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ABSTRACT

The WorldSID project is a global effort to design a new generation side impact crash test dummy under the direction of the International Organization for Standardization (ISO). The first WorldSID crash dummy will represent a world-harmonized mid-size adult male. This paper discusses the research and rationale undertaken to define the anthropometry of a world standard midsize male in the typical automotive seated posture. Various anthropometry databases are compared region by region and in terms of the key dimensions needed for crash dummy design. The Anthropometry for Motor Vehicle Occupants (AMVO) dataset, as established by the University of Michigan Transportation Research Institute (UMTRI), is selected as the basis for the WorldSID mid-size male, updated to include revisions to the pelvis bone location. The proposed mass of the dummy is 77.3kg with full arms. The rationale for the selected mass is discussed. The joint location and surface landmark database is appended to this paper.

INTRODUCTION

The Anthropomorphic Test Devices Working Group of the International Organization for Standardization (ISO), (ISO/TC22/SC12/WG5) initiated the WorldSID project to develop a single, worldwide harmonized, mid-sized male side impact crash test dummy to replace the existing regulatory and research side impact dummies. The ISO goal is to have a single side impact dummy with improved biofidelity and worldwide acceptance for both regulatory and research use. A Task Group has been formed to lead the development of this new dummy consisting of members from the Americas, Asia/Pacific and European regions.

A number of federal governments worldwide, including the U.S., Canada, the European Union, Australia and Japan, have joined forces under a cooperative agreement named the International Harmonization Research Activities (IHRA) to conduct crash test and biomechanics research. The results of these activities are intended to form the basis for future harmonized standards. One of the ad hoc assignments of the IHRA Biomechanics group was to review the available anthropometric data for the purpose of specifying the anthropometry for WorldSID [1]. IHRA-Biomechanics determined the design will require:

- Some combination of world anthropometric data to facilitate the representation of international populations.
- Sufficient anthropometric definition to allow the specification of WorldSID.
- Anthropometric design specifications that accommodate current secular trend and projected trends.

IHRA-Biomechanics used the 1990 report, “International Data on Anthropometry” by Jürgens et al [2]. Jürgens divided the world population into twenty regions for which certain body measurements were available in the 25 to 45 year old age group. For each of these regions, nineteen ergonomically important body measurements were compiled for both genders for the 5th, 50th and 95th percentiles. The Jürgens data was corrected for the effects of secular growth projected to the year 2000.

IHRA-Biomechanics entered the nineteen body measurements (Table A 3) reported by Jürgens for the twenty regions of the world into a database and analyzed the data in five ways:

1. Un-weighted worldwide mean.
2. Worldwide mean weighted by population in each region.
3. Un-weighted mean of regions containing Organization for Economic Cooperation and Development (OECD) countries.
4. Mean weighted by population for each region containing OECD countries.
5. Mean weighted by fatality rate for the OECD country in that region.

IHRA determined Methods 1 and 2 tend to bias the data towards a smaller anthropometry because of the large populations in China, SE Asia and South America who are smaller in stature, but do not necessarily represent a dominant portion of the population of vehicle occupants likely to be fatally injured. IHRA applied weighting methods 3 to 5 to develop an anthropometry for those OECD countries that have a quantifiable road trauma problem. This data was then compared to the adult Hybrid III crash dummy family with the following comments:

- Methods 1 and 2 yield dimensions that are smaller than the current Hybrid III family.
- Methods 3 and 4 yield dimensions that are larger than the current Hybrid III family, particularly the 95th male.
- Method 5 yields dimensions that are similar for the 50th male, but larger for the 5th female and 95th male than the current Hybrid III family.

IHRA concluded that the anthropometry projected by Method 5 would be most appropriate for WorldSID. This paper compares this anthropometry dataset with other sources to produce a detailed dataset for WorldSID.

ANTHROPOMETRY DATABASES

Crash test dummy design requires significantly more detailed anthropometry specifications than typically available in general anthropometry studies. The dummy requires internal joint center locations, segment masses, segment center of gravity locations, inertial properties and an external flesh surface. The dummy must also simulate the human in the typical semi-reclined automotive seated posture. There are two sources containing this enhanced anthropometry:

- Anthropometry of Motor Vehicle Occupants (AMVO) [3].
- RAMSIS – Rechnergestiitztes Anthropologisch-Mathematisches System zur Insassen – Computer supported anthropological mathematical system for passenger simulation [4].

The AMVO project is a definitive study undertaken by the University of Michigan Transportation Research Institute (UMTRI) to develop specifications specifically for crash test dummies. AMVO measured surface landmarks of 25 adults and calculated the internal joint locations and segment masses and created a dataset of 147 points defining the surface landmarks, joint centers, segment origins and segment centers of gravity (Figure 2). It was published in 1985. UMTRI also developed the full sized clay models of the 5th, 50th and 95th percentiles that were subsequently molded into fiberglass shells and then scanned and surfaced for use with CAD systems (Figure 1).

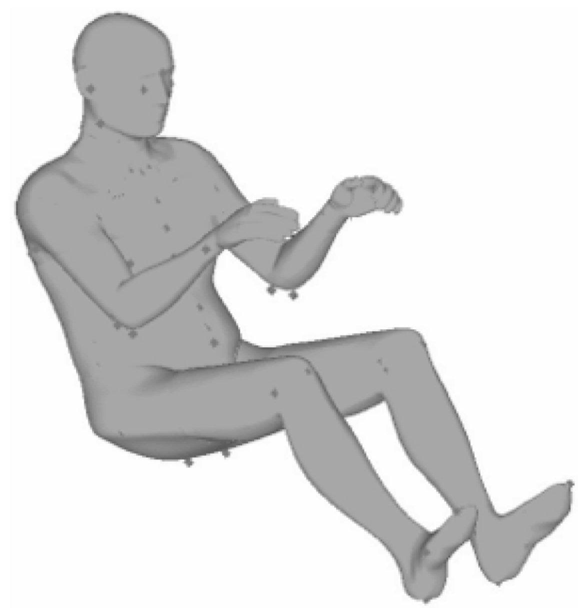

Figure 1. AMVO Surface Shell CAD Model

RAMSIS is a 3D-CAD-Ergonomics software tool developed by Tecmath AG in cooperation with the German automotive industry. The RAMSIS software predicts human internal and external anthropometry based on the input of three anthropometry parameters:

- Sitting height
- Stature (standing height)
- Waist Circumference

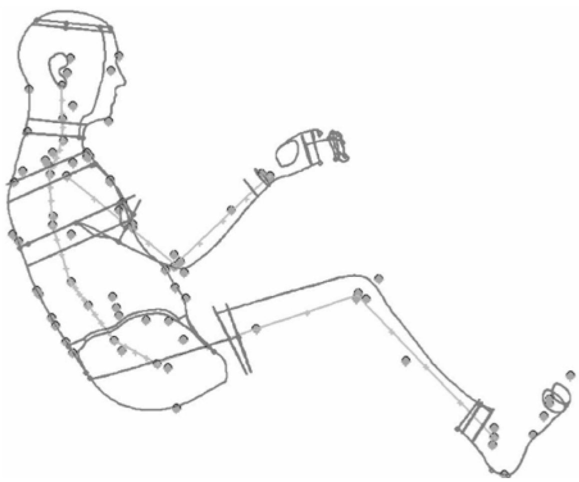

Figure 2. AMVO Point Dataset

The parameters can be entered in absolute terms or as population percentiles. Additionally, the posture can be defined as standing or seated, or in the semi-reclined, automotive seated posture. The anthropometry is further refined by groupings according to age, secular growth and gender, and the reference anthropometry database can be chosen from several sources, either individually or combined. These sources are:

- Germany (formerly East Germany)
- US and Canada (Hanes 1979)
- Japan and Korea (HQL)
- US updated (Hanes 1997, proprietary)
- Japan updated (HQL 1997, proprietary)

RAMSIS outputs internal joint coordinates for the selected size and posture, together with body segmentations, masses, C.G. locations and moments of inertia. It also creates a faceted surface model for import to CAD systems.

COMPARISON OF ANTHROPOMETRY DATABASES

Table 1 compares the statures (standing height), seated heights and weight for the IHRA proposal, the AMVO dataset and the five databases from the RAMSIS software [5]. The deviation from the IHRA proposal is shown in parentheses.

Excluding the Japan and Korea studies, the predicted statures are very similar, with a maximum deviation of 17mm for the East German study. The AMVO mid-size male is 1mm smaller than the IHRA proposal. The seated heights for all the databases, including the Japan and Korea studies, are within 10mm. This implies the major anthropometrical difference between the Asian and Western populations is in the leg length.

Since there is very little difference between the studies, and the AMVO data contains all segment lengths, the AMVO stature of 1753mm is adopted for WorldSID.

Table 1. Comparison of Anthropometry Studies for the Mid-Size Male (* Proprietary anthropometry studies)

Study	Stature (mm)	Seated Height (mm)	Weight (kg)
IHRA (Jurgens)	1754	921	
AMVO	1753 (-1)	911 (-10)	76.7
RAMSIS German	1771 (+17)	931 (+10)	79.2
RAMSIS Japan *	1689 (-65)	911 (-10)	64.8
RAMSIS USA *	1765 (+6)	923 (+2)	82.0
RAMSIS US/Canada	1755 (+1)	917 (-4)	72.7
RAMSIS Japan/Korea	1695 (-59)	921 (0)	66.6

WEIGHT – The IHRA data, based on the Jurgens study, does not include a mass proposal for the mid-size male. The average weight for the four Western databases in Table 1 is 77.6kg.

Masses predicted by RAMSIS show large variations, and in particular the two US studies vary from 72.7kg to 82.0kg. The RAMSIS software predicts anthropometry based on three parameters – stature, seated height and waist circumference, which can be classified as a measure of corpulence. Variations in the waist circumference could account for large variations in the predicted mass whereas the stature shows very little variation.

The AMVO study used the 1974 NHANES II data to establish the target body weight for the midsize male ATD. The median male weight in NHANES II is 77.3kg. The 25 men who were measured in Phase 3 of AMVO to determine the final specifications averaged 76.7 kg, which became the defined weight for the AMVO midsize male. The AMVO segment mass values were obtained by using the McConville regression equations to predict the segment volumes, calculating segment mass by assuming a density of 1gm/cm^3, and linearly scaling the resulting values so that the sum of the segment masses equaled the average body mass of the measured subjects. However it is argued the segment mass estimates should have been scaled to the target mass of 77.3kg rather than the averaged measured mass of 76.7kg.

Since the AMVO target mass is closer to the average database mass, and less than 1% different to the AMVO measured weight, the recommended body weight of the WorldSID with full arms is 77.3kg. Segment masses should be scaled by 77.3/76.7.

UPDATE TO AMVO STUDY

The Society of Automotive Engineers (SAE) Cooperative Research Program ASPECT – (Automotive Seat and Package Evaluation and Comparison Tools) has developed the next generation of seating manikin. This study identified some inaccuracies in the original AMVO dataset with respect to the location of the pelvis bone relative to the surface shell and the upper torso. Essentially the anterior superior iliac spine (ASIS) was out of position and there was too much flesh under the pelvis bone.

The pelvis bone should be located approximately 10.4mm lower and 2.0mm forward than originally specified. Extending the lower lumbar spine by this amount accommodates this offset.

RE-POSITIONING PROCEDURE – UMTRI has defined a re-positioning procedure to update the original AMVO dataset.

Alignment of Surface Shell

1. Use surface landmarks at L5 (point 12) and T8 (point 9) to set the shell model recline angle as drawing MM-101 (24.6 deg).
2. Set Z coordinate of posterior calcaneus (point 92) to the AMVO drawing MM-101.
3. Set X coordinate of Glabbela (point 1) to the AMVO drawing MM-101.
4. Check the points in the lumbar/torso area to confirm the model position, adjusting X by 3mm.

Relocation of H-Point

1. Locate the mid-point between the two ASIS points and translate to 0,0,0.
2. Enter following reference coordinates:

Location	X (mm)	Y (mm)	Z (mm)
L5	-150	2	-72
L5 S1 Joint	-687	0	-43
Right Hip Joint	23	-835	-934
Left Hip Joint	23	835	934

3. Translate the model so that mid H-point is 0,0,0.
4. Move L5/S1 (point 60) to (-89, 0, 39).
5. Reposition L2/L3 (point 59) so that it is located 60% of the distance from L5/S1 (point 60) to T12/L1 (point 58).

The translation vector from the mid-point of the old H-point to that of the new H-point is:

$$H(new) = H(old) + dH$$

where: $dH = 2i + 10.4k$, $(x=i, y=j, z=k)$

COMPARISON OF AMVO AND RAMSIS MODELS

The two datasets and surface files were merged into one CAD file and translated so that files have common H-point at 0,0,0 (Figure 3).

Figure 3 illustrates the initial positioning of the two datasets and they exhibit a very similar profile. There is a discrepancy at the back centerline and the back of the head. The foot angles are different and the arm positions, but this can be corrected by re-posturing.

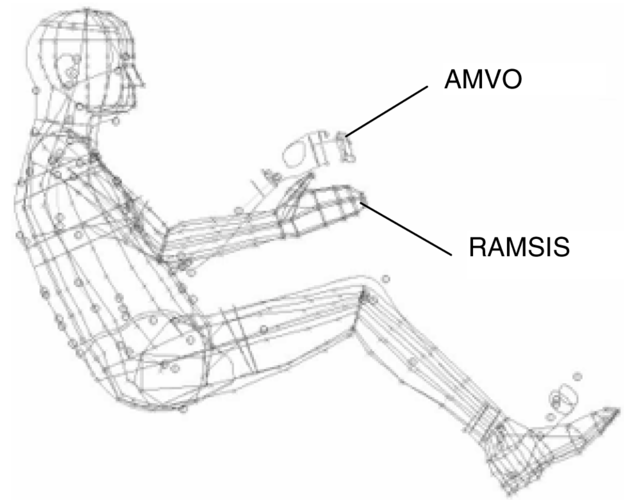

Figure 3. AMVO and RAMSIS Datasets Overlay

The RAMSIS model was rotated rearward by 2.5 degrees about the H-point. The overlay is shown in Figure 4. The two datasets now match very closely.

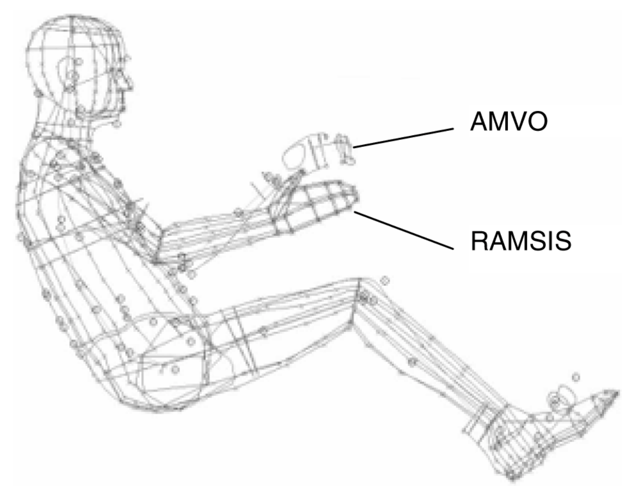

Figure 4. AMVO and RAMSIS Overlay - RAMSIS rotated rearward 2.5 degrees

Figure 5 shows the datasets overlaid with the surface landmarks and the surface shells hidden, leaving just the internal joint coordinates. This is known as the 'Stickman'. The RAMSIS data exhibits increased spine lordosis, and a shorter upper arm segment.

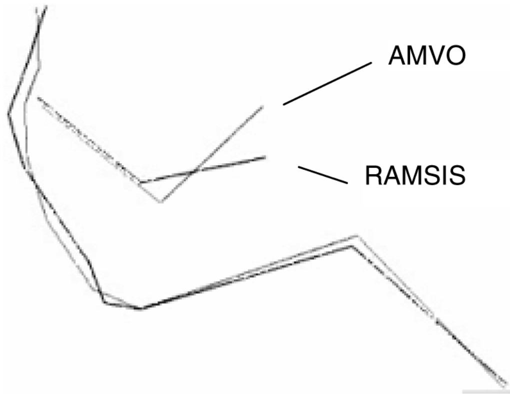

Figure 5. AMVO and RAMSIS Stickman

ARM SEGMENT LENGTH – The AMVO upper arm segment length is 295.6mm and the RAMSIS is 256.4mm, a difference of 39.2mm. This is a significant difference and further study was necessary.

Table 2 compares values of arm and forearm segment lengths obtained from several different studies. The primary source for comparison is the AMVO study [3]. The AMVO values are compared to a simple scaling from Drillis and Contini [6] and two sets of values derived from Webb Associates [7].

Table 2. Comparison of Arm Segment Lengths for Men 1753mm Tall

Study	Arm Length (mm)	Forearm Length (mm)
Schneider et al. AMVO [1]	296	276
Drillis and Contini [2]	326	256
Webb Associates (50%male) [3]	304	273
Webb Associates Length Calcs [4]	298	258

1. Schneider et al. (1985) [3].
2. Drillis and Contini [6] scaled from stature.
3. Webb Associates [7] reported median male values.
4. Calculated values for reference stature (1.753m) using Webb Associates methods [7], which reference Trotter and Gleser [8] and Dempster [9].

One important question in assessing the validity of the AMVO study [3] is whether the 25 men who were measured had appropriate upper extremity segment lengths. Table 3 shows the values of three standard anthropometric measures compared to those obtained from the Anthropometric Survey of U.S. Army Personnel (ANSUR) [10] using linear regressions on stature. The AMVO exterior dimensions are very close to the values expected for males 1753mm tall. Notably, shoulder-elbow length and radiale-stylion length are within 3mm of the values predicted from ANSUR.

Table 3. Comparison of AMVO and ANSUR Derived Upper Extremity Length (mm)

Study	Shoulder to Elbow Length	Forearm to Hand Length	Radiale to Stylion Length
AMVO [3]	365	474	269
ANSUR	368	483	269

The men in the AMVO study had upper extremity exterior dimensions (standard anthropometry) that closely match those expected based on the much larger ANSUR survey of U.S. Army personnel [10]. Consequently, any discrepancies in segment length between AMVO and other studies with the same size individuals are likely due to differences in the manner in which the joint locations are calculated from external landmarks.

The Webb Associates calculation methods use regression equations based on an extensive study of U.S. servicemen's remains to estimate long-bone lengths from stature [7]. Ratios developed by Dempster [9] from cadaver dissections are then used to relate the bone lengths to the functional segment lengths. For example, the humerus length for a male 1753mm tall is estimated to be 333mm, and the arm segment length is estimated to be 89.44 percent of the humerus length, or 298mm.

The Webb Associates methods give a value for the arm segment length very similar to that obtained in the AMVO study. However, the forearm segment length differs by about 18mm. Based on the available information, the AMVO value would appear to be the more reliable, because it is based on landmark locations measured on men who are demonstrably typical in their upper extremity segment exterior dimensions for men of their stature.

Based on the foregoing analyses, the recommended arm segment lengths for WorldSID are those from the AMVO study:

- Arm Segment Length 296mm
- Forearm Segment Length 276mm

The Hybrid III 50th Dummy upper arm length is also shorter than the AMVO data, although in the 'hands-on-wheel' posture with approximately 90 degrees between upper arm and forearm, the exterior surfaces of the Hybrid III arm align well with the AMVO data. The difference is caused by the location of the elbow joint. The AMVO data correctly puts the joint at the outer surface of the arm, whereas the Hybrid III elbow joint is at the center of the arm cross-section. When the Hybrid III arm is straightened, it is approximately 60mm shorter than the typical midsize male.

CONCLUSIONS

1. The 1983 AMVO study has been compared to available anthropometrical databases, and is consistent with the stature and mass predictions for a world mid-size male.
2. The AMVO study is the recommended source to define the anthropometry of the mid-size male WorldSID. The WorldSID anthropometry is defined in Appendix 2.

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ISO WorldSID Task Group.

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APPENDIX 1

Comparison of statures and masses across different anthropometry databases.

Table A1. Summary Comparison of Anthropometry Databases (Figures in brackets denote deviation from IHRA definition)
* Proprietary Anthropometry Studies

	IHRA/ Jurgens	AMVO	RAMSIS Database				
Body Measurement			**US/ Canada**	**US***	**Germany**	**Japan/ Korea**	**Japan***
Stature (mm)	1754 (0)	1753 (-1)	1755 (1)	1765 (11)	1771 (17)	1695 (-59)	1689 (-65)
Sitting Height (mm)	921 (0)	911 (-10)	917 (-4)	923 (2)	931 (10)	921 (0)	911 (-10)
Chest width (mm)		312[1]	296	313	308	300	311
Hip Breadth - sitting (mm)	347	322[2] (-25)	339 (-8)	353 (6)	351 (4)	326 (-21)	340 (-7)
Body Mass (kg)		76.7	72.7	82	79.2	66.6	64.8

1. At 10th rib
2. At iliocristale

APPENDIX 1 (CONTINUED)

Table A2. Detailed Comparison of Anthropometry Databases. Dimensions in mm unless otherwise noted.

	IHRA/ Jurgens	AMVO	RAMSIS				
Body Measurement			**US & Canada**	**US (prop)**	**German**	**Japan & Korea**	**Japan (prop)**
Stature	1754	1753	1755	1765	1771	1695	1689
Sitting Height	921	911	917	923	931	921	911
Eye Height, sitting	804						
Forward Reach (fingertips)	845						
Shoulder breadth (bideltoid)	447	449	462	482	478	457	448
Shoulder breadth (biacromial)	388	395					
Hip Breadth (standing)	337						
Knee Height	539		549	548	546	499	533
Lower leg length (popliteal height)	443						
Elbow-grip length	353						
Buttock - knee length	600	593	604	615	615	594	560
Buttock - heel length	1058						
Hip Breadth (sitting)	347		339	353	351	326	340
Hand length	190						
Hand breadth	088						
Foot length	262	264	291	296	295	280	223
Head circumference	568	571					
Head length	191	197	219	223	224	223	235
Head breadth	155	158	155	159	159	156	161
Head depth			191	194	196	195	189
Neck length			100	93	098	095	90
Upper arm length			328	337	336	343	331
Forearm length with hand			465	475	474	443	441
Forearm circumference		254	273	285	282	269	167
Chest width			296	313	308	300	311
Chest depth			212	234	226	221	206
Waist circumference		859	847	942	903	810	800
Pelvis Width			299	313	309	287	284
Foot Height			091	093	093	087	067
Foot width		96	105	108	108	103	096
Body Mass (kg)		76.7	72.7	082	79.2	66.6	64.8

APPENDIX 1 (CONTINUED)

Table A3. Mean Percentiles for Male & Female Body Measurements across 8 Regions containing OECD Countries (Weighted by Road Fatality Rates). Dimensions in mm unless otherwise noted.

	Men	Men	Men	Women	Women	Women
Percentile	**5th**	**50th**	**95th**	**5th**	**50th**	**95th**
Stature	1647	1754	1863	1534	1632	1731
Sitting height	867	921	979	812	868	920
Eye height, sitting	747	804	857	693	746	804
Forward reach (fingertips)	792	845	901	735	789	841
Shoulder breadth (bi-deltoid)	409	447	485	357	396	428
Shoulder breadth (bi-acromial)	354	388	421	319	351	387
Hip breadth (standing)	305	337	364	311	348	396
Knee height	492	539	583	452	489	527
Lower leg length (popliteal height)	402	443	482	358	396	433
Elbow-grip length	322	353	389	298	326	361
Buttock-knee length	553	600	647	521	566	612
Buttock-heel length	977	1058	1139	925	996	1070
Hip breadth (sitting)	309	347	382	317	365	420
Hand length	175	190	207	156	173	189
Hand breadth	80	88	93	70	76	84
Foot length	242	262	283	218	239	261
Head circumference	536	568	594	518	546	571
Head length	179	191	202	167	179	191
Head breadth	145	155	165	137	146	156

APPENDIX 2 – WORLDSID ANTHROPOMETRY

Land-mark	Description	X (mm)	Y (mm)	Z (mm)
	Head			
1	Glabbela	-78	0	661.4
2	Infraorbitale (L,R)	-94	±34	630.4
3	Tragion (L,R)	-183	±83	624.4
4	Gonion (L,R)	-171	±70	554.4
5	Gnathion	-99	0	521.4
6	Nuchale	-260	0	589.4
	Vertebral Column			
7	C7	-264	0	499.4
8	T4	-291	0	390.4
9	T8	-282	0	263.4
10	T12	-244	0	156.4
11	L2	-215	0	097.4
12	L5	-172	0	023.4
13	Mid-Spine 10th Rib	-240	0	148.4
14	Superior Margin Scapula (L,R)	-274	±79	413.4
15	Inferior Margin Scapula (L,R)	-294	±126	277.4
16	R10 Projection To Back	-207	0	81.4
17	Iliocristale Projection To Back	-186	0	45.4
	Torso			
18	Suprasternale	-137	0	445.4
19	Mesosternale	-96	0	395.4
20	Substernal	-70	0	346.4
21	Bimammary, Midline	-50	0	291.4
22	Nipple (L,R)	-50	±113	300.4
23	10th Rib, Anterior, Mid-Line	17	0	201.4
24	Umbilicus	37	0	163.4
25	Maximum Abdominal Protrusion	58	0	139.4
26	10th Rib (L,R)	-91	±156	143.4
	Pelvis			
27	Iliocristale	-78	±161	103.4
28	Anterior Superior Illac Spine (L,R)	-23	±116	93.4
29	Pubic Symphysis	53	0	51.4
30	Thigh/Abdominal Junction	23	±122	91.4
31	Throchanterion (Skeletal Reconstruction) (L,R)	22	±203	-9.6
32	H-Point	0	±84	0
	Shoulder			
33	Clavicale (L,R)	-143	±23	453.4
34	Acromio-Clavicular Artic (L,R)	-213	±182	453.4
35	Greater Tubercle Humerus (L,R)	-171	±218	431.4
36	Acromion (L,R)	-222	±203	429.4
37	Anterior Scye (L,R)	-095	±154	390.4
38	Posterior Scye (L,R)	-212	±197	316.4

APPENDIX 2 – WORLDSID ANTHROPOMETRY (CONTINUED)

Land-mark	Description	X (mm)	Y (mm)	Z (mm)
	Arm			
39	Lateral Humeral Epicondyle (L,R)	34	±242	234.4
40	Radiale (L,R)	48	±243	219.4
41	Medial Humeral Epicondyle (L,R)	34	±173	209.4
42	Olecranon (L,R)	55	±210	196.4
43	Ulnar Styloid (L,R)	228	±191	397.4
44	Stylion (L,R)	213	±135	409.4
	Leg And Foot			
45	Lateral Femoral Epicondyle (L,R)	406	±189	139.4
46	Medial Femoral Epicondyle (L,R)	409	±087	152.4
47	Tibiale (L,R)	426	±88	138.4
48	Petalla (L,R)	451	±150	182.4
49	Sphyrion (L,R)	686	±61	-138.6
50	Metatarsal-Phalangeal (I) (L,R)	798	±84	-75.6
51	Digit (Ii) (L,R)	841	±147	-26.6
52	Metatarsal-Phalangeal (V) (L,R)	787	±174	-113.6
53	Malleolus (L,R)	682	±126	-174.6
	Joint Centers			
54	Head/Neck	-194	0	598.4
55	C7/T1	-191	0	479.4
56	T4/T5	-218	0	407.4
57	T8/T9	-213	0	297.4
58	T12/L1	-175	0	175.4
59	L2/L3	-141	0	120.8
60	L5/S1	-89	0	3.9
61	Sternoclavicular	-143	±43	443.4
62	Claviscapular	-228	±168	437.4
63	Glenohumeral	-184	±173	403.4
64	Elbow	38	±208	211.4
65	Wrist	230	±158	403.4
66	Hip (H-Point) = 32	0	±835	0
67	Knee	408	±138	146.4
68	Ankle	686	±94	-158.6
	Origins Of Segments			
69	Head	-183	0	624.4
70	Neck = 7	-264	0	499.4
71	Thorax = 16	-207	0	81.4
72	Abdominal	-91	0	143.4
73	Pelvis	-23	0	93.4
74	Upper Arms = 36	-222	±203	429.4
75	Lower Arms = 40	48	±243	219.4
76	Upper Legs = 31	22	±203	-9.6
77	Lower Legs = 47	426	±88	138.4
78	Feet	798	±126	-85.6

Land-mark	Description	X (mm)	Y (mm)	Z (mm)
	Est. Segment Centers Of Gravity			
79	Head	-177	0	656.4
80	Neck	-193	0	525.4
81	Thorax	-175	0	277.4
82	Abdomen	-83	0	120.4
83	Pelvis	-72	0	27.4
84	Upper Arms	-78	±191	329.4
85	Lower Arms	151	±174	330.4
86	Upper Legs	202	±131	74.4
87	Lower Legs	506	±125	5.4
88	Feet	765	±110	-153.6
	Hip Segmentation Plane Points			
89	Pubotuberosity	53	±35	51.4
90	Shifted Asis = 28	-23	±116	93.4
91	Inferior Tuberosity Projection	39	±49	-96.6
	Heel Point On Floor Of Seating Buck			
92	Posterior Calcaneus	707	±94	-239.6