RATIONALE

Not applicable.

FOREWORD

Worldwide, vehicle impacts with pedestrians constitute the most frequent cause of traffic-related fatalities. As a result, knowledge about pedestrian crashes is essential to the reduction of fatalities and injuries for these "vulnerable road users" (see definitions). Currently available tools and methods for studying pedestrian casualties include statistical databases, component testing, and computer simulations. While currently in limited use, full-scale vehicle tests with a pedestrian crash-test dummy are an essential component for understanding the motions and sequence of body component impacts which lead to pedestrian trauma and for developing appropriate countermeasures. Possible uses for such a dummy could include the:

– Study of pedestrian kinematics
– Facilitation of crash reconstruction techniques including pedestrian kinematics
– Assessment of injury risk probabilities for given vehicle, crash, and countermeasure combinations
– Design of pedestrian protection systems
– Evaluation of active systems (pop-up hoods, airbags, etc.)
– Refinement of component test parameters and procedures
– Validation of computer simulations

NOTE: This SAE document is intended as a guide toward standard practice and is subject to change to keep pace with experience and technical advances.

TABLE OF CONTENTS

1. SCOPE

While it is recognized that collisions involve pedestrians of all sizes, this Information Report addresses performance specifications for a midsize adult male research dummy. This approach stems from the greater knowledge of biomechanics and existing dummy technologies for the midsize male relative to other adult sizes and children. While not the initial objective, it is envisioned that additional performance specifications for other sizes of pedestrian research dummies will be developed in the future based on accepted scaling procedures.

The specific requirements for the pedestrian dummy have been based on a collective assessment of pedestrian injury, response, and anthropometry priorities from the experimental, epidemiologic, and computational literature. In general, the objective was to specify performance specifications based on human characteristics and the impact response of post-mortem human subjects rather than to specify the design of a particular physical device.

Based on the perceived applications for a research pedestrian dummy, the primary focus of this document centered on biofidelic whole-body kinematics during a vehicle-pedestrian impact. Specific body regions were prioritized (see A.1.5) based on a combination of pedestrian injury, including both severity and frequency. Based on the priorities established by a review committee, the specifications provided in this document include both mandatory and recommended requirements as indicated by the terms "shall" and "should," respectively. As pedestrian injury trends and dummy hardware continue to evolve in the future, it is anticipated that this document will expand to include more mandatory requirements in more body regions.

Finally, it should be noted that the test procedures described in this document only apply to the specific tests required to assess pedestrian dummy biofidelity. It is anticipated that pedestrian dummies meeting the performance criteria of this document will be used in a wide variety of tests, requiring specialized test and data procedures.

1.1   Purpose

This document specifies the performance requirements for a midsize adult male pedestrian dummy that can be used to study pedestrian-vehicle interactions.

2.   REFERENCES

2.1   Applicable Documents

The following publications form a part of this specification to the extent specified herein. Unless otherwise indicated, the latest issue of SAE publications shall apply.

2.1.1   SAE and Stapp Publications

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2.3   Definitions

Arm	That portion of the upper extremity from the shoulder to the elbow
Forearm	That portion of the upper extremity from the elbow to the wrist
Hand	That portion of the upper extremity from the wrist to the finger tips
Thigh	That portion of the lower extremity from the hip to the knee
Leg	That portion of the lower extremity from the knee to the ankle
Foot	That portion of the lower extremity from the ankle to the end of the toes
Shall	Used to denote specifications, performances, or requirements which must be met in order to comply with this Information Report
Should	Used to denote specifications, performances, or requirements which are recommended, but failure to comply does not constitute a failure to comply with the Information Report
Valgus Bending	Bending about the fore-aft dummy axis (x)
Stub Arm	An upper extremity terminated at or proximal to the elbow (i.e., does not include the forearm and the hand)
Vulnerable Road Users	Terminology used in Global Technical Regulations, European Union regulations, and commonly used in the field of safety research (see ESV session guide) to describe pedestrians and the lightly protected road users
xversion	lateral rotation of the ankle joint (inversion or eversion)

2.4   Symbols, Subscripts and Abbreviations

2.4.1   Abbreviations

A(x,y,z)	Acceleration with direction noted by subscript
ATD	Anthropomorphic Test Dummy
AMVO	Anthropometry for Motor Vehicle Occupants Database as established by UMTRI-83-53-1
ANSUR	1988 Anthropometric Survey of U.S. Army Personnel as listed in 2.1.3
C1, C2, etc.	Cervical vertebrate number 1, 2, etc.
CAESAR	Civilian American and European Surface Anthropometry Resource as listed in 2.1.1
CARE	Community database on Accidents on the Roads in Europe
c.g.	Center of gravity
CFR	Code of Federal Regulations
CV	Coefficient of variation defined as the standard deviation divided by the average
DAS	Data acquisition system, normally consisting of sensors, signal conditioning and Recorders
ESV	Conference on the Enhanced Safety of Vehicles
FMVSS	Federal Motor Vehicle Safety Standard
FPS	Frames per second
ICRASH	International Journal of Crashworthiness
IRCOBI	International Research Council on the Biomechanics of Impact
ISB	International Society of Biomechanics
ISO	International Organization for Standardization
LVDT	Linear variable differential transducer
M(x,y,z)	Moment with direction noted by subscript
MHD	Magnetohydrodynamic sensor used to measure angular velocity
NASA	National Aeronautics and Space Administration
NHTSA	The National Highway Traffic Safety Administration
NPA	National Police Agency of Japan
PMHS	Post mortem human subject (i.e., cadaver)
SAFE	Survival and Flight Equipment Association
THOR	**T**est Device for **H**uman **O**ccupant **R**estraint, an advanced frontal crash test dummy developed by the NHTSA beginning in the 1990's
UMTRI	University of Michigan Transportation Research Institute

2.4.2   Symbols

2.4.2.1   Vehicle Reference System (fixed with respect to the moving vehicle) (4.8.4.1.2)

x Positive motions are forward with respect to the car
z Positive motions are down
V_r Resultant velocity in the vehicle reference system xz plane

2.4.2.2   Dummy Positioning Reference System (4.8.3) per SAE J211-1

X + forward from dummy
Y + right from dummy
Z + down

2.4.2.3   Imager Frame Reference System (4.8.4.1.2)

x_F + left in the image (assuming the image is of the left side of the car and the rear of the dummy)
z_F + down in the image

3.   REQUIREMENTS

3.1   Head

3.1.1   Geometric and Mass Characteristics

3.1.1.1   Geometric Properties

The midsize male dummy head external dimensions should be approximately the midsize male head dimensions documented in AMVO (AMVO Table I.4) and shown in Figure 1, and the average of the values documented in CAESAR and ANSUR and shown in Figure 2, 3, and 4.

3.1.1.2   Mass

Based on AMVO (AMVO Table 5.8) the midsize male head mass should be 4.1 ± 0.2 kg.

3.1.1.3   Center of Gravity

The AMVO body segment c.g. data (AMVO Table 5.9), aligned upright, and combined with the H-Point height in Table 7, indicates that the head c.g. should be 1697 mm ± 35 mm from the bottom of the shoes when the dummy is laying flat with its feet against a vertical surface.

3.1.2   Head Biofidelity

When tested per 4.1 the head shall meet performance criteria set for frontal and lateral impact requirements as defined in 3.1.2.1 and 3.1.2.2 respectively.

3.1.2.1   Frontal Drop Test

The disarticulated head shall meet frontal drop test performance criteria set out by NHTSA in 49CFR572.32 [October 1, 2006].

Head height
= 231 mm ± 12 mm
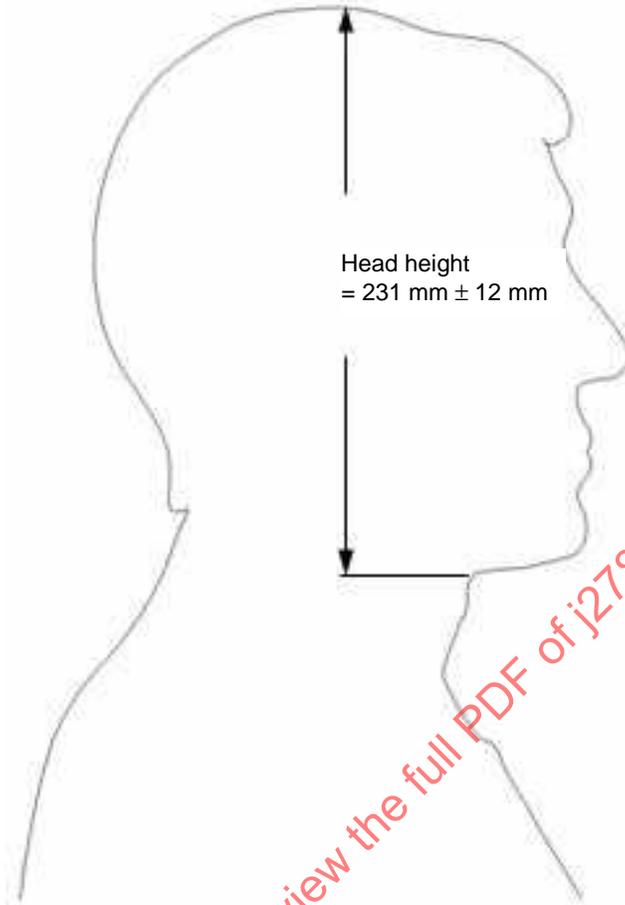
FIGURE 1 - HEAD HEIGHT

Head breadth
= 153 mm ± 9 mm
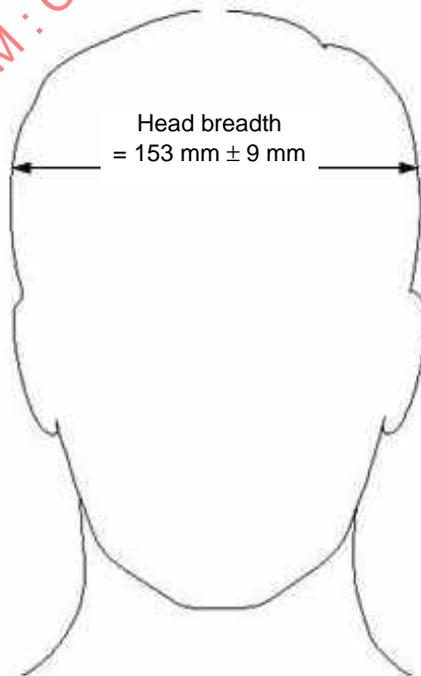
FIGURE 2 - HEAD BREADTH

SAENORM.COM : Click to view the full PDF of j2782_201010

Head circumference
= 571 mm ± 30 mm
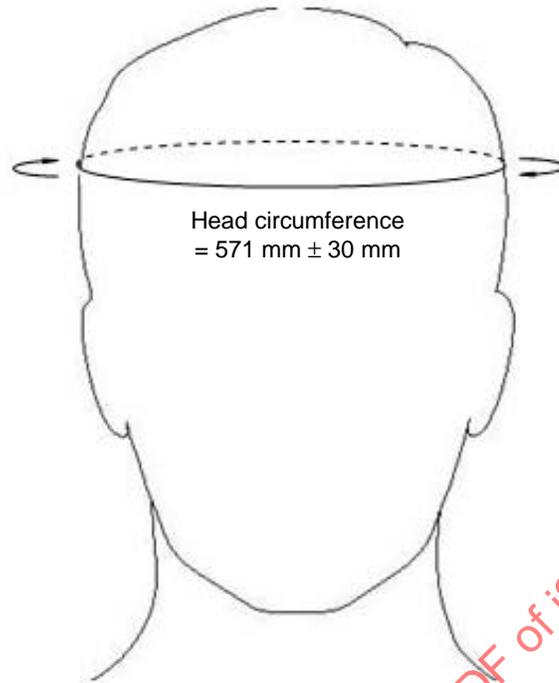
FIGURE 3 - HEAD CIRCUMFERENCE

Head length
= 198 mm ± 10 mm
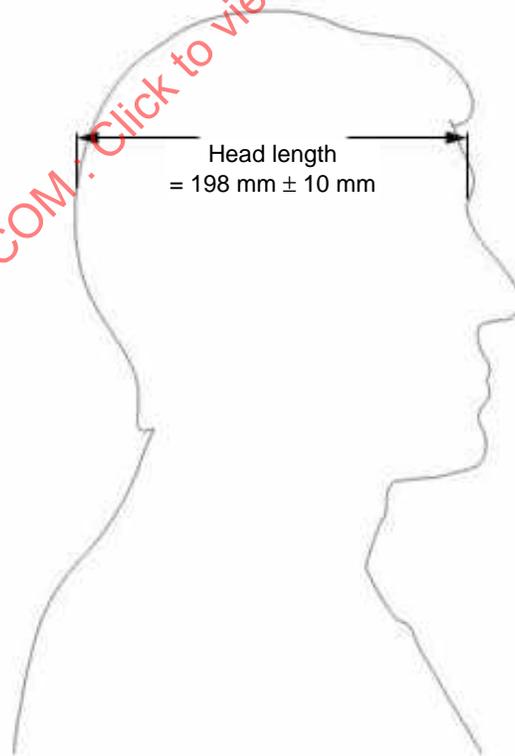
FIGURE 4 - HEAD LENGTH

3.1.2.2 Lateral Drop Test

The disarticulated head shall meet lateral drop test performance criteria set out by NHTSA in 49CFR572.112 [October 1, 2006].

3.1.3 Repeatability and Reproducibility

3.1.3.1 The same head when subjected to three repeat tests as described in 4.1.1 and 4.1.2 shall result in a repeatability CV of 5% or less.

3.1.3.2 Three different heads when subjected to a single test for each part as described in 4.1.1 and 4.1.2 shall result in a reproducibility CV of 10% or less.

3.2 Neck

3.2.1 MASS CHARACTERISTICS

3.2.1.1 Mass

Based on AMVO (AMVO Table 5.8) the midsize male neck mass should be 1.00 kg ± 0.05 kg.

3.2.1.2 Center of Gravity

The AMVO body segment c.g. data (AMVO Table 5.9) aligned upright, and combined with the H-Point height in Table 7 indicates that the neck c.g. should be 1564 mm ± 50 mm from the bottom of the shoes when the dummy is laying flat with its feet against a vertical surface.

3.2.2 Neck Biofidelity

Due to the multi-directional aspects of pedestrian to vehicle impacts, the neck design when tested per 4.2 should include at least flexion-extension and lateral bending biofidelity performance as defined in 3.2.2.1 and 3.2.2.2.

3.2.2.1 Frontal Pendulum Test – The disarticulated head and neck shall meet frontal pendulum test performance criteria set out by NHTSA in 49CFR572.33.

3.2.2.2 Lateral Pendulum Test – The disarticulated head and neck shall meet lateral pendulum test performance criteria set out by NHTSA in 49CFR572.113 [August 4, 1998] as amended at 66 FR 51882, October 11, 2001.

3.2.3 Repeatability and Reproducibility

3.2.3.1 The same neck when subjected to three repeat tests as described in 4.2.1 and 4.2.2 shall result in a repeatability CV of 5% or less

3.2.3.2 Three different necks where subjected to a single test as described in 4.2.1 and 4.2.2 shall result in a reproducibility CV of 10% or less.

3.3 Shoulder

3.3.1 Geometric Properties

The midsize male dummy shoulder breadth (Bideltoid) should be approximately the average of the values documented in CAESAR and ANSUR and shown in Figure 5.
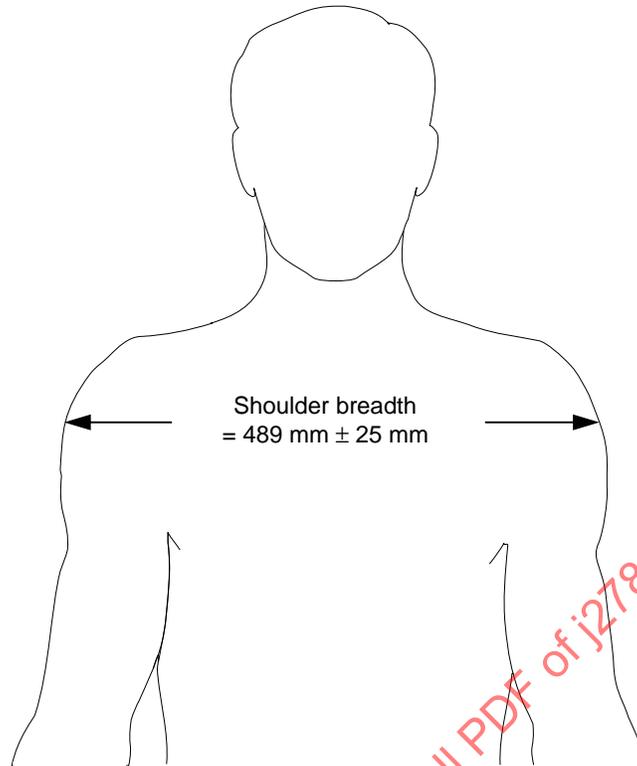
FIGURE 5 - SHOULDER BREADTH

3.3.2   Shoulder Biofidelity

The shoulder design should satisfy lateral biofidelity performance as demonstrated in a lateral pendulum test. When tested per 4.3 the dummy should meet the performance criteria defined by ISO/TR 9790:1999(E) Section 4.1.4. For this test the required force time corridor is shown in Figure 6 and defined in Table 1.

3.3.3   Repeatability and Reproducibility

3.3.3.1   The same shoulder when subjected to three repeat tests as described in 4.3.1 should fall within the corridors specified in 3.3.2.1 and the peak forces should have a CV of 5% or less.

3.3.3.2   Three different shoulders when subjected to a single test as described in 4.3.1 should fall within the corridors specified in 3.3.2.1 and the peak forces should have a CV of 10% or less.

ISO 9790 Shoulder Test 1 Corridor
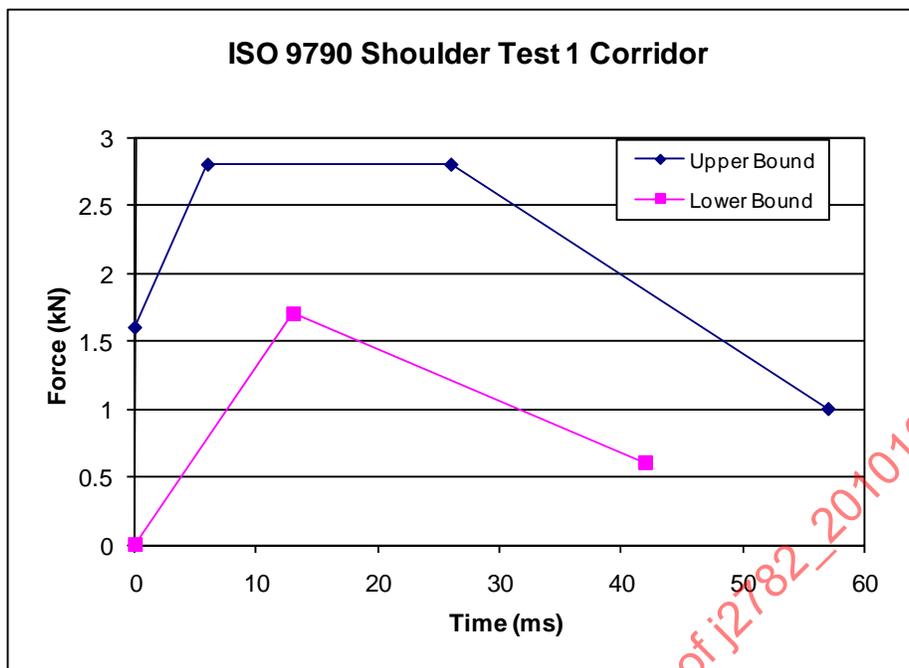
FIGURE 6 - FORCE VERSUS TIME LATERAL SHOULDER CORRIDOR

TABLE 1 - LATERAL SHOULDER PENDULUM FORCE - TIME CORRIDOR

Point	Upper Bound		Lower Bound	
	T (ms)	Force (kN)	T (ms)	Force (kN)
1	0	1.6	0	0
2	6	2.8	13	1.7
3	26	2.8	42	0.6
4	57	1.0		

3.4   Thorax

3.4.1   Geometric and Mass Characteristics

3.4.1.1   Geometric Properties

The midsize male dummy thorax external geometry should be approximately the average of the values documented in CAESAR and ANSUR and shown in Figures 7 and 8.

3.4.1.2   Mass

Based on AMVO (AMVO Table 5.8) the midsize male thorax mass should be 23.8 kg ± 1.2 kg.

3.4.1.3   Location of Center of Gravity (c.g.)

The AMVO body segment c.g. data (AMVO Table 5.9) aligned upright and combined with the H-Point height in Table 7 indicates that the dummy thorax c.g. should be 1293 mm ± 75 mm from the bottom of the shoes when the dummy is laying flat with its feet against a vertical surface.

Circumference at interscye
= 1015 mm ± 50 mm

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FIGURE 7 - THORAX CIRCUMFERENCE

Interscye distance
= 397 mm ± 20 mm
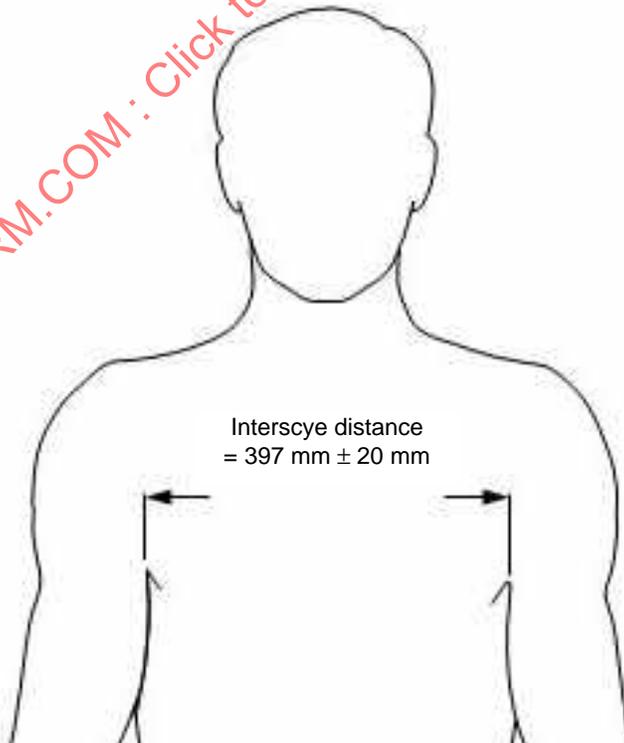
FIGURE 8 - THORAX INTERSCYE DISTANCE

3.4.2   Thorax Biofidelity

When tested per 4.4 the thorax should satisfy frontal and lateral performance criteria as defined in 3.4.2.1 and 3.4.2.2.

3.4.2.1   Frontal Pendulum Test

When tested per 4.4.1 the complete dummy should meet the pendulum force versus sternal deflection performance criteria specified by Kroell (SAE P-67, 1976) for 4.27 m/s pendulum impacts. For this impact speed the required force deflection corridor is shown in Figure 9 and defined in Table 2.
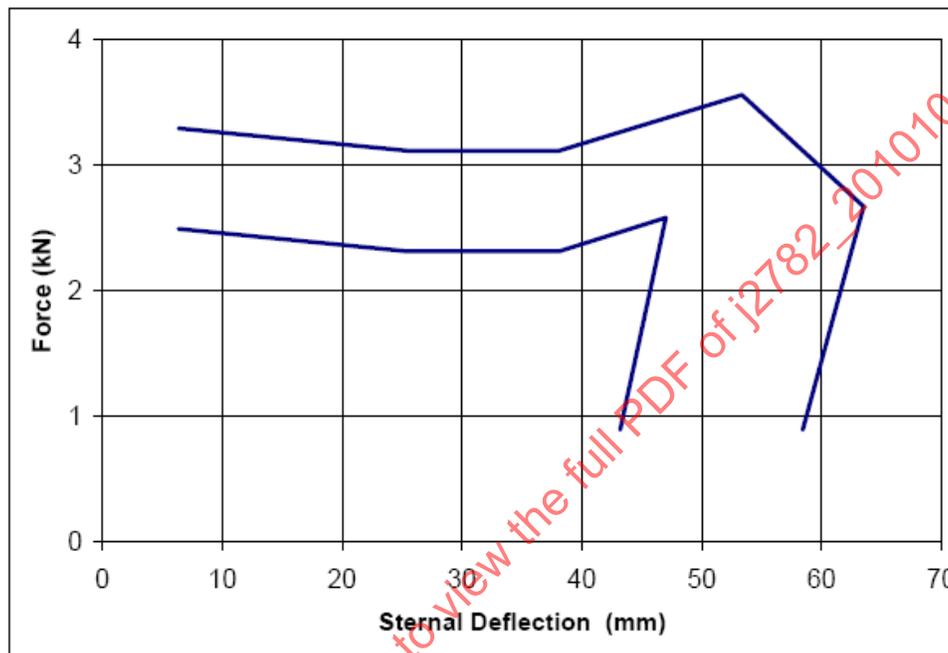
FIGURE 9 - 4.27 M/S FRONTAL PENDULUM FORCE-DEFLECTION RESPONSE CORRIDOR

TABLE 2 - 4.27 M/S FRONTAL PENDULUM FORCE-DEFLECTION RESPONSE CORRIDOR

	Upper Bound		Lower Bound	
Point	Def (mm)	Force (kN)	Def (mm)	Force (kN)
1	6.35	3.293	6.35	2.492
2	25.4	3.115	25.4	2.314
3	38.1	3.115	38.1	2.314
4	53.34	3.56	47	2.581
5	63.5	2.67	43.18	0.89
6	58.42	0.89	–	–

3.4.2.2   Lateral Pendulum Test

When tested per 4.4.2 the dummy should meet the performance criteria defined by ISO/TR 9790:1999(E) Section 4.2.4 For this test the required force corridor is shown in Figure 10 and defined in Table 3.
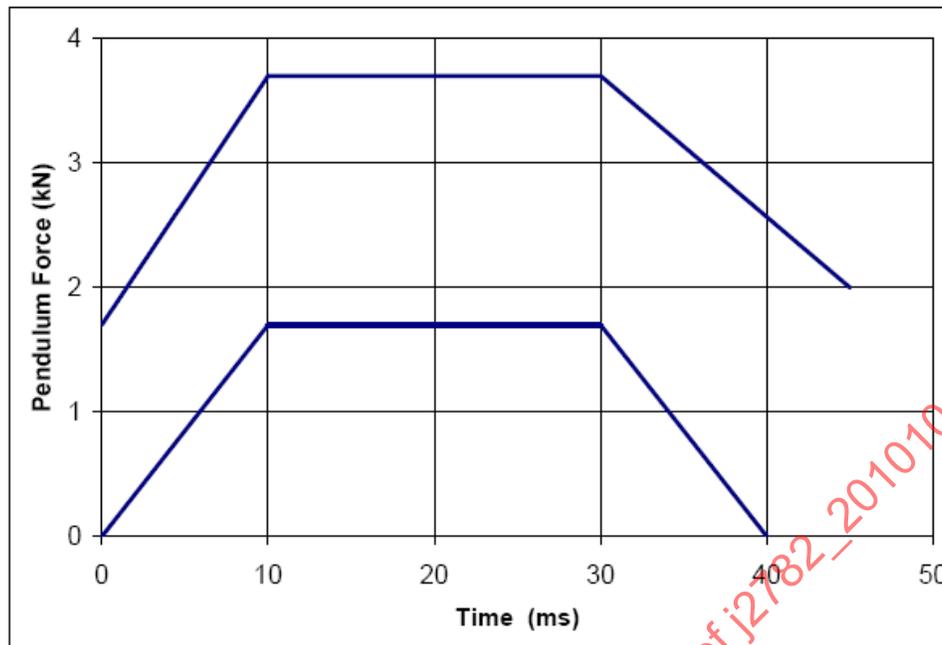
FIGURE 10 - ISO/TR 9790:1999(E) FORCE VERSUS TIME LATERAL THORAX CORRIDOR

TABLE 3 - ISO/TR 9790:1999(E) FORCE VERSUS TIME LATERAL THORAX CORRIDOR

Point	Upper Bound		Lower Bound	
	Force (kN)	Time (ms)	Force (kN)	Time (ms)
1	1.7	0	0	0
2	3.7	10	1.7	10
3	3.7	30	1.7	30
4	2.0	45	0	40

3.4.3 Repeatability and Reproducibility

3.4.3.1 The same thorax when subjected to three repeat tests as described in 4.4.1 and 4.4.2, should fall within the corridors specified in 3.4.2.1 and 3.4.2.2 respectively, and the peak forces in each test type should have a CV of 5% or less.

3.4.3.2 Three different parts, when subjected to a single test for each part as described in 4.4.1 and 4.4.2, should fall within the corridors specified in 3.4.2.1 and 3.4.2.2 respectively, and the peak forces in each test type should have a CV of 10% or less.

3.5 Upper Extremities

The dummy may be equipped with either complete upper extremities or stub arms.

3.5.1 Location of Center of Gravity

3.5.1.1 The AMVO body segment c.g. data (AMVO Table 5.9) aligned upright and combined with the elbow height in Table 7 indicates that the arm c.g. should be 1305 mm ± 75 mm from the bottom of the shoes when the dummy is laying flat with its feet against a vertical surface.

3.5.1.2 The AMVO body segment c.g. data (AMVO Table 5.9) aligned upright and combined with the elbow height in Table 7 indicates that the forearm plus hand c.g. should be 976 mm ± 50 mm from the bottom of the shoes when the dummy is laying flat with its feet against a vertical surface.

3.5.2   Mass

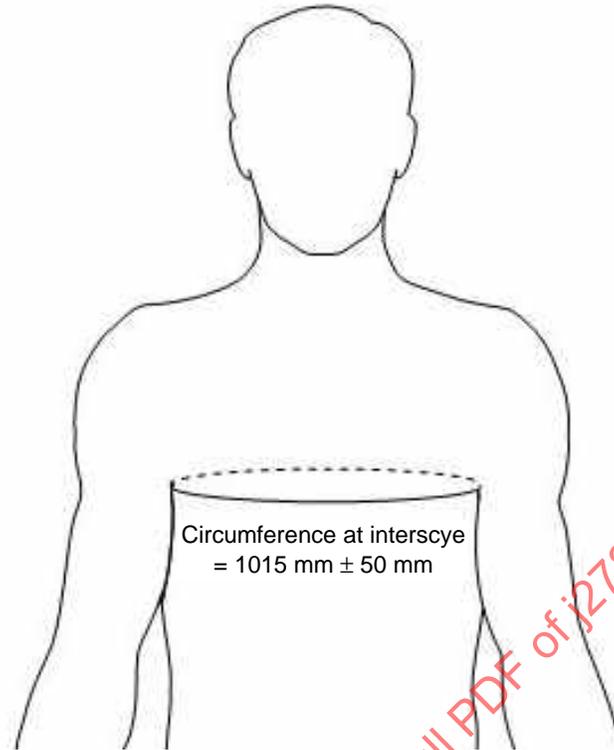Based on the AMVO mass distribution (AMVO Table 5.8) the total mass for two arms should be approximately 3.5 kg $\pm$ 0.2 kg and the total mass for two forearms and hands should be approximately 4.0 kg $\pm$ 0.2 kg. If used, the mass of dummy stub arms should be equal to the arm mass.

3.6   Abdomen and Pelvis

3.6.1   Geometric and Mass Characteristics

3.6.1.1   Geometric Properties

The midsize male dummy pelvis external geometry should be approximately the average of the values documented in CAESAR and ANSUR and shown in Figures 11 and 12.

Hip circumference
= 1000 mm $\pm$ 50 mm
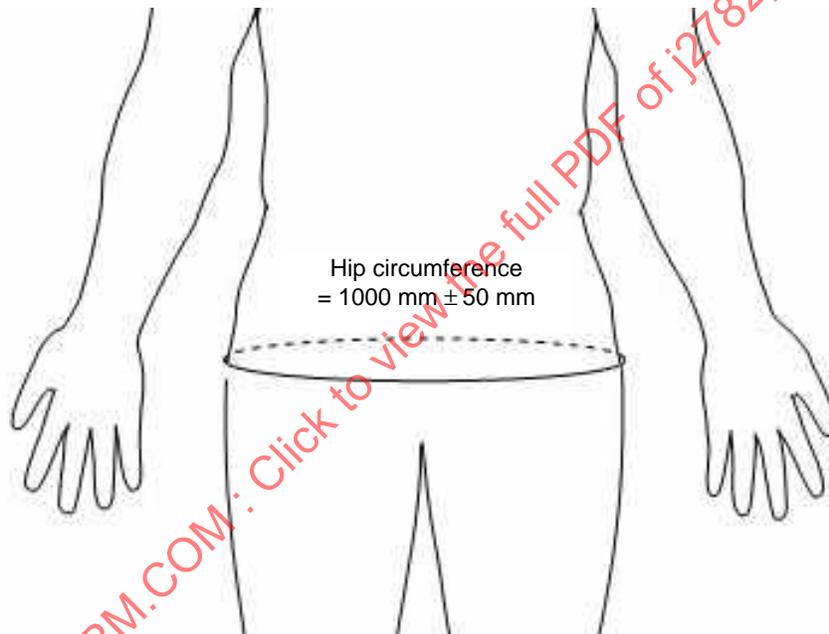
FIGURE 11 - HIP CIRCUMFERENCE

Bi-trochanteric breadth
363 mm ± 18 mm
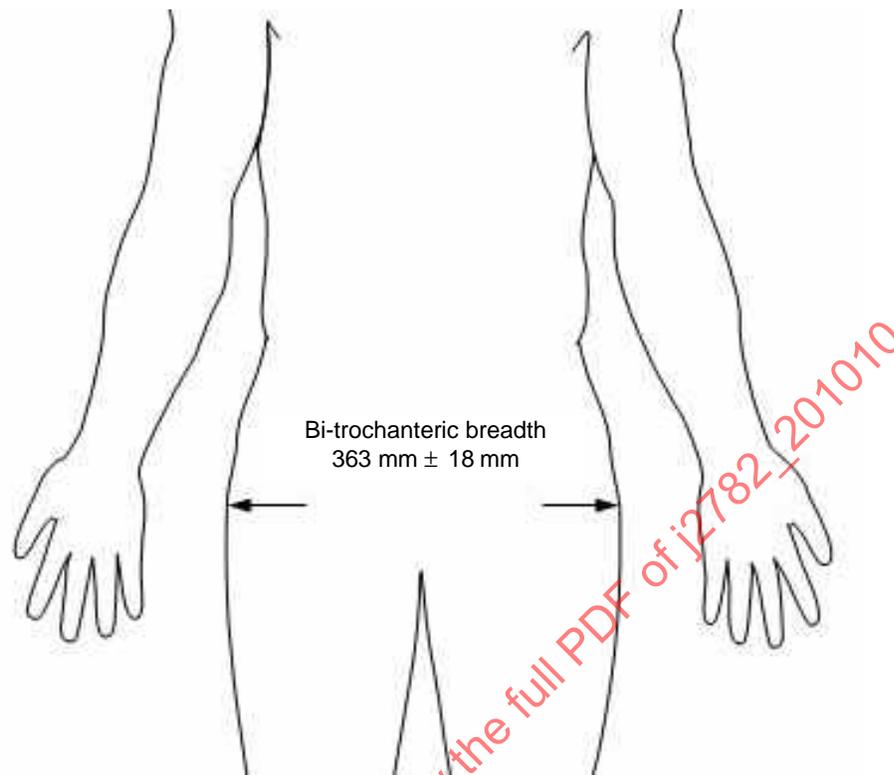
FIGURE 12 - BI-TROCHANTERIC BREADTH

3.6.1.2   Mass

Based on AMVO (AMVO Table 5.8) the midsize male abdomen mass should be 2.4 kg ± 0.1 kg and the pelvis mass should be 11.4 kg ± 0.6 kg.

3.6.1.3   Location of Center of Gravity

The AMVO body segment c.g. data (AMVO Table 5.9) aligned upright and combined with the H-Point height in Table 7 indicates that the abdomen and pelvis centers of gravity should be 1101 mm ± 50 mm and 1024 mm ± 50 mm respectively, from the bottom of the shoes when the dummy is laying flat with its feet against a vertical surface.

3.6.2   Pelvis Biofidelity

The pelvis design should satisfy lateral biofidelity performance as defined in 3.6.2.1 and 3.6.2.2.

3.6.2.1   Lateral Pendulum Test (6 m/s)

When tested per 4.5.1 the dummy should meet the performance criteria defined by ISO/TR 9790:1999(E) Section 4.3.4. For this test the required force velocity corridor is shown in Figure 13 and defined in Table 4.

3.6.2.2   Lateral Pendulum Test (10 m/s)

When tested per 4.5.2 the dummy should meet the performance criteria defined by ISO/TR 9790:1999(E) Section 4.3.4. For this test the required force velocity corridor is shown in Figure 13 and defined in Table 4.
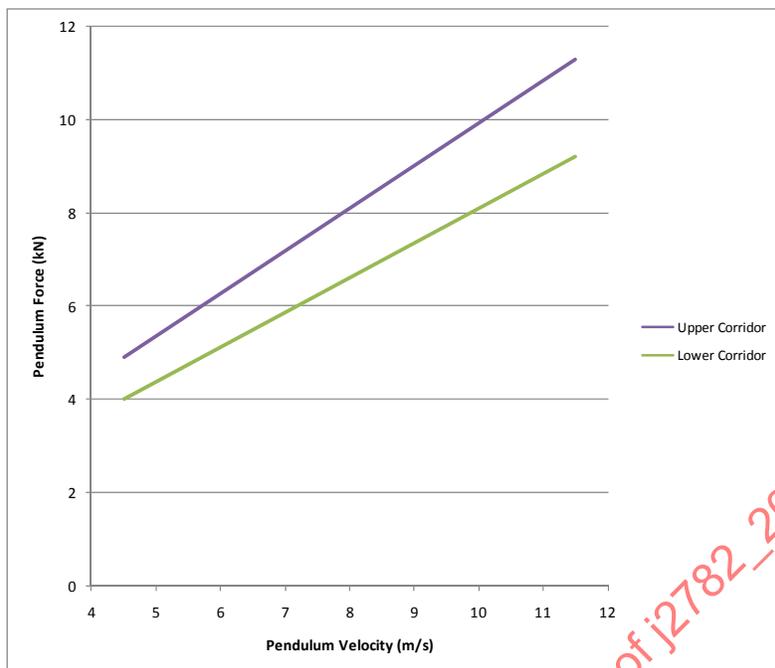
FIGURE 13 - FORCE VERSUS VELOCITY LATERAL PELVIS CORRIDOR

TABLE 4 - LATERAL PELVIS PENDULUM FORCE - VELOCITY CORRIDOR

Point	Upper Bound		Lower Bound	
	m/s	kN	m/s	kN
1	4.5	4.9	4.5	4.0
2	11.5	11.3	11.5	9.2

3.6.3   Repeatability and Reproducibility

3.6.3.1   The same pelvis when subjected to three repeat tests as described in 4.5.1 and 4.5.2 should fall within the corridors specified in 3.6.2.1 and 3.6.2.2 respectively, and the peak forces in each test type should have a CV of 5% or less.

3.6.3.2   Three different pelvices when subjected to a single test as described in 4.5.1 and 4.5.2 should fall within the corridors specified in 3.6.2.1 and 3.6.2.2 respectively, and the peak forces in each test type should have a CV of 10% or less.

3.7   Thigh

3.7.1   Geometric Properties

The midsize male dummy thigh external geometry should be approximately the average of the values documented in CAESAR and ANSUR and shown in Figure 14.

Maximum thigh circumference
= 593 mm ± 35 mm
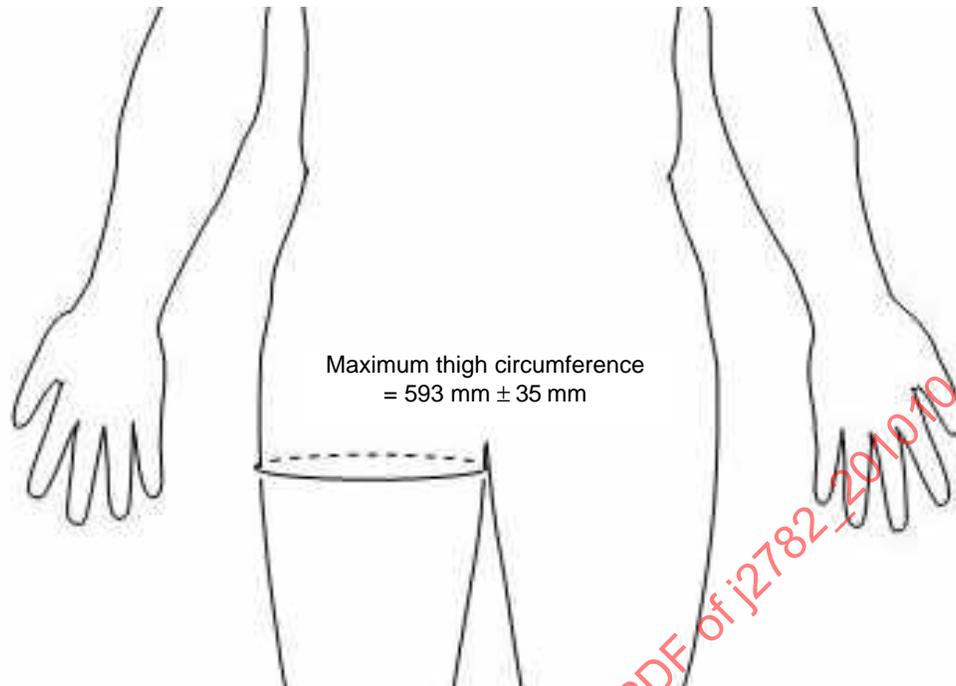
FIGURE 14 - THIGH CIRCUMFERENCE

3.7.2   Mass

Based on AMVO (AMVO Table 5.8) the midsize male dummy mass for two thighs should be 17.2 kg ± 1 kg.

3.7.3   Location of Center of Gravity

The AMVO body segment c.g. data (AMVO Table 5.9) aligned upright and combined with the H-Point height in Table 7 indicates that the thigh c.g. should be 742 mm ± 40 mm from the bottom of the shoes when the dummy is laying flat with its feet against a vertical surface.

3.8   Knees

3.8.1   Geometric Properties

The midsize male dummy knee circumference should be approximately the average of the values documented in NASA Reference Publication 1024 and ANSUR as illustrated in Figure 15.

3.8.2   Knee Biofidelity

Using test procedures described in 4.6, the dynamic valgus (latero-medial) response of the dummy knee shall conform to the response corridor (Ivarsson, IRCOBI 2004) shown in Figure 16 and defined in Table 5.

3.8.3   Repeatability and Reproducibility

3.8.3.1   The same knee component, when subjected to three repeat tests as described in 4.6.1, should fall within the corridor specified in 3.8.3.1 and the peak moment between 10 and 15 degrees should have a CV of 5% or less.

3.8.3.2   Three different knee parts, when subjected to tests as described in 4.6.1, should fall within the corridor specified in 3.8.3.1 and the peak moment between 10 and 15 degrees should have a CV of 10% or less.
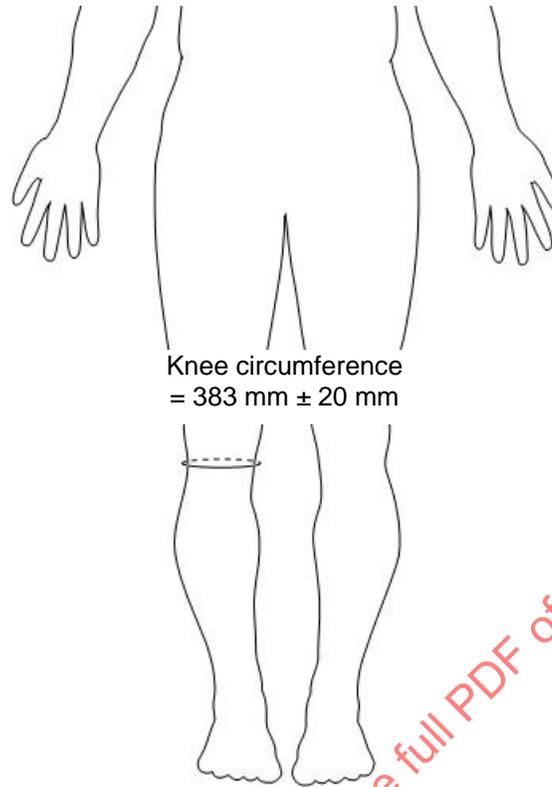
FIGURE 15 - KNEE CIRCUMFERENCE
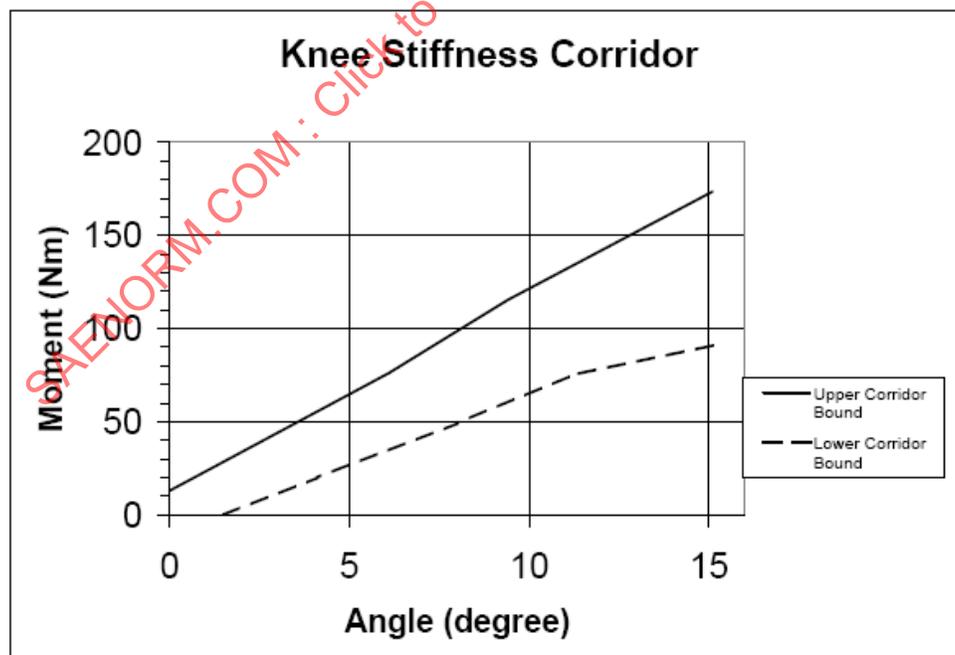
FIGURE 16 - LINEAR BOUNDARIES OF KNEE LATERO-MEDIAL RESPONSE CORRIDOR

TABLE 5 - KNEE STIFFNESS CORRIDOR

	Angle (deg)	Moment (Nm)
Upper	0	13.0
	6.1	76.2
	9.4	115.4
	15.1	173.6
	Angle (deg)	Moment (Nm)
Lower	1.5	0
	4.1	20.0
	8.0	49.2
	11.2	75.1
	15.1	91.0

3.9   Legs

3.9.1   Geometric Properties

The midsize male dummy maximum leg circumference should be approximately the average of the values documented in AMVO and ANSUR as illustrated in Figure 17.

3.9.2   Mass

Based on AMVO (AMVO Table 5.8) the midsize male mass of two legs should be 7.2 kg ± 0.4 kg.

3.9.3   Location of Center of Gravity

The AMVO body segment c.g. data (AMVO Table 5.9) aligned upright and combined with the H-Point height in Table 7 indicates that the leg c.g. should be 353 mm ± 20 mm from the bottom of the shoes when the dummy is laying flat with its feet against a vertical surface.

3.9.4   Leg Biofidelity

Using test procedures described in 4.7, the dynamic latero-medial response of the dummy leg at the midleg location shall conform to the response corridor (Ivarsson, IRCOBI 2004)) shown in Figure 18 and defined in Table 6.

3.9.5   Repeatability and Reproducibility

3.9.5.1   The same leg, when subjected to three repeat tests as described in 4.7.1, should fall within the corridor specified in 3.9.4.1 and the peak force between 30 and 40 mm should have a CV of 5% or less.

3.9.5.2   Three different legs, when subjected to tests as described in 4.7.1, should fall within the corridor specified in 3.9.4.1 and the peak force between 30 and 40 mm should have a CV of 10% or less.
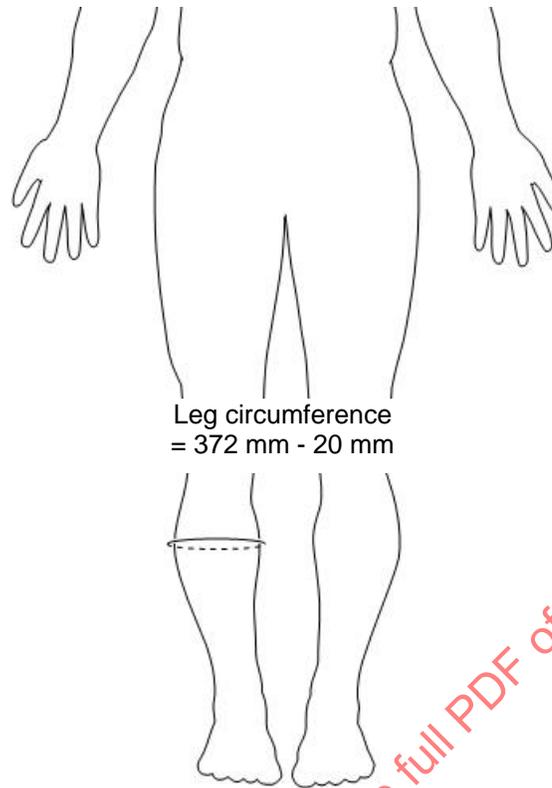
FIGURE 17 - MAXIMUM LEG CIRCUMFERENCE
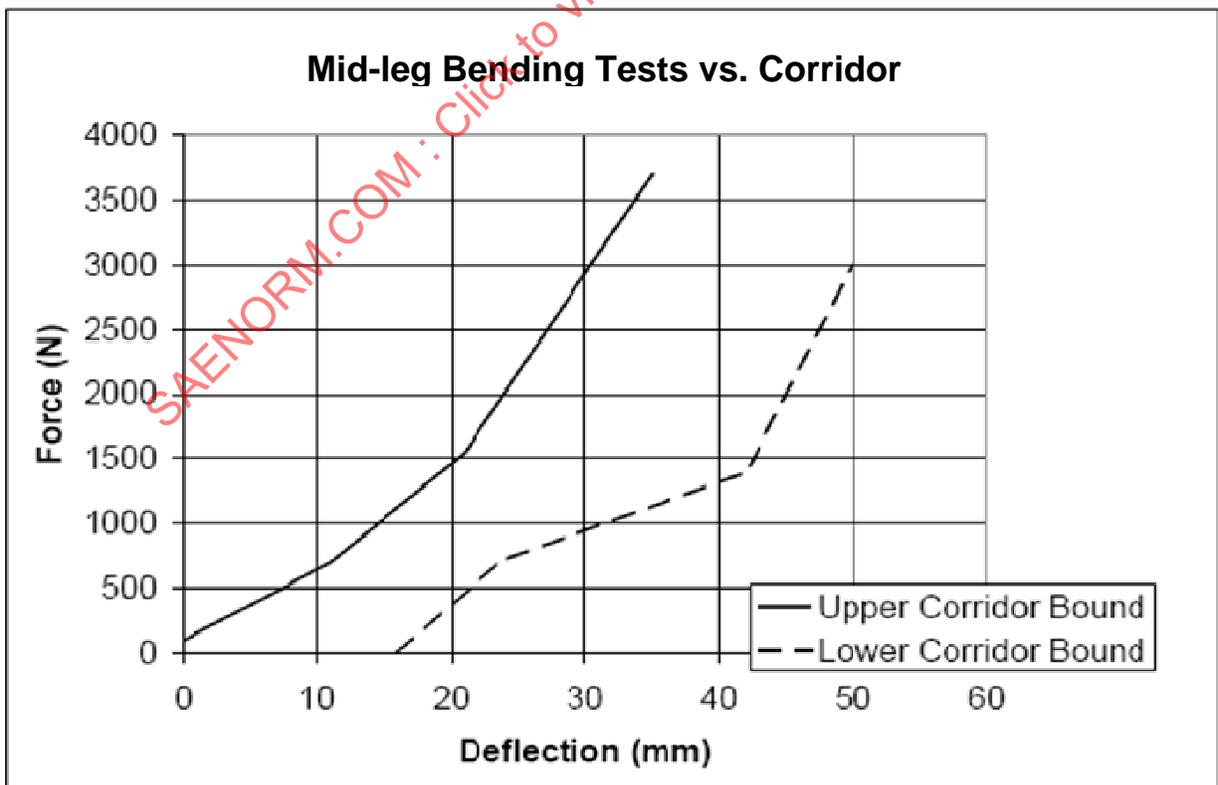
FIGURE 18 - LINEAR BOUNDARIES OF LEG LATERAL BENDING RESPONSE CORRIDOR

TABLE 6 - LEG STIFFNESS CORRIDOR

	Deflection (mm)	Force (N)
Upper Bound	0	100
	11	700
	21	1550
	35	3700
	Deflection (mm)	Force (N)
Lower Bound	16	0
	23.5	700
	42	1400
	50	3000

3.10 Ankles and Feet

3.10.1 Shoes

The dummy shall be compatible with the use of typical male shoes or should have shoes included as an integral part of the foot assembly. Removable or integral shoes shall increase overall dummy height by 30 mm ± 10 mm.

3.10.2 Mass

Based on AMVO (AMVO Table 5.8) the midsize male mass for two feet should be approximately 2.0 kg ± 0.1 kg. If shoes are integral with the feet, the mass for two feet and integral shoes should be 3.0 kg ± 0.2 kg. If the shoes are not integral the per shoe mass should be 0.5 kg ± 0.05 kg.

3.10.3 Location of Center of Gravity

The AMVO body segment c.g. data (AMVO Table 5.9) aligned upright and combined with the H-Point height in Table 7 indicates that the foot and ankle c.g. should be 63 mm ± 3 mm from the bottom of the shoes when the dummy is laying flat with its feet against a vertical surface.

3.11 Clothing

Dummy clothing may be integral to the dummy assembly (for example, a suit which serves the function of the dummy external skin and clothing) or an added item to provide some level of dust and dirt protection to the dummy. In no case is the clothing to increase the dummy mass above that specified in 3.12.2.2, nor should the clothing significantly alter the dummy joint ranges of motion. At a minimum, the clothing should cover the dummy torso, pelvis, thighs, and shoulders.

3.12 Whole Body

3.12.1 Body Structures

The dummy shall consist of all major body segments including head, neck, thorax, abdomen, pelvis, upper extremities (stub or full), and lower extremities. In order to provide human like motions during whole body testing, minimum joint articulations should include degrees of freedom for the ankle, knee, hip, lumbar spine, cervical spine, shoulder and elbow (if a full upper extremity is used). The specific degree of joint motions is left to the dummy designer but motions should be near human-like as for example documented by Hoppenfeld (1976), Robbins (UMTRI 1983), AMVO, and Kapandji (1987, 2007, and 2008).

3.12.2   Geometric and Mass Characteristics

3.12.2.1   External Geometry

The dummy shall meet the dimensional specifications listed in Table 7. The top of head, upper spine/lower neck joint, and H-Point values in Table 7 are based on the average of the values documented in the CAESAR, AMVO, and ANSUR studies. Due to the lack of documented standing values in AMVO, all other values in Table 7 are based on the average of CAESAR and ANSUR only.

TABLE 7 - DUMMY WHOLE BODY DIMENSIONS
(ALL DIMENSIONS ARE WITH SHOES)

Description of Measured Distance	Value (mm)[1]	Comment
Distance from the bottom of the shoes to the top of the head	1785 ± 15	Required
Distance from the bottom of the shoes to the upper spine/lower neck joint	1542 ± 15	Recommended
Distance from the bottom of the shoes to the center of the shoulder/arm rotation joint	1473 ± 20	Recommended
Distance from the bottom of the shoes to the center of rotation of the elbow	1140 ± 20	Recommended
Distance from the bottom of the shoes to the center of rotation of the hip socket (H point)	952 ± 15	Recommended
Distance from the bottom of the shoes to the center of rotation of the wrist	881 ± 20	Recommended
Distance from the bottom of the shoes to the center of rotation of the knee	527 ± 15	Required
Distance from the bottom of the shoes to the center of rotation of the ankle	99 ± 5	Recommended

1. All distances are horizontal distances, perpendicular to a vertical surface, with the dummy, including shoes, lying on its back on a horizontal surface, lower extremities straight with feet together and the bottom of the shoes flat against the vertical surface, upper extremities straight and at the side of the torso.

3.12.2.2   Mass

As documented by CAESAR, the mass of the assembled dummy shall be 79.6 kg ± 4 kg including sensors, and internal DAS (if present). When equipped with stub arms the assembled dummy mass shall be 75.6 kg ± 4 kg.

NOTE: When dummies are used with an external DAS, the mass of that portion of the external cable which is coupled to the dummy should be included in the total dummy mass.

3.12.3   Instrumentation Compatibility

Delineation of dummy sensor requirements is provided in 3.13. For kinematic assessment of dummy trajectories, photo target mounts or alternate provisions for attaching photo targets shall be provided at the posterior surface centerline as follows:

– With the dummy, including shoes, laying on a horizontal surface, legs and feet straight, with the bottom of the shoes flat against the vertical surface.
– Distance to upper spine motion reference point = 1525 mm ± 5 mm
– Distance to midthorax motion reference point = 1375 mm ± 5 mm
– Distance to pelvis motion reference point = 1025 mm ± 5 mm

NOTE: All distances are horizontal distances, measured perpendicular to a vertical surface.

In addition to the above targets, to facilitate video motion analysis, the head external surface should be covered with a color which contrasts to the lab camera view background, the neck and shoulders, and the car.

3.12.4   Biofidelity

When tested in a full scale impact test using a vehicle-like test buck per 4.8 the dummy shall meet performance requirements as defined in 3.12.4.1 and 3.12.4.2 from the time of initial buck-to-dummy contact until initial head-to-buck contact.

NOTE: For this performance validation test the use of a standardized vehicle-like buck would be preferred, however no such standardized device was available at the time of the writing of this document.

3.12.4.1   Trajectory

The dummy head centroid, upper spine, midthorax, and pelvis reference point trajectories shall lie entirely within a PMHS based motion corridor established using the same test buck used for the dummy test. An example of this type of analysis may be found in SAE J2868.

3.12.4.2   Head Centroid Velocity

The dummy head centroid xz resultant velocity shall lie entirely within a PMHS based motion corridor established using the same test buck used for the dummy test. An example of this type of analysis may be found in SAE J2868.

3.12.5   Handling

3.12.5.1   Joint Positioning

The dummy joints shall be able to be positioned to the designated test setup defined in 4.8.3.

3.12.5.2   Joint Adjustments

The dummy joint stiffnesses should be adjustable.

3.12.5.3   Dummy Stabilization

The dummy should be able to maintain the stabilized test setup position defined in 4.8.3 for at least 50 ms without any support or suspension.

3.12.6   Repeatability and Reproducibility

3.12.6.1   Repeatability

The same dummy when subjected to three successive tests as described in 4.8 shall meet the requirements found in 3.12.4.

3.12.6.2   Reproducibility

Three dummies when subjected to the tests described in 4.8 shall meet the requirements found in 3.12.4.

3.12.7   Durability

A dummy assembly including resident sensors and DAS if present, should be able to withstand a 50 km/h impact with the vehicle-like buck using the test conditions specified in 4.8 or a 40 km/h vehicle impact and resulting ground impact without non-cosmetic damage to non-frangible parts.

3.13 Sensors and Data Acquisition Systems (DAS)

3.13.1 Sensor Locations

A dummy shall be capable of accommodating the sensor measurements as specified in Table 8.

3.13.2 Sensor and DAS Specifications

Sensors and DAS shall satisfy the specifications included in SAE J211-1 and SAE J2570. Sensor sign convention should comply with SAE J1733.

3.13.3 Data Acquisition

Either internal and/or external DAS may be used. When using external DAS with umbilical cables, the cable mass should be minimized and the attachment point should be near the dummy pelvis to minimize effects on dummy kinematics.

It should be noted that in either case, the DAS intended for use with the dummy shall be included in the test defined in 4.8.

TABLE 8 - DUMMY SENSOR MEASURES[5]

Body Region	Linear Accelerations[2]	Rotational Accelerations[2]	Forces	Moments	Displacements	Rotations
Head	Required[1]	Required[1]				
Neck			Required[3]	Required[3]		
Thorax	Required[1]				Recommended lateral and frontal measures at mid and lower thoracic levels	
Abdomen						
Pelvis	Required[1]		Pubic, Acetabular and Iliac Recommended			
Thigh	Recommended		Recommended[3,4]	Recommended[3,4]		
Knee			Recommended[3]	Recommended[3]	Recommended[3]	Recommended[3]
Leg	Ay required and tri-axial recommended at upper shaft Tri-axial recommended at lower shaft		Upper Shaft Fz required[4] Fx Fy recommended Lower shaft Fz required[4]	Upper Shaft Mx My required[4] Mz recommended Lower shaft Mx My required[4] Mz recommended		

1. The location shall be near the c.g. and the actual location shall be documented.
2. Unless noted otherwise all acceleration measures shall be tri-axial.
3. Upper neck tri-axial load cell, with the actual load cell location relative to the occipital condyle documented.
4. Load cell diameter should be minimized to prevent non-human like impacts with the vehicle.
5. Data may be recorded directly by a sensor or calculated from other data (e.g., head rotational acceleration may be calculated using data from an array of linear accelerometers).

4.   TEST METHODS AND ANALYSIS PROCEDURES

NOTE: Unless noted elsewhere all tests shall be performed in an environment between 20.6 and 22.2 °C after all parts
           have been soaked at this temperature for at least 4 h.

4.1   Head Biofidelity

4.1.1   Frontal Drop Test

The disarticulated head shall be tested in the frontal drop test set out by NHTSA in 49CFR572.32 [October 1, 2006]. In
cases where the procedure described by NHTSA in 49CFR572 [October 1, 2006] may be overly specific to a particular
dummy design, the procedure should be modified to match the intent of the test procedure.

4.1.2   Lateral Drop Test

The disarticulated head shall be tested in the lateral drop test set out by NHTSA in 49CFR572.112 [October 1, 2006]. In
cases where the procedure described by NHTSA in 49CFR572 [October 1, 2006] may be overly specific to a particular
dummy design, the procedure should be modified to match the intent of the test procedure.

4.2   Neck

4.2.1   Neck Flexion Test

The disarticulated head and neck shall be tested in a neck flexion test as described by NHTSA in 49CFR572.33 [2006].
In cases where the procedure described by NHTSA in 49CFR572 may be overly specific to a particular dummy design,
the procedure should be modified to match the intent of the test procedure.

4.2.2   Lateral Pendulum Test

The disarticulated head and neck shall be tested in a lateral pendulum test as described by NHTSA in 49CFR572.113
[October 2006]. In cases where the procedure described by NHTSA in 49CFR572 may be overly specific to a particular
dummy design, the procedure should be modified to match the intent of the test procedure.

4.3   Shoulder

A lateral pendulum impact test between 4.4 and 4.6 m/s should be conducted according to the test procedure for Shoulder
Test 1 outlined in ISO/TR 9790:1999(E) Section 4.1.

4.4   Thorax

4.4.1   Frontal Pendulum Test

The frontal pendulum impact test should be conducted at an impact speed of 4.27 m/s according to the test procedure
outlined in 49CFR572.34 [October 1, 2006]. In cases where the procedure described by NHTSA in 49CFR572 [October
1, 2006] may be overly specific to a particular design, the procedure should be modified to match the intent of the test
procedure.

4.4.2   Lateral Pendulum Test

A 4.3 m/s lateral pendulum impact test should be conducted according to the test procedure for Thorax Test 1 outlined in
ISO/TR 9790:1999(E) Section 4.2.

4.5   Pelvis

4.5.1   Lateral Pendulum Test (6 m/s)

A 6.0 m/s lateral pendulum impact test should be conducted according to the test procedure for Pelvis Test 1 outlined in
ISO/TR 9790:1999(E) Section 4.3.

4.5.2   Lateral Pendulum Test (10 m/s)

A 10 m/s lateral pendulum impact test should be conducted according to the test procedure for Pelvis Test 2 outlined in ISO/TR 9790:1999(E) Section 4.3.

4.6   Knee

The fully extended dummy knee shall be subjected to a valgus bending moment using a four-point bend test fixture (see Figure 19). A knee bending rate of approximately 1 degree/ms shall be used to determine the knee joint response. The knee shall be simply supported with an effort to minimize shear reaction and rotation moment at the supports. A two-point loading device shall be attached to the load cell so that it can freely rotate around the mounting point. The span of the four-point fixture is variable but should include all knee components (i.e., ligament representations) while minimizing the overall distance from the joint in an effort to reduce deformation of the tibia and femur. Shear loads and valgus bending moments shall be measured in the femur directly using a multi-axis load cell. These forces will be transferred to the knee joint using a rigid body assumption, the recorded angular and linear accelerations of the segment between the load cell and knee, and the inertial attributes of the segment. Since the distal half of the load cell is included in the knee segment, M_F and V_F are given by the load cell signals with the distance from the load cell to the center of gravity of the segment designated as x_F and the distance from the center of gravity to the center of the knee designated as x_K. Thus, the moment at the knee joint, M_k can be calculated from femur support load cell measurements using the equations indicated below (see Figure 20) where $\ddot{u}$ represents the linear acceleration of the proximal knee segment, $\ddot{\theta}$ represents the angular acceleration of the proximal knee segment, M is the mass, and I is the moment of inertia of the proximal knee segment.
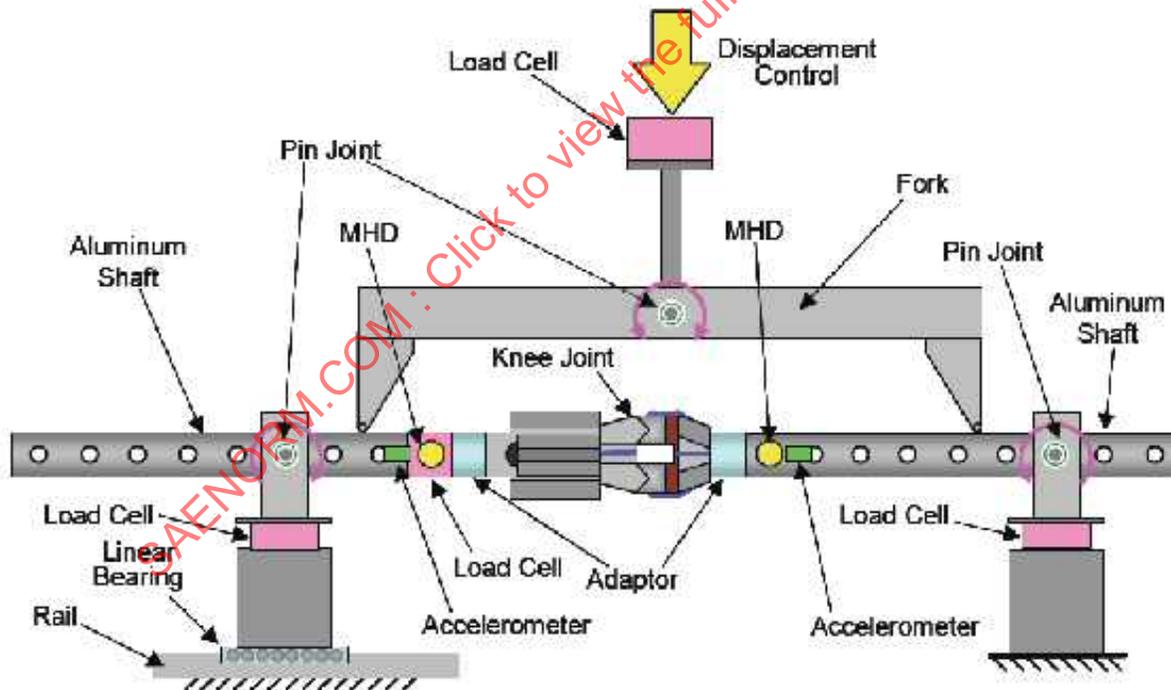
FIGURE 19 - KNEE EXAMPLE TEST SET-UP
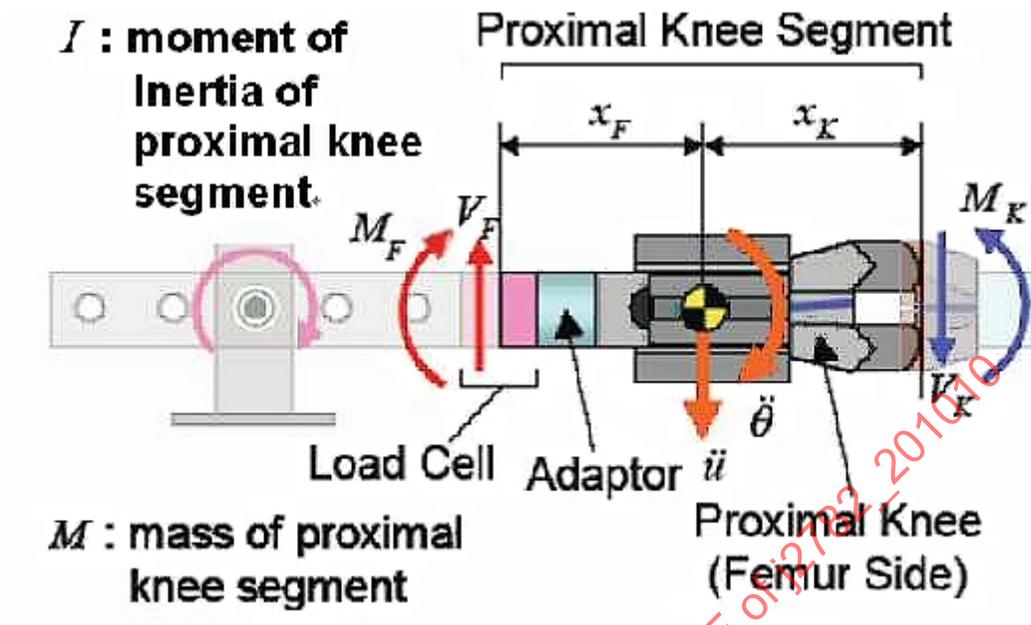
$$M_K = M_F + V_F(x_F + x_K) + M\ddot{u}x_K - I\ddot{\theta}$$

FIGURE 20 - SCHEMATIC FOR KNEE JOINT KINETICS

4.7   Legs

The dummy leg shall be subjected to latero-medial 3-point bending at an approximate deflection rate of 1.5 m/s. The leg shall be simply supported with an effort to minimize shear reaction forces at the supports (see Figure 21). A total span of 334 mm shall be provided between the supports with the impact load applied midspan. Stationary support load cells shall be used to record vertical reaction forces and a displacement transducer (LVDT or string potentiometer) shall measure cross-head displacement.

$$F_{imp} = F_1 + F_2 \qquad\qquad\qquad \text{(Eq. 1)}$$

where:

F_{imp} : applied force by impactor

F_1, F_2 : reaction forces at support load cells
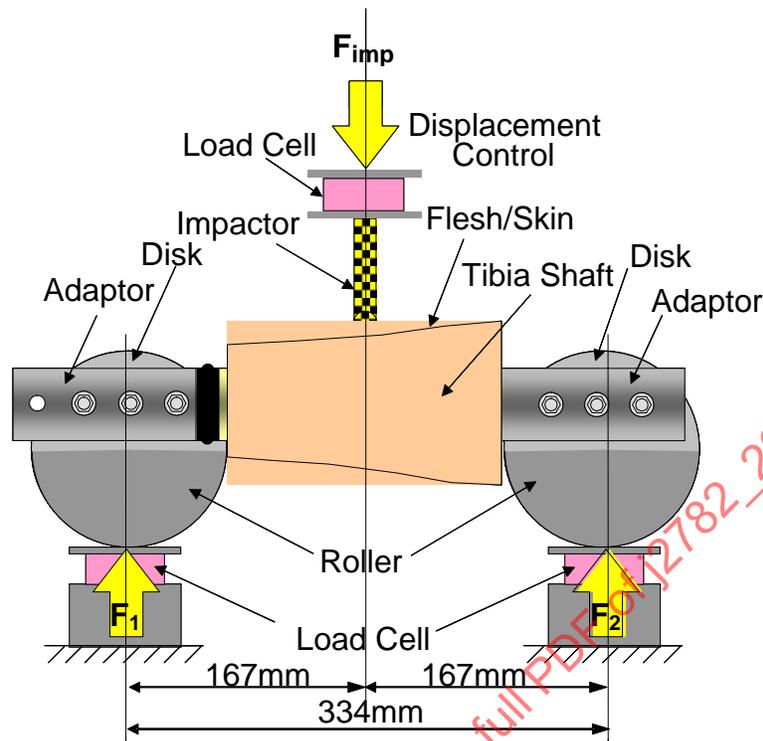
FIGURE 21 - LEG EXAMPLE TEST SET-UP

4.8   Whole Body

The whole body response of the dummy will be evaluated in full-scale vehicle-like test buck impact tests. Specifications are provided for the impact conditions (buck and speed), pedestrian orientation, and film analysis procedures.

4.8.1   Buck Specifications

The buck for the whole body biofidelity and repeatability testing specified in 3.12.4 and 3.12.6 respectively should be fabricated such that it is representative of the geometry and stiffness of a production vehicle (see SAE J2868 for example). A standardized buck would be preferred but at the time of publication no standardized vehicle-like buck was available. Until such time the choice of the buck is left to the discretion of the validating organization.

4.8.1.1   Buck Construction

The buck should simulate at least the front half of a vehicle structure, up to the B-pillar, and be rigidly mounted to a horizontal sled system. Any vehicle-like suspension components should be locked so that they do not deflect.

4.8.1.2   Buck Attitude

The buck should be set to represent a vehicle attitude where the vehicle side sill is parallel to the ground line ±2.5 degrees and the simulated bumper height is set such that the midpoint of the structural bumper beam is at a height above the ground plane which is representative of a production vehicle.

4.8.1.3   Condition

The front structure of the buck shall be in good condition and repaired or rebuilt after each test.

4.8.2   Impact Speed

The test laboratories shall use an impact velocity of 40 km/h ± 1 km/h. No buck braking shall occur until after primary head to buck impact.

4.8.3   Dummy Pre-Test Position

The dummy pre-test position is shown in Figure 22 and a detailed discussion of the rationale behind the initial position is provided in the A.2.2.

4.8.3.1   The dummy shall be oriented laterally with the head normal to the axis of impact (anterior-posterior axis of the pedestrian dummy oriented parallel to the front axle of the wheels of the vehicle-like buck).

4.8.3.2   Feet and Ankle

The feet of the dummy, in shoes, shall be placed on a rigid surface at ground height. The toe and heel of the feet/shoes will rest entirely on the ground surface. The feet shall be aligned with the sagittal plane of the dummy such that the ankle xversion and rotational angles are set to 0 degrees ± 5 degrees. The heel point shall be established as the intersection of the long-axis of the foot with the posterior surface of the shoe. The anterior-posterior distance of the right and left heel points shall be 310 mm ± 10 mm. The lateral distance between the two heel points shall be 280 mm ± 10 mm.

4.8.3.3   Lower Extremities

The dummy's legs shall be placed in a midstance gait configuration. The angles of femur and tibia shall be set in accordance with the angles shown in Table 9 and Figure 22.

4.8.3.4   Torso

The dummy's upper body shall be oriented vertically such that the thoracic spine angle is 83 degrees ± 5 degrees (leaning slightly forward) relative to horizontal. Similarly, the midsagittal plane of the dummy shall be vertical and perpendicular to the buck's longitudinal centerline. The H-point of the dummy shall be aligned such that it is within 100 mm of the buck centerline.

4.8.3.5   Head

The angle of the transverse plane of the dummy head shall be -7 degrees ± 5 degrees (head down) from horizontal.

4.8.3.6   Upper Extremities

The pedestrian's arms shall be adjacent to the torso with sagittal planes as close to vertical as possible. The shoulders should be extended until the elbows are anterior to the ventral surface of the torso with the upper arm angle set at 65 degrees ± 5 degrees. The distance between the elbows shall be 420 mm ± 10 mm. If present, the forearms of the dummy shall be crossed with the impact side limb oriented on top of the non-impact side limb. Crossing of the extremities should occur at the level of the wrist.

4.8.3.7   Hands and Wrists

The wrists of the pedestrian dummy, if present, shall be tightly bound with a stiff material with the wrists positioned such that the impact side wrist is forward of the non-impact side wrist with both palms facing rearward. A summary of the positioning targets and tolerances are provided in Table 9 with a schematic of the dimensions shown in Figure 22.

TABLE 9 - POSITIONING MEASURES

	Segment	Aspect	Units	Axis(SAE J211-1)	Target	Tolerance
A	Head Angle		deg	About Y	−7	±5
B			deg	About X	0	±5
C	Torso Angle		deg	About Y	83	±5
D			deg	About X	0	±5
E	Knee Height	Impact side	mm	Z	505	±10
F		Non-impact side	mm	Z	520	±10
G	Knee Bend Angle	Impact side	deg	Angle in XZ plane	164	±5
H		Non-impact side	deg	Angle in XZ plane	171	±5
I	Tibia Angle	Impact side	deg	About Y	73	±5
J		Non-impact side	deg	About Y	98	±5
K	Femur Angle	Impact side	deg	About Y	89	±5
L		Non-impact side	deg	About Y	107	±5
M		Impact side	deg	About X	87	±5
N		Non-impact side	deg	About X	94	±5
O	Knee to Knee Width		mm	Y	280	±10
P	Heel to Heel Distance		mm	X	310	±10
Q			mm	Y	280	±10
R	Elbow to Elbow Width		mm	Y	420	±10
S	Upper Arm Angle		deg	About X	65	±5

4.8.3.8   Pedestrian Supporting and Release

The dummy shall be supported by a tether that allows release 35 ms ± 5 ms prior to initial contact between the buck bumper face and the dummy lower extremity.

NOTE: Any time lags in the release mechanism must be accounted for in the determination of release activation.

4.8.4   High Speed Cameras and Analysis Procedures

High speed video shall be recorded using a posterior view of the pedestrian. The video camera used in the video analysis shall have a frame rate of at least 1000 frames per second, a lens focal length of at least 30 mm, and should possess an image resolution of at least 1024 pixel by 1024 pixel (1.0 mega pixel). The camera's field of view shall be perpendicular to the buck motion and should stretch horizontally from approximately 1 m before the impact point to a location approximately 3 m from the impact point (alternate imagers and fields of view can be used as long as the resolution is no more than 4 mm/pixel and all dummy body regions of interest are visible up to the time of head to buck impact). In order to facilitate the scaling of the image, two targets a known distance apart (e.g., 1 m), located in the plane of the pedestrian (i.e., center line of the buck) should be visible. Alternative scaling procedures, utilizing the transformation of other established reference distances in alternate frames or planes, can be used as long as parallax is accounted for.
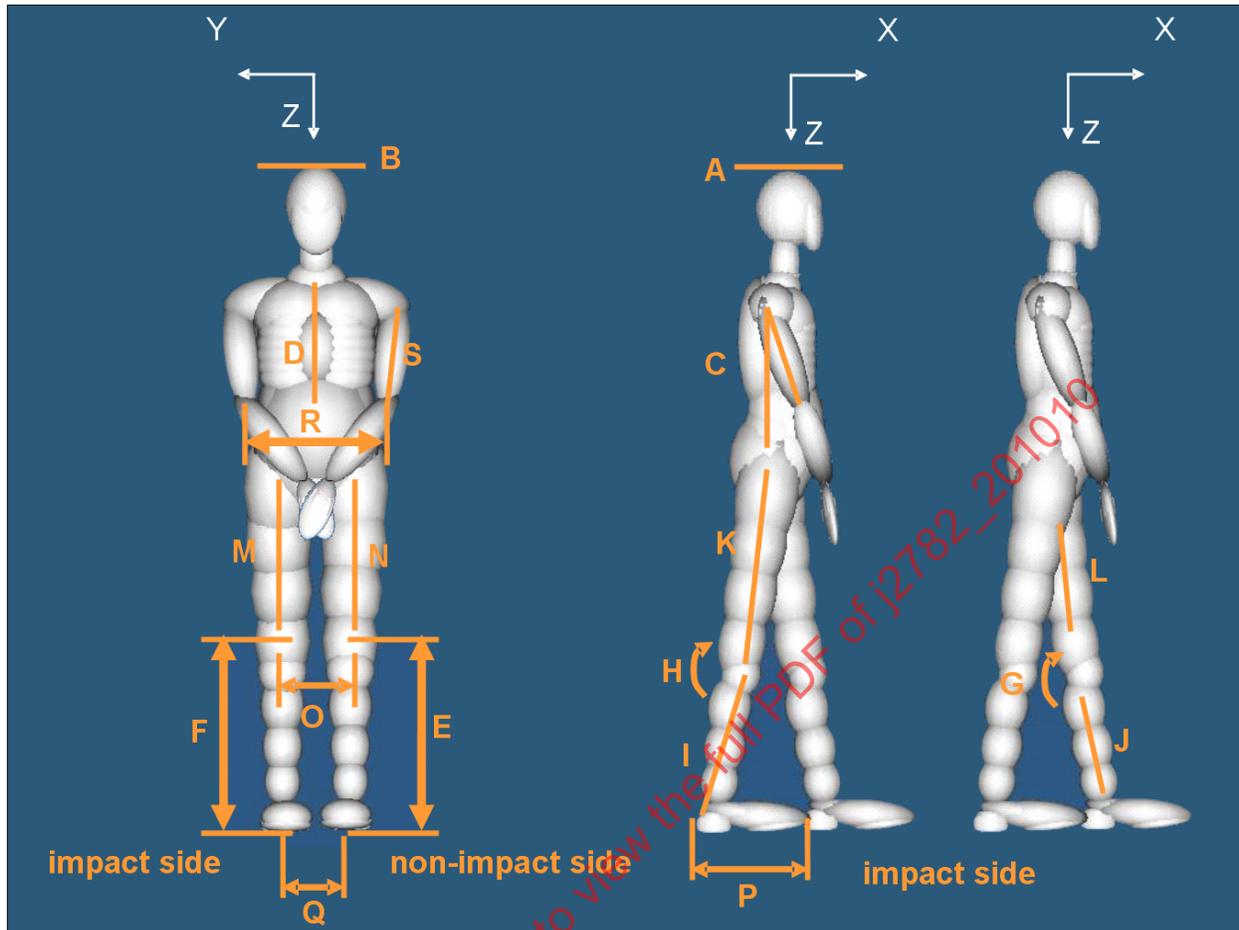
FIGURE 22 - SCHEMATIC OF THE POSITIONING MEASURES

A: Angle of X axis of head accelerometer
B: Angle of Y axis of head accelerometer
C: Angle of thoracic spine about Y axis
D: Angle of thoracic spine about X axis
E: Vertical height from ground to non-impact knee joint center
F: Vertical height from ground to impact knee joint center
G: Angle between non-impact femur and thigh
H: Angle between impact femur and thigh
I: Impact tibia angle about Y axis
J: Non-impact tibia angle about Y axis
K: Impact femur angle about Y axis
L: Non-impact femur angle about Y axis
M: Impact femur angle about X axis
N: Non-impact femur angle about X axis
O: Distance in Y direction between knee joint centers
P: Heel to heel distance in the X axis
Q: Distance in Y direction between heel points
R: Distance in Y direction between elbow joint centers
S: Angle of upper arm about X axis

- Coordinate system of the dummy shall be in accordance with SAE J211-1. Note that this dummy axis system is different than the Vehicle Reference axis system used for film analysis.
- All the angles, except G and H, shall be measured from horizontal line.

4.8.4.1   Film Analysis Procedures

4.8.4.1.1   Target Locations

4.8.4.1.1.1   Dummy

For film analysis purposes, three targets shall be placed on the dummy at the locations specified in 3.12.3. Head targets shall not be used for film analysis but rather the head centroid, defined as the center of a circle which circumscribes the head as seen in each film image, shall be tracked.

NOTE: When the dummy is placed in its pretest "striding" position as shown in Figure 22, the head centroid and three other midsagittal plane targets used for film analysis (see 3.12.3) should be located at the following nominal heights above the bottom of the shoes.

Head centroid   1659 mm
Upper spine reference point   1501 mm
Midthorax reference point   1352 mm
Pelvis reference point   1005 mm

NOTE: The target dimensions noted above define the vertical location of the targets when the dummy is in a pre-test "striding" configuration (legs flexed, etc.) and are thus by definition less than those found in 3.12.3 which define the target locations when the dummy is laying flat on a horizontal surface with all limbs straight. The dimensions above are not to be used to place targets (see 3.12.3 for placement), but are rather to be used to verify a correct striding position. Also, as noted in 3.12.3, these targets are located at "motion reference points" and thus are not intended to coincide with key body segment locations noted in Table A2.

The targets should be attached such that they move with the dummy structural components and not with the dummy clothing or skin.

4.8.4.1.1.2   Buck

Securely attach a photo target to the front side of the buck which faces the camera. The target shall be attached such that it moves with the buck frame and is not subject to localized vibrations. In order to facilitate the scaling of the image, two targets a known distance apart (e.g., 1 m), located in the plane of the buck target should be visible. Alternative scaling procedures, utilizing the transformation of other established reference distances in alternate frames or planes, can be used as long as parallax is accounted for.

4.8.4.1.2   Trajectory Data

NOTE: The following procedures assume a camera view of the left side (driver's side) of the car. Reverse left and right directions for right side views.

For the purpose of the trajectory data analysis, two coordinate systems are defined. The second coordinate system, the vehicle coordinate system, will be defined later (it should be noted that neither of these coordinate systems is the same as the dummy positioning coordinate system described in Figure 22). The imager frame coordinate system is defined by the view of the high speed imager. This coordinate system is fixed with respect to the laboratory. The x_F direction is defined as the horizontal axis of the imager frame and z_F is defined as the vertical axis of the imager frame. Positive x_F is to the left (for an impact to the right side of the dummy the buck travels in the positive x_F direction) and positive z_F points down. The motions of all of the photo targets shall be tracked in the frame coordinate system by digitizing the location of the photo target in each analysis frame. The origin for the frame coordinate system shall be as follows:

$x_F = 0$ corresponds to a vertical line passing through the head centroid, upper spine reference point, midspine reference point, and pelvis reference point at t = 0. If some alignment error between points exists the line should be located so as to minimize the cumulative X^2 errors.

$z_F = 0$ corresponds to the horizontal surface on which the bottom of the dummy shoes rests prior to impact.

Motion analysis shall proceed as follows:

4.8.4.1.2.1   Identify the image frame which just precedes the first indication of impact between the car bumper and the dummy. (This could for example be the last frame prior to the illumination of a contact light or prior to any visible movement or deformation of the dummy.) This frame becomes analysis frame 0, and corresponds to t = 0.

4.8.4.1.2.2   Identify a series of analysis frames (i.e., frames in which the targets will be digitized) prior to and after frame 0 with a time interval between analysis frames of approximately 4 ms. For example, when using a 1000 FPS video camera every 4th frame prior to and after frame 0, will be an analysis frame.

4.8.4.1.2.3   For each analysis frame, digitize the location of the head centroid, upper spine, midthorax, and pelvis reference points, and the car side target.

4.8.4.1.2.4   To prevent the impact altered post impact motions and the position averaging filter from affecting the calculated pre-impact and impact positions and velocities of the head, the X_F and Z_F coordinates of the head in the 4 ms interval prior to head-to-buck impact shall be used to straight line extrapolate virtual X_F and Z_F coordinates after head-to-buck impact. Such virtual points will be unaffected by the impact decelerations.

4.8.4.1.2.5   Using reference targets a known distance apart (or other similar means), located in a plane coincident with the dummy targets, and in a plane coincident with the buck target, determine geometric scale factors for the dummy and buck target which can be used to convert image dimensions to real dimensions. For example, if the field of view at the dummy centerline is 4 m and the camera image consists of 1024 horizontal pixels, the scale factor would be:

$$SF_{Dummy} = 4000\,mm \Big/ 1024\,pixels = 3.906\,mm \Big/ pixels \qquad (Eq.\ 2)$$

Note that the scale factor for the buck side target will generally be different than that used for the dummy.

4.8.4.1.2.6   The filtering convention specified in ISO 13232-4 (ISO, 2005) shall be used to smooth the position data. All signals shall be filtered with four passes of the moving average filter:

$$x_{Fi,f} = \frac{x_{Fi-1} + 2x_{Fi} + x_{Fi+1}}{4}$$
$$z_{Fi,f} = \frac{z_{Fi-1} + 2z_{Fi} + z_{Fi+1}}{4} \qquad (Eq.\ 3)$$

where

   $x_{Fi,f}$, $z_{Fi,f}$ are the filtered x_F and z_F positions at frame i, in mm
   x_{Fi}, z_{Fi} are the unfiltered (or filtered on the previous pass) x_F and z_F positions, in the frame coordinate system at frame i, in mm
   i - 1 and i + 1 designate the preceding and next analysis frames

4.8.4.1.2.7   Transfer the origin of all surrogate photo target position signals to the vehicle reference frame as follows:

$$x_{v,i} = x_{Fi,f} - \left(vx_{F,i,f} - vx_{F,o,f} \right)$$
$$z_{v,i} = z_{Fi,f} - \left(vz_{F,i,f} - vz_{F,o,f} \right) \qquad (Eq.\ 4)$$

where:

$x_{Fi,f}$, $z_{Fi,f}$ are the filtered x_F and z_F position of each of the surrogate photo targets at analysis frame i, in mm, in the frame coordinate system

$vx_{F,i,f}$, $vz_{F,i,f}$ are the filtered x_F and z_F positions of the buck photo target at frame i, in mm, in the frame coordinate system

$x_{,v,i}$, $z_{,v,i}$ are the x and z positions of each of the surrogate photo targets at frame i in the vehicle reference coordinate system, in mm

$vx_{F,o,f}$, $vz_{F,o,f}$ are the filtered x and z positions of the buck photo target at analysis frame 0, in mm, in the frame coordinate system

4.8.4.1.2.8   The second coordinate system is the buck coordinate system. The buck coordinate system is fixed to and moves with the buck, and is defined as follows:

− Positive x is forward with respect to the buck.
− Positive z is down.
− $x = 0$ corresponds to a vertical line passing through the head centroid, upper spine reference point, midthorax reference point, and pelvis reference point at t = 0. If some alignment error between points exists the axis line should be located so as to minimize the cumulative X^2 errors. This is the same vertical line as the frame coordinate system at analysis frame 0.
− $z = 0$ corresponds to the horizontal surface on which the bottom of the dummy shoes rests prior to impact. This is the same horizontal surface as the frame coordinate system at analysis frame 0.

NOTE: The buck coordinate system moves in the imager frame coordinate system positive x direction.

4.8.4.1.3   Velocity Data

Body segment velocities in the buck coordinate system shall be calculated using the methodology recommended in ISO 13232-5 (ISO, 2005). The component velocities in the x and z directions of each body segment shall be calculated as:

$$V_{x,i} = \frac{x_{i+1} - x_{i-1}}{t_{i+1} - t_{i-1}}$$

$$V_{z,i} = \frac{z_{i+1} - z_{i-1}}{t_{i+1} - t_{i-1}}$$

(Eq. 5)

where

$V_{x,i}$, $V_{z,i}$ are each photo target's component velocity, in m/s, in the x (fore/aft) and z (vertical) directions at frame i, in the buck coordinate system
t_i is the time, in ms, at frame i
$i + 1$ and $i - 1$ designate the next and preceding analysis frames

Resultant velocities shall be computed using the length of the velocity vector defined by the components in Equation 5.

5. NOTES

5.1   Marginal Indicia

A change bar (l) located in the left margin is for the convenience of the user in locating areas where technical revisions, not editorial changes, have been made to the previous issue of this document. An (R) symbol to the left of the document title indicates a complete revision of the document, including technical revisions. Change bars and (R) are not used in original publications, nor in documents that contain editorial changes only.

PREPARED BY THE SAE PEDESTRIAN DUMMY TASK FORCE OF THE SAE HUMAN BIOMECHANICS AND SIMULATIONS STANDARDS STEERING COMMITTEE

APPENDIX A - RATIONALE REGARDING BACKGROUND AND REQUIREMENTS FOR A
STANDARDIZED PEDESTRIAN RESEARCH DUMMY

A.1   BACKGROUND

A.1.1   Overview of Pedestrian Injuries and Fatalities Worldwide

Pedestrian injury is a global public health problem. Sixty-five percent of the 1.17 million people that die annually in road traffic accidents worldwide are pedestrians (World Bank, website data accessed in 2006). While the percentage of pedestrian fatalities is much higher in developing than in industrialized nations, pedestrians still comprise 11 to 30% of road traffic fatalities in the US, the European Union, and Japan (NHTSA, 2003, NPA, 2003, CARE, 2002).

Although pedestrians are frequently killed as a result of a vehicle collision, the number of pedestrians injured actually outweighs the number of fatalities by 15 to 1 in the United States (NHTSA 2003). Due to the severity of even low speed collisions, pedestrian injuries are often life-threatening and debilitating. Given the complexity and severity of these injuries, medical and traffic safety professionals are faced with the challenge of finding ways to mitigate their degree and frequency.

A.1.2   Need for a Standardized Pedestrian Research Dummy

Worldwide, vehicle impacts with pedestrians constitute the most frequent cause of traffic-related fatalities. Knowledge about pedestrian/vehicle impacts is essential to reduce vulnerable road user fatalities and injuries.

Currently available tools and methods for studying pedestrian casualties include statistical databases, component testing, and computer simulations; however, full-scale vehicle tests with a research dummy, that is representative of a pedestrian, are essential for understanding the mechanisms of pedestrian trauma and for developing appropriate countermeasures. Such a dummy could be used to:

–   Study pedestrian kinematics
–   Facilitate crash reconstruction including pedestrian kinematics
–   Predict injury probabilities for given vehicle, impact, and countermeasure combinations
–   Design countermeasures
–   Evaluate active systems (e.g., pop-up hoods, airbags) and sensors
–   Refine component test parameters and procedures
–   Validate computer simulations
–   Elucidate the influence of pedestrian size on interaction, injury, and outcome

While it is recognized that collisions involve pedestrians of all sizes, it is proposed that performance specifications for a midsize adult male research dummy be developed as the first step. This approach stems from the greater knowledge of biomechanics and existing dummy technologies for the midsize male relative to other adult sizes and children. While not the initial objective, it is envisioned that additional performance specifications for other sizes of pedestrian research dummies will be developed in the future.

Researchers are currently working to develop both computational models and improved dummies with the goals of (1) quantifying pedestrian kinematics and kinetics to further understand pedestrian injury mechanisms, and (2) developing and testing vehicle countermeasures in component-level and full-scale impact situations. The success of these efforts is predicated on utilizing a pedestrian dummy that possesses biofidelity, repeatability, and reproducibility.

A.1.3   Differences Between Pedestrian Dummies and Vehicle Occupant Dummies

Industry has long recognized the need for different dummies for different types of safety studies. For example, different dummies are used for frontal, rear, and side impact research and highly specialized test dummies have been used for military applications and to study motorcycle crashes. Every dummy design involves numerous design compromises between the needs for biofidelic force/deflection properties, structural integrity, durability, instrumentation installations, and repeatability. In addition, different uses require specialized injury predictive tools based on the associated injury priorities. Vehicle occupant dummies have been developed to represent a person in seated posture who will interact with the interior components of a vehicle along a given axis. Pedestrian dummies must have the ability to represent a standing person who engages the exterior structures of the vehicle. This requires that the dummy have some level of lateral and frontal biofidelity because of the rotation of the pedestrian as it interacts with the front end of the vehicle. Most occupant dummies cannot assume a standing posture and would require extensive modification for use in a pedestrian environment.

A single universal dummy that can be used in multiple applications and crash directions is not possible with the currently available technology.

A.1.4   Survey of Differences Among Existing Pedestrian Dummies

Serious attempts at using ATDs for pedestrian impact research can be traced back to the 1960s and 1970s. During that period devices such as the *Alderson 50th Percentile Anthropometric Dummy* were used to study vehicle damage patterns and pedestrian throw distance (Schneider Stapp 1974). Since that time significant advances have been achieved in ATD technology.

In the early 1980s the first specialized pedestrian impact dummy, the Rotationally Symmetric Pedestrian Dummy (RSPD), was developed by Chalmers University of Technology and INRETS (Aldman ESV 1984). This device was developed to represent a 50th percentile male struck from the side, however it was symmetrical about the vertical axis with no arms and only one leg. The RSPD had major joints along the vertical axis at locations corresponding to the neck, midthoracic spine, lower-thoracic spine, lumbar spine, hip, knee, and ankle.

More recently, there have been three main configurations of pedestrian dummies in use. These include modified versions of the Hybrid-II and Hybrid-III frontal crash test dummies, the Autoliv pedestrian dummy, and the Polar-II. The Hybrid-II and Hybrid-III are vehicle occupant dummies developed for frontal crash testing and require extensive modifications for use in pedestrian testing. These modifications include the addition of a straight lumbar spine, a modified pelvic structure (FTSS, 2009) (Denton ATD, 2009) and knee slider replacements (Hattori, et al., SAE 2000). Typically, these modified Hybrid dummies are shorter than 50th percentile because they were designed based on a seated posture. The Autoliv pedestrian dummy consists of a EuroSID head and neck, US DOT-SID torso, Hybrid II standing pelvis, modified knee structures, and lumbar spring spine which has bending, shearing and elongation capability (Fredriksson, et al., ESV 2001). The Polar-II dummy is based on an early version of the THOR advanced frontal crash test dummy with extensive modifications to the shoulder, thoracic spine, and lumbar spine. The Polar-II also incorporates a totally redesigned lower extremity which includes a human-like knee structure and flexible tibia (Akiyama, et al., 1999, Akiyama, et al., ESV 2001).

A.1.5   Body Region Priorities Based on Injury Frequency of Occurrence and Severity

In order to determine body region priorities for a variety of performance specifications including instrumentation compatibility, component biofidelity, and whole body kinematics for a dummy design, a detailed review of available field injury studies was undertaken. The study showed a variety of investigations detailing injury frequency, injury severity, injury cost, and disability probabilities. Attempts to objectively combine the results of the various studies were hampered by a lack of common procedures, terminology, and body segmentations. In order to prioritize body regions, a group of 10 experts (in attendance at the 4th Pedestrian Dummy Task Force, Biofidelity Sub-Group meeting held in August 2004) familiar with the available studies were asked to prioritize the body regions (as shown below 1 = least important, 10 = most important) based on such factors as the frequency of injury to the body region, the societal cost associated with the injury, and the probability of disability. The results showed that the body regions could be combined into four priority groups (group A - most important and group D - least important). The results of the rankings are shown in Figure A1. Additional details describing the ranking procedures and results may be found in SAE J2868 Appendices B and C.
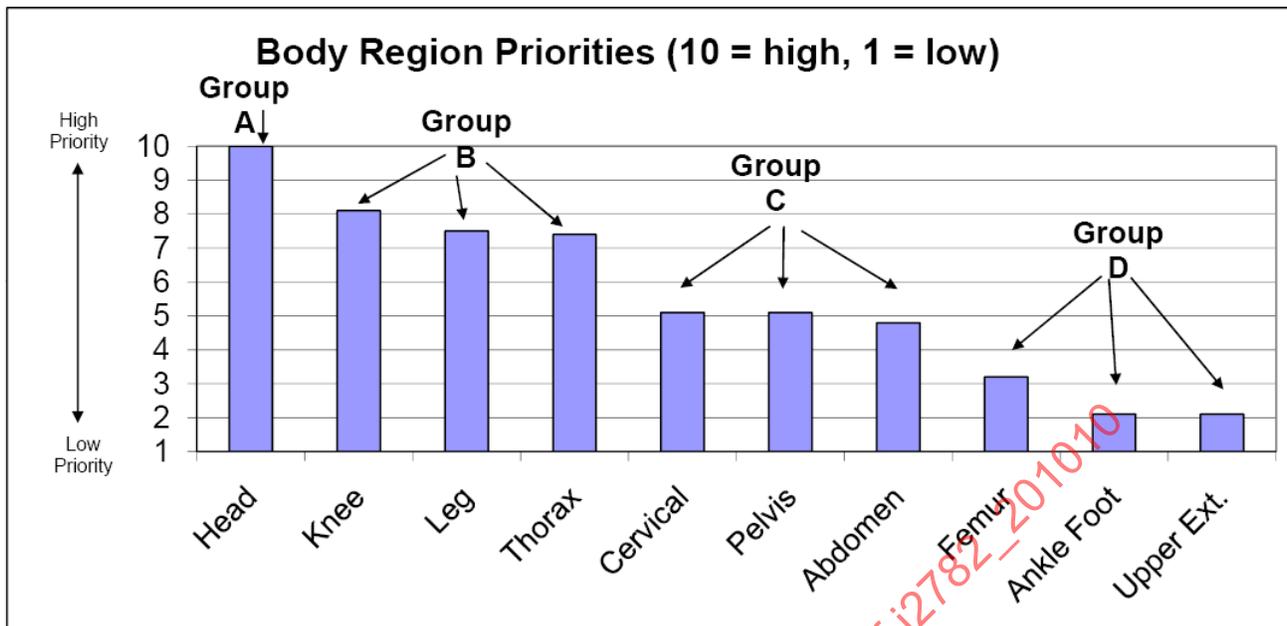
FIGURE A1 - BODY REGION RANKINGS BASED ON INJURY FREQUENCY,
SEVERITY, COST, AND DISABILITY

Some example factors on which the above rankings were based included:

– Head injuries were the most frequent severe injuries
– Knee (including distal femur and proximal tibia) and leg injuries were the most frequent AIS 2 + injuries
– Cervical injuries, although not common are extremely costly and severe when they do occur
– Thorax injuries were of moderate frequency but high severity
– Upper extremity injuries were of moderate frequency and low severity

The body region priorities shown in Figure A1 were used in the development of this document.

A.2   TECHNICAL REQUIREMENTS FOR A PEDESTRIAN RESEARCH DUMMY

A.2.1   Functional Description

The primary requirement for a pedestrian dummy is to reproduce the kinematics of the human body when it is struck by a vehicle front. As agreed upon by the SAE Pedestrian Dummy Task Force and specified in the Task Force Terms of Reference (see SAE J2868 Appendix A), proper whole body kinematics are critical to ensure that dummy motions are representative of humans.

In addition to the first priority of reproducing body kinematics, a secondary priority for the pedestrian dummy is to directly assess the risk of pedestrian injuries in, for example, research projects investigating potential countermeasures, using dummy mounted sensors and appropriate injury risk analysis.

A.2.2   Loading Conditions and Interactions

Primary priority was given to lateral impacts because accident data indicate that more than 68% of pedestrian crashes involve pedestrians walking across the road (Kam et al., SAE 2005, Chidester and Isenberg, ESV 2001). In addition to the body orientation, it was necessary to specify the pedestrian leg orientation (stance). The Kam et al. study indicates that approximately 65% of pedestrian casualties are in a gait stance at the time of collision. Although the initial impact is lateral, Meissner et al. (SAE 2004) illustrated the potential of subsequent rotation of the pedestrian during impact with the vehicle structures. Given the potential for contact of not only the side but also the front of the pedestrian with the vehicle, lateral and frontal biofidelity of the upper body were considered necessary requirements for a pedestrian dummy.