53	(58)/72	(94)/118	(187)/233	(245)/305
Chest					
Sternal compression (mm)	28	31	41	50	55
Sternal compression rate (m/s)	8.0	8.5	8.2	8.2	8.2
Spine acceleration (G)	55	60	73	60	54
Legs					
Femur compression (N): see Fig. 4.6	—				
Tibia—femur trans. (mm)	—	—	12	15	17
Tibia plateau compression					
Medial or lateral (N)	—	—	2,552	4,000	4,920
Tibia compression (N)	—	—	5,104	8,000	9,840
Tibia index*	—	—	1	1	1
MC (Nm)	—	—	115	225	307
PC (kN)	—	—	22.9	35.9	44.2
Ankle moment (Nm)	—	—	115	225	307

*Tibia index = $M(t)/MC + P(t)/PC$ where $M(t)$ is the resultant bending moment and $P(t)$ is the absolute value of the corresponding axial compressive force at time t.
HIC, Head Injury Criterion.

TABLE 4.7. Injury assessment reference values for measurements made with CRABI family of dummies.

Injury assessment criteria	6-month	12-month	18-month
Head			
15 ms HIC	377	390	440
Peak acceleration (G)	50	51	52
Head—neck junction			
Flexion moment (Nm)	24	27	29
Extension moment (Nm)	10	11	12
Axial tension (N)	730	780	850
Axial compression (N)	890	960	1,040
Fore/aft shear (N)	690	744	806
Neck—thorax junction			
Flexion moment (Nm)	58	65	70
Extension moment (Nm)	24	26	29
Chest			
Sternal compression (mm)	29	31	33
Sternal compression rate (m/s)	7.8	7.6	7.9
Spine acceleration (G)	50	50	50

Note: CRABI dummies are not instrumented to measured sternal compression.

TABLE 4.8. Injury assessment reference values for measurements made with side impact dummies.

Injury assessment criteria	SID-IIs	BIOSID	EUROSID	SID-HIII
Head				
15-ms HIC	779	700	1,000*	1,000*
Peak acceleration (G)	193	180	—	—
Head—neck junction				
Lateral moment (Nm)	72	143	143	143
Flexion moment (Nm)	95	190	190	190
Extension moment (Nm)	49	96	96	96
Axial tension (N): see Fig. 4.3				
Axial compression (N): see Fig. 4.4				
Fore/aft/lateral shear (N): see Fig. 4.5				
Neck—thorax junction				
Lateral moment (Nm)	173	347	—	—
Flexion moment (Nm)	228	461	—	—
Extension moment (Nm)	118	233	—	—
Shoulder				
Lateral force (N)	2,700	4,000	—	—
Lateral deflection (mm)	62	75	—	—
Chest				
Rib to spine deflection (mm)	34	42	42	—
Rib deflection rate (m/s)	8.2	8.2	8.2	—
TTI (sedan/coupe) (G)	—	—	—	85/90
Spine acceleration (G)	73	60	—	—
Abdomen				
Rib to spine deflection (mm)	32	39	—	—
Rib deflection rate (m/s)	8.2	8.2	—	—
Internal load (N)	—	—	2,500	—
Pelvis				
Lateral acceleration (G)	160	130	—	130
Pubic symphysis force (N)	4,000	6,000	6,000	—
Iliac crest force (N)	4,000	6,000	—	—
Sacrum force (N)	—	6,000	—	—

*36-ms HIC.
TTI, Thoracic Trauma Index.

have been proposed for assessing the potential for neck sprains in low-severity rear-end collisions.[42] The ISO has initiated a project to develop a side impact dummy, called WORLDSID, as a possible replacement for SID, SID-HIII, EUROSID-1, and BIOSID. Several concepts of leg/foot structures that attempt to simulate passive muscle tone have been developed.[38,43]

Dummy Harmonization

The goal is to have crash safety regulations that are in harmony, if not identical, throughout the world. There is no reason why this shouldn't be the case. Currently the only dummy that is used worldwide for design and regulatory assessment of frontal restraint systems is the Hybrid III midsize adult male dummy. However, there is no consistency of the frontal crash test types, dummy response measurements, or limit values specified by the various international regulations.

NHTSA has incorporated the Hybrid III and CRABI dummy families into its safety standards. There is a good possibility that other countries will adopt the use of the Hybrid III small female and large male dummies into their safety standards because there are no programs being funded to develop competing dummies or upgraded parts for these dummies. The Hybrid III child and CRABI dummies will probably not be accepted worldwide because

TNO has been funded by EU to develop the Q-dummies to compete with these dummies. The SID-IIs dummy may be accepted worldwide since there is no competing dummy.

The lack of harmonization of international crash safety regulation is being perpetuated by nationalistic and commercial interests. It is highly probable that because of these special interests, the harmonized Hybrid III midsize male dummy will become disharmonized in a few years, given the uncoordinated dummy development programs that are currently being conducted.

To make harmonization a reality, an international process must be adopted for identifying the appropriate set of test conditions, crash test dummies, and dummy measurements needed to assess occupant restraint potential. The ISO has established such a process through its Impact Test Procedure Subcommittee (SC10) and Restraint System Subcommittee (SC12) of its Road Vehicle Technical Committee (TC22). It was through the ISO process that worldwide agreement on the use of the Hybrid III 50th percentile adult male dummy was obtained. Recently, ISO has initiated an international dummy project to develop a harmonized midsize adult male side impact dummy, WORLDSID. ISO can be the focal point for determining the appropriate test procedures and crash test dummies for worldwide crash safety regulation. However, for harmonization to occur, all regulatory agencies would have to support the ISO process.

Injury Assessment Reference for Child and Adult Dummies

Injury assessment reference values (IARVs) were first proposed by GM[44] for measurements made with the Hybrid III, midsize adult male dummy. Each IARV was chosen so that if the value was not exceeded, then the corresponding injury would be unlikely to occur to that size occupant. With the development of injury risk curves, "unlikely" has become defined as a less than 5% risk of a significant injury.[45] IARVs that are used for the Hybrid III family of dummies are given in Table 4.6 and Figs. 4.3 to 4.6.[2,3,6–8,44–49] IARVs for the CRABI family of infant dummies[45,49,50] and the side impact dummies[2,3,15,16] are given in Tables 4.7 and 4.8, respectively.

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