
Respiratory protective devices — Human factors —

Part 2:
Anthropometrics

*Appareils de protection respiratoire — Facteurs humains —
Partie 2: Anthropométrie*

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Foreword

ISO (the International Organization for Standardization) is a worldwide federation of national standards bodies (ISO member bodies). The work of preparing International Standards is normally carried out through ISO technical committees. Each member body interested in a subject for which a technical committee has been established has the right to be represented on that committee. International organizations, governmental and non-governmental, in liaison with ISO, also take part in the work. ISO collaborates closely with the International Electrotechnical Commission (IEC) on all matters of electrotechnical standardization.

International Standards are drafted in accordance with the rules given in the ISO/IEC Directives, Part 2.

The main task of technical committees is to prepare International Standards. Draft International Standards adopted by the technical committees are circulated to the member bodies for voting. Publication as an International Standard requires approval by at least 75 % of the member bodies casting a vote.

In other circumstances, particularly when there is an urgent market requirement for such documents, a technical committee may decide to publish other types of document:

- an ISO Publicly Available Specification (ISO/PAS) represents an agreement between technical experts in an ISO working group and is accepted for publication if it is approved by more than 50 % of the members of the parent committee casting a vote;
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An ISO/PAS or ISO/TS is reviewed after three years in order to decide whether it will be confirmed for a further three years, revised to become an International Standard, or withdrawn. If the ISO/PAS or ISO/TS is confirmed, it is reviewed again after a further three years, at which time it must either be transformed into an International Standard or be withdrawn.

Attention is drawn to the possibility that some of the elements of this document may be the subject of patent rights. ISO shall not be held responsible for identifying any or all such patent rights.

ISO/TS 16976-2 was prepared by Technical Committee ISO/TC 94, *Personal safety — Protective clothing and equipment*, Subcommittee SC 15, *Respiratory protective devices*.

ISO/TS 16976 consists of the following parts, under the general title *Respiratory protective devices — Human factors*:

- *Part 1: Metabolic rates and respiratory flow rates* [Technical Specification]
- *Part 2: Anthropometrics* [Technical Specification]

Introduction

For an appropriate design, selection and use of respiratory protective devices, basic physiological demands of the user must be considered. Type and intensity of work affect the metabolic rate (energy expenditure) of the wearer. Weight and weight distribution of the device on the human body can also influence metabolic rate. Metabolic rate is directly correlated with oxygen consumption, which determines the respiratory demands and flow rates. The work of breathing is influenced by the air flow resistances of the device and the lung airways. The work (or energy cost) of a breath is related to the pressure gradient created by the breathing muscles and the volume that is moved in and out of the lung during the breath. Anthropometric and biomechanical data are required for appropriate design of various components of a respiratory protective device as well as for the design of relevant test methods.

This technical specification forms Part 2 of a series of documents providing basic anthropometric measurement methods and data on humans. It contains information about the description, definition and diagram of landmarks and dimensions, up-to-date head and face data for various race/ethnic groups, and human test panels.

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Respiratory protective devices — Human factors —

Part 2: Anthropometrics

1 Scope

This part of ISO/TS 16976 is one part of a series of technical specifications that provide information on factors related to human anthropometry, physiology, ergonomics and performance for the preparation of standards for design, testing and use of respiratory protective devices. This part of ISO/TS 16976 contains information related to anthropometry. In particular, information is given for:

- anthropometric measurement methods;
- anthropometric data for head, face and neck dimensions;
- anthropometric data for torso dimensions;
- human test panels;
- models of headforms.

2 Normative references

The following referenced documents are indispensable for the application of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

EN 14143, *Respiratory equipment — Self-contained re-breathing diving apparatus*

3 Terms and definitions

For the purposes of this document, the terms and definitions given in Annexes A and B apply.

4 Anthropometric measurements

4.1 Anthropometric instrument and software

The standard measurement tools which are recommended are the anthropometer, a spreading calliper, a sliding calliper, a pupillometer, and a steel measuring tape. A suitable data entry, editing and analysis software is described by Zhuang et al.^{[3][4]}.

4.1.1 Anthropometer, a specialized tool for measuring linear distance between points on the body and standard reference surfaces, such as the floor or a seat platform.

4.1.2 Spreading and sliding callipers, used for measuring the breadth and depth of body segments, as well as the distance between reference marks.

4.1.3 Measuring tape, used for measuring the arc and circumference of body segments.

4.1.4 Pupillometer, a standard ophthalmic device used for measuring the interpupillary distance.

4.2 Measurement procedures

4.2.1 Landmarking

Landmarks are generally, although not always, skeletal points that are usually marked on the skin overlying the point. Selected landmarks are listed in Table 1 and described in Annex A. Subjects are landmarked with a surgical marker or an eyeliner pencil prior to measurement.

4.2.2 Measuring

After landmarking, subjects are measured for each of the dimensions. Data are recorded on data sheets and simultaneously entered into computer software. The data entry and editing software evaluate each measurement as it is entered, and indicate when a measurement value is out of the previously measured range, or is otherwise unexpected. In such cases, the measurement shall be repeated or data input errors corrected.

4.3 Dimensions to be measured

The dimensions to be measured are listed in Table 2. The detailed dimension descriptions are provided in Annex B. All dimensions are measured in millimetres and body weight is measured in kilograms.

Table 1 — List of landmarks

| Landmarks | Landmark positioning |
|------------------|----------------------|
| Alare | Right and left |
| Cheilion | Right and left |
| Chin | — |
| Ectocanthus | Right and left |
| Frontotemporale | Right and left |
| Glabella | — |
| Gonion | Right and left |
| Infraorbitale | Right and left |
| Menton | — |
| Nasal root point | Right and left |
| Pronasale | — |
| Pupil | Right and left |
| Sellion | — |
| Subnasale | — |
| Top of head | — |
| Tragion | Right and left |
| Zygion | Right and left |
| Zygofrontale | Right and left |

Table 2 — List of face dimensions

| Dimensions | Common terms |
|--------------------------|--------------|
| Bigonial breadth | Jaw width |
| Bitragion chin arc | |
| Bitragion coronal arc | |
| Bitragion frontal arc | |
| Bitragion subnasale arc | |
| Bizygomatic breadth | Face width |
| Head breadth | |
| Head circumference | |
| Head length | |
| Interpupillary distance | |
| Lip length | |
| Maximum frontal breadth | |
| Menton-sellion length | Face length |
| Minimum frontal breadth | |
| Nasal root breadth | |
| Neck circumference | |
| Nose breadth | |
| Nose protrusion | |
| Subnasale-sellion length | Nose length |
| Stature | Height |
| Weight | |

5 Anthropometric data for head, face and neck dimensions

Test panels for the development of an International Standard must be representative of the world population. An anthropometric study of the US work population was conducted by the National Institute for Occupational Safety and Health (NIOSH) in 2003. See Reference [3]. The survey consisted of three age strata (18 years to 29 years, 30 years to 44 years, 45 years to 66 years), two gender strata (male and female), and four racial/ethnic group strata (white, African American, Hispanic and other). The selected test panel could be seen as almost representative for the worldwide population, since the US population is multi-ethnic. Height, weight, 19 face dimensions and neck circumferences were measured using traditional methods. A total of 3 997 subjects (2 543 male and 1 454 female) were measured. The sampling strategy called for equal representation in each of the sampling cells. This was done to ensure that we had adequately captured the anthropometric variability in all segments of the population. NIOSH research has resulted in the development of Table 3.

The NIOSH data were supplemented with additional measurements in China and other data for various countries. See References [5] and [6]. The data were compared to the NIOSH US Data and were found to be within the 5th and 95th percentiles for US population in Table 3.

Table 3 — Anthropometric data for head, face, and neck dimensions by gender
(weight in kilograms, all other values in millimetres)

Males

| Dimension | Number | Mean | Standard deviation | Min. | Max. | Percentiles | | |
|--------------------------|--------|---------|--------------------|-------|-------|-------------|-------|-------|
| | | | | | | 5th | 50th | 95th |
| Bigonial breadth | 2 543 | 120,4 | 10,4 | 90 | 160 | 105 | 120 | 140 |
| Bitracion chin arc | 2 543 | 331,2 | 15,5 | 271 | 393 | 306 | 330 | 355 |
| Bitracion coronal arc | 2 543 | 350,7 | 13,9 | 310 | 405 | 330 | 350 | 375 |
| Bitracion frontal arc | 2 543 | 304,1 | 13,0 | 263 | 349 | 282 | 305 | 326 |
| Bitracion subnasale arc | 2 543 | 294,8 | 13,2 | 253 | 345 | 275 | 295 | 315 |
| Bizygomatic breadth | 2 543 | 143,5 | 6,9 | 120 | 170 | 132 | 143 | 155 |
| Head breadth | 2 543 | 153,0 | 6,0 | 135 | 179 | 144 | 153 | 163 |
| Head circumference | 2 543 | 575,7 | 17,1 | 520 | 639 | 547 | 575 | 604 |
| Head length | 2 543 | 197,3 | 7,4 | 174 | 225 | 185 | 197 | 210 |
| Interpupillary distance | 2 543 | 64,5 | 3,6 | 53 | 79 | 59 | 65 | 71 |
| Lip length | 2 543 | 51,1 | 4,2 | 40 | 70 | 44 | 51 | 58 |
| Maximum frontal breadth | 2 543 | 112,3 | 5,5 | 95 | 131 | 104 | 112 | 122 |
| Menton-sellion length | 2 543 | 122,7 | 7,0 | 100 | 156 | 111 | 123 | 135 |
| Minimum frontal breadth | 2 543 | 105,5 | 5,7 | 90 | 127 | 95 | 105 | 115 |
| Nasal root breadth | 2 543 | 16,6 | 2,3 | 10 | 29 | 13 | 16 | 20 |
| Neck circumference | 1 023 | 406,7 | 32,6 | 312 | 570 | 355 | 403 | 465 |
| Nose breadth | 2 543 | 36,6 | 4,1 | 26 | 58 | 31 | 36 | 45 |
| Nose protrusion | 2 543 | 21,1 | 2,7 | 13 | 32 | 17 | 21 | 26 |
| Stature | 2 543 | 1 753,9 | 67,7 | 1 488 | 2 012 | 1 642 | 1 754 | 1 866 |
| Subnasale-sellion length | 2 543 | 52,0 | 4,1 | 40 | 66 | 45 | 52 | 59 |
| Weight | 2 540 | 90,4 | 17,5 | 42,9 | 167,8 | 65,7 | 88,4 | 122,7 |

Females

| Dimension | Number | Mean | Standard deviation | Min. | Max. | Percentiles | | |
|--------------------------|--------|---------|--------------------|-------|-------|-------------|-------|-------|
| | | | | | | 5th | 50th | 95th |
| Bigonial breadth | 1 454 | 110,1 | 8,9 | 88 | 150 | 98 | 110 | 125 |
| Bitracion chin arc | 1 454 | 303,9 | 14,9 | 248 | 375 | 280 | 305 | 328 |
| Bitracion coronal arc | 1 454 | 339,3 | 15,0 | 290 | 425 | 315 | 340 | 365 |
| Bitracion frontal arc | 1 454 | 287,4 | 11,9 | 250 | 330 | 270 | 287 | 305 |
| Bitracion subnasale arc | 1 454 | 277,5 | 13,1 | 238 | 335 | 258 | 277 | 300 |
| Bizygomatic breadth | 1 454 | 135,1 | 6,5 | 115 | 157 | 124 | 135 | 146 |
| Head breadth | 1 454 | 146,8 | 5,6 | 129 | 165 | 137 | 146 | 156 |
| Head circumference | 1 454 | 554,9 | 17,8 | 475 | 654 | 527 | 555 | 585 |
| Head length | 1 454 | 187,5 | 7,2 | 152 | 215 | 175 | 187 | 199 |
| Interpupillary distance | 1 452 | 61,9 | 3,5 | 52 | 78 | 56 | 62 | 68 |
| Lip length | 1 454 | 48,0 | 4,0 | 35 | 63 | 42 | 48 | 55 |
| Maximum frontal breadth | 1 454 | 108,6 | 5,3 | 92 | 130 | 100 | 108 | 117 |
| Menton-sellion length | 1 454 | 113,4 | 6,1 | 91 | 135 | 104 | 113 | 124 |
| Minimum frontal breadth | 1 454 | 102,9 | 5,4 | 84 | 126 | 94 | 103 | 111 |
| Nasal root breadth | 1 454 | 16,3 | 2,0 | 10 | 25 | 13 | 16 | 20 |
| Neck circumference | 793 | 339,5 | 30,9 | 260 | 505 | 295 | 335 | 395 |
| Nose breadth | 1 454 | 33,2 | 3,9 | 22 | 54 | 28 | 33 | 41 |
| Nose protrusion | 1 454 | 19,8 | 2,7 | 11 | 29 | 16 | 20 | 25 |
| Stature | 1 454 | 1 625,4 | 67,5 | 1 310 | 1 862 | 1 513 | 1 627 | 1 731 |
| Subnasale-sellion length | 1 454 | 48,2 | 3,8 | 32 | 59 | 42 | 48 | 55 |
| Weight | 1 454 | 75,7 | 18,7 | 34,2 | 176,4 | 51,8 | 72,1 | 112,1 |

6 Anthropometric data for torso dimensions

The application for the torso to be developed is to hold an RPD (respiratory protective device) designed to be worn on the human body, in position, during testing. The data given for this torso are not appropriate for use in the design of the RPD. Since there will be no test where ergonomic features are checked by using the torso, it has been agreed to use the ADULTDATA handbook^[7] mean values of males and females. A subset of the ADULTDATA including anthropometric data for a number of surveys from UK, Sweden, Italy, France, China, Japan and USA was used.

The mean values of the designated measurements identifying the main dimensions of a torso illustrated in Figure 1 are listed in Table 4. The measure reference identification numbers have been taken from the ADULTDATA handbook as they are numbered originally to allow comparison.

The last column in Table 4 shows the mean for male and female mean data which leads to the neutral dimension to be taken for modelling of the torso.

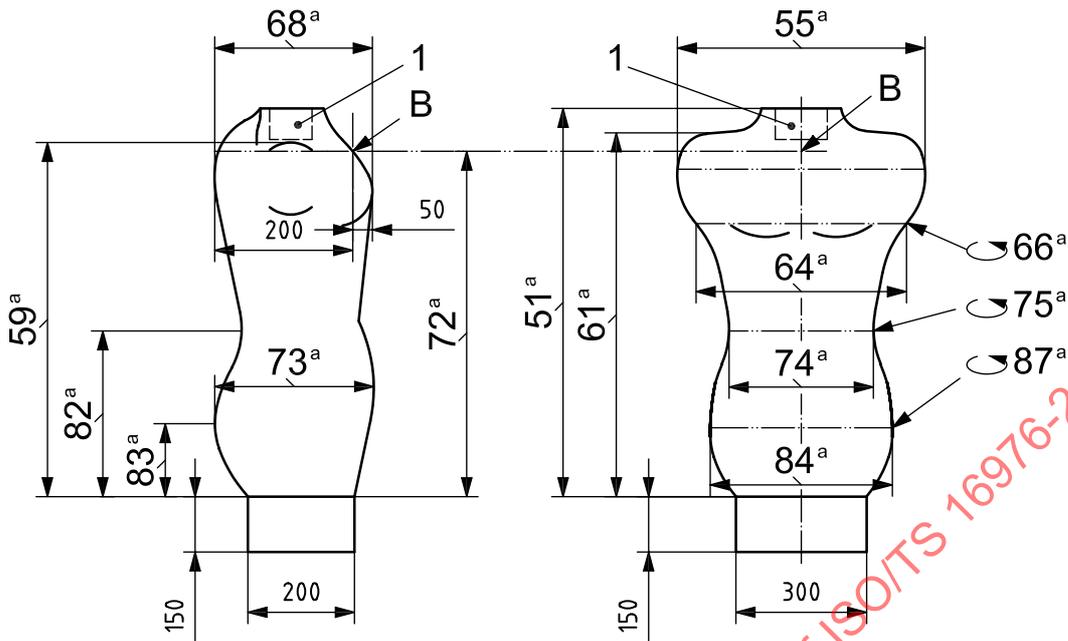
The torso is positioned on an elliptical contoured platform with the axis $a = 200$ mm, $b = 300$ mm and a minimum height of 150 mm. This generates some space for parts of an RPD extending beyond the torso, but which are not in contact with the plateau, whichever way the torso is placed. The RPD will be fixed to the torso by the harness without touching the plateau.

The torso will have a socket at the top for inserting the headforms described in this part of ISO/TS 16976.

Table 4 — Mean anthropometric data for torso dimensions by gender and combined population

| ADULTDATA measure reference identification number | Description | Dimension | Dimension | Dimension |
|---|---|--------------|----------------|--------------|
| | | 50 % male | 50 % female | 50 % mean |
| | | mm | mm | mm |
| 51 | Height of prominent neck vertebra, sitting | 667 | 628 | 648 |
| 55 | Shoulder breadth (deltoid) | 458 | 416 | 437 |
| 59 | Shoulder (acromion) height, sitting | 605 | 569 | 587 |
| 61 | Mid-shoulder height, sitting | 632 | 579 | 606 |
| 64 | Chest breadth at level of nipples | 329 | 282 | 306 |
| 66 | Chest circumference, at level of nipples | 916 | 921 | 919 |
| 68 | Chest depth, at level of nipples | 248 | 251 | 250 |
| 72 | Trunk height to the top of breast bone, sitting | 597 | 573 | 585 |
| 73 | Lower abdominal depth | 284 | 250 | 267 |
| 74 | Waist breadth | 259 | 264 | 262 |
| 75 | Waist circumference – natural indentation | 839 | 769 | 804 |
| 82 | Height of maximum lumbar curvature, sitting | 241 | 232 | 237 |
| 83 | Sacral height, sitting | 162 | 159 | 161 |
| 84 | Hip breadth | 327 | 321 | 324 |
| 87 | Mid-hip circumference | 1 060 | 1 056 | 1 058 |
| NOTE | Measure reference numbers are taken from ADULTDATA handbook dimensions. | | | |

Dimension in millimetres



Key

- 1 socket for headform
- B top of breast bone

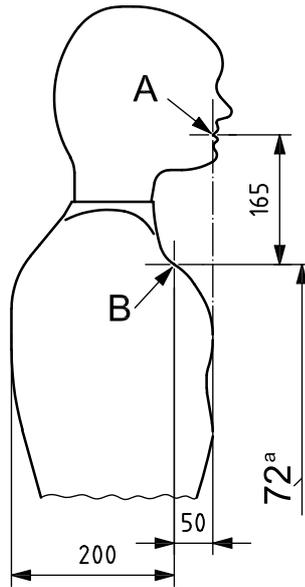
^a All numbers are reference numbers in accordance with Table 4.

Figure 1 — Torso contour given by measure references

7 Interface between headform and torso

The torso described in this part of ISO/TS 16976 will be able to carry the five different headforms by a socket at the top. In order to test the RPD in its operational position, the headforms will be used to connect the RPD with the breathing machine/simulator whilst fixed to the torso. The headform will have a fixed position in relation to the torso by using reference points (A and B) which are illustrated in Figures 1 and 2. The reference for all headforms is the point A, the centre of the mouth opening. This point will be positioned always 165 mm above the top of the breast bone (point B) as defined by measure reference number 72 of the torso contour. The length of the headform necks have to be designed accordingly. This relation is based on the information given in EN 14143.

Dimension in millimetres

**Key**

- A centre of the mouth opening
- B top of breast bone, according to measure 72 of Table 4

^a All numbers are reference numbers in accordance with Table 4

Figure 2 — Interface between head and torso

8 Human test panels for facial features

8.1 General

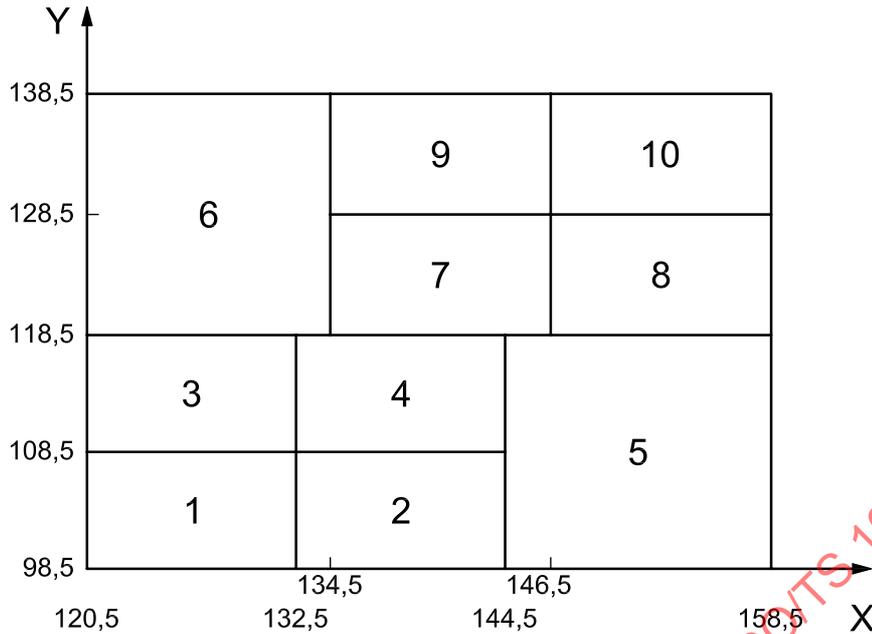
This clause shows how collected anthropometric data are used to develop human test panels; see Reference [4]. Two such panels are described.

8.2 Bivariate panel

The human test panel based on face length and face width is shown in Figure 3. This panel covers 96,7 % of males and 98,7 % of females of the selected population. This panel has limits of 98,5 mm to 138,5 mm for face length and 120,5 mm to 158,5 mm for face width. These limits were first based on the male mean plus two standard deviations (SDs) and the female mean minus two SDs. Cell boundaries were then adjusted so that the population can be distributed among cells as uniformly as possible. The boundaries were set so that at least 95 % of the population was included in the panel. See also Annex C.

The standards writers can use this bivariate panel, the composition of which will be representative of target populations. A test panel shall use a minimum of ten subjects with at least one subject from each of the cells representing the target population.

In Figure 3, the cells are numbered from 1 to 10. When the subject's face length or face width falls on the boundaries, the subject is classified into the higher number cells with greater face dimensions.



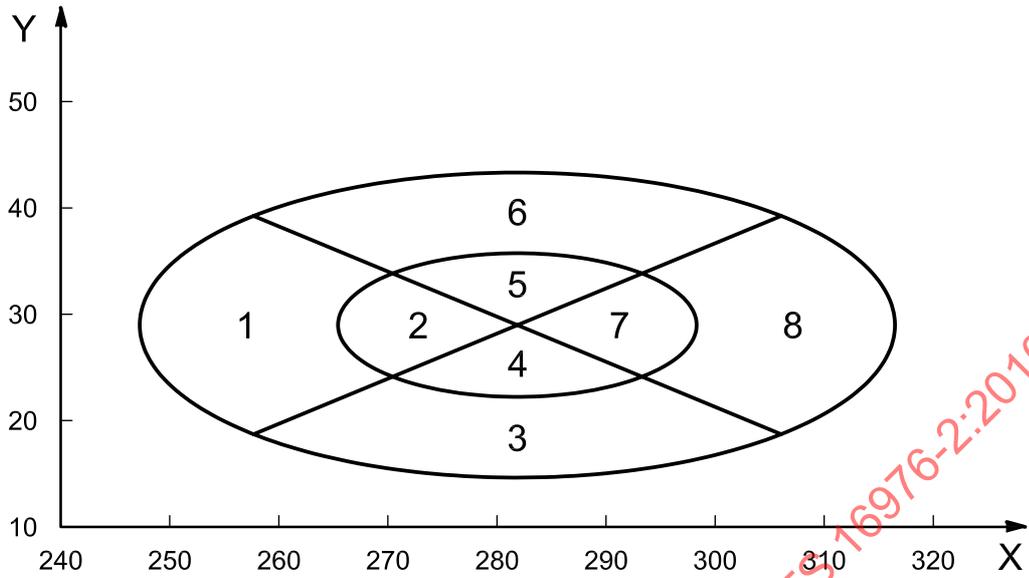
Key
 X face width in millimetres
 Y face length in millimetres

Figure 3 — Bivariate panel based on face length and face width

8.3 Principal component analysis (PCA) panel

The human test panel based on the PCA scores is shown in Figure 4. This panel covers 95,3 % of the males and 97,6 % of the females of the selected population. The layout of cells is different from the bivariate panel. The limit of this panel is based on an ellipse in which more than 95 % of the population is included. The inner ellipse includes 50 % of the population. The rationale for the rest of the PCA configuration is to have uniform distributions for each cell. Thus, two lines were used to divide the two ellipses into four quadrants resulting in eight cells. The population is then uniformly distributed among the cells.

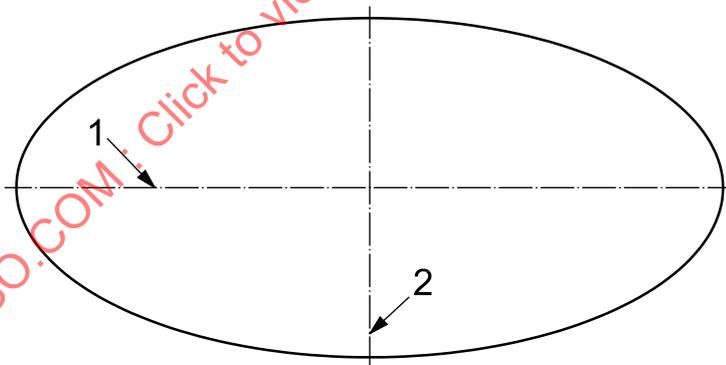
The standards writers can use this PCA panel, the composition of which will be representative of target populations. A test panel shall use a minimum of ten subjects with at least one subject from each of the cells representing the target population.



a) The PCA panel based on two principal components with cells numbered from 1 to 8

Key

- X first principal component
- Y second principal component



b) The PCA panel based on two principal components with cells numbered from 1 to 4

Key

- 1 major axis
- 2 minor axis

Figure 4

To construct the PCA panel, the ten face dimensions or the 18 face dimensions (see Table 2), as measured in millimetres in accordance with Clause 4 and Annex B, are entered into the following algorithm. The first and second principal components (PC1 and PC2) are then calculated as follows.

$$PC1 = 0,343\ 264 \times (\text{minimum frontal breadth A}) + 0,426\ 498 \times (\text{face width B}) + 0,372\ 717 \times (\text{bigonial breadth C}) + 0,329\ 648 \times (\text{menton sellion length D}) + 0,363\ 474 \times (\text{interpupillary distance E}) + 0,372\ 241 \times (\text{head breadth F}) + 0,113\ 578 \times (\text{nose protrusion G}) + 0,301\ 125 \times (\text{nose breadth H}) + 0,202\ 311 \times (\text{nasal root breadth J}) + 0,193\ 650 \times (\text{subnasale-sellion length K})$$

$$PC2 = -0,152\ 951 \times (\text{minimum frontal breadth A}) + 0,039\ 087 \times (\text{face width B}) - 0,093\ 279 \times (\text{bigonial breadth C}) + 0,359\ 799 \times (\text{menton sellion length D}) + 0,173\ 099 \times (\text{interpupillary distance E}) + 0,013\ 306 \times (\text{head breadth F}) + 0,551\ 842 \times (\text{nose protrusion G}) + 0,210\ 833 \times (\text{nose breadth H}) + 0,341\ 235 \times (\text{nasal root breadth J}) + 0,584\ 261 \times (\text{subnasale-sellion length K})$$

Then make the following calculations:

$$x = PC1 - 281,621\ 761\ 8$$

$$y = PC2 - 28,986\ 505\ 4$$

$$\text{slope} = 5,584\ 793\ 0 / 13,699\ 110\ 8 = 0,407\ 675\ 6$$

$$a = 2,54 \times 13,699\ 110\ 8$$

$$b = 2,54 \times 5,584\ 793\ 0$$

$$c = 1,21 \times 13,699\ 110\ 8$$

$$d = 1,21 \times 5,584\ 793\ 0$$

$$r_1 = \sqrt{\frac{x^2}{a^2} + \frac{y^2}{b^2}}$$

$$r_2 = \sqrt{\frac{x^2}{c^2} + \frac{y^2}{d^2}}$$

where

x and y are new coordinates for translating the origin of PC1 and PC2 from their mean values (281,621 761 8 for PC1 and 28,986 505 4 for PC2) to zero;

slope is the slope value for the two lines dividing the ellipse into eight cells;

a is a constant for the length of the semi-major axis for the outer ellipse (see the illustration below);

b is the constant for the length of the semi-minor axis for the outer ellipse (see the illustration below);

c is a constant for the length of the semi-major axis for the inner ellipse;

d is the constant for the length of the semi-minor axis for the inner ellipse;

r_1 and r_2 are values calculated to determine where a particular data point or a subject is, e.g. the data point is outside the outer ellipse when $r_1 > 1$ or on the outer ellipse when $r_1 = 1$ or inside the outer ellipse when $r_1 < 1$.

Use the x , y and r_1 values and the algorithm below to determine if the subject is in cells 1, 3, 6 and 8:

if $x \geq 0$ and $y \geq 0$ and $r_1 \leq 1$ and $\text{abs}(y)/\text{abs}(x) \leq \text{slope}$, then cell = 8;

if $x \geq 0$ and $y < 0$ and $r_1 \leq 1$ and $\text{abs}(y)/\text{abs}(x) < \text{slope}$, then cell = 8;

if $x \geq 0$ and $y < 0$ and $r_1 \leq 1$ and $\text{abs}(y)/\text{abs}(x) \geq \text{slope}$, then cell = 3;

if $x < 0$ and $y < 0$ and $r_1 \leq 1$ and $\text{abs}(y)/\text{abs}(x) > \text{slope}$, then cell = 3;

if $x < 0$ and $y < 0$ and $r_1 \leq 1$ and $\text{abs}(y)/\text{abs}(x) \leq \text{slope}$, then cell = 1;

if $x < 0$ and $y \geq 0$ and $r_1 \leq 1$ and $\text{abs}(y)/\text{abs}(x) < \text{slope}$, then cell = 1;

if $x < 0$ and $y \geq 0$ and $r_1 \leq 1$ and $\text{abs}(y)/\text{abs}(x) \geq \text{slope}$, then cell = 6;

if $x \geq 0$ and $y \geq 0$ and $r_1 \leq 1$ and $\text{abs}(y)/\text{abs}(x) > \text{slope}$, then cell = 6.

If the r_2 value ≤ 1 , use the following algorithm to adjust the cell number:

if cell = 8 and $r_2 \leq 1$, then cell = 7;

if cell = 3 and $r_2 \leq 1$, then cell = 4;

if cell = 1 and $r_2 \leq 1$, then cell = 2;

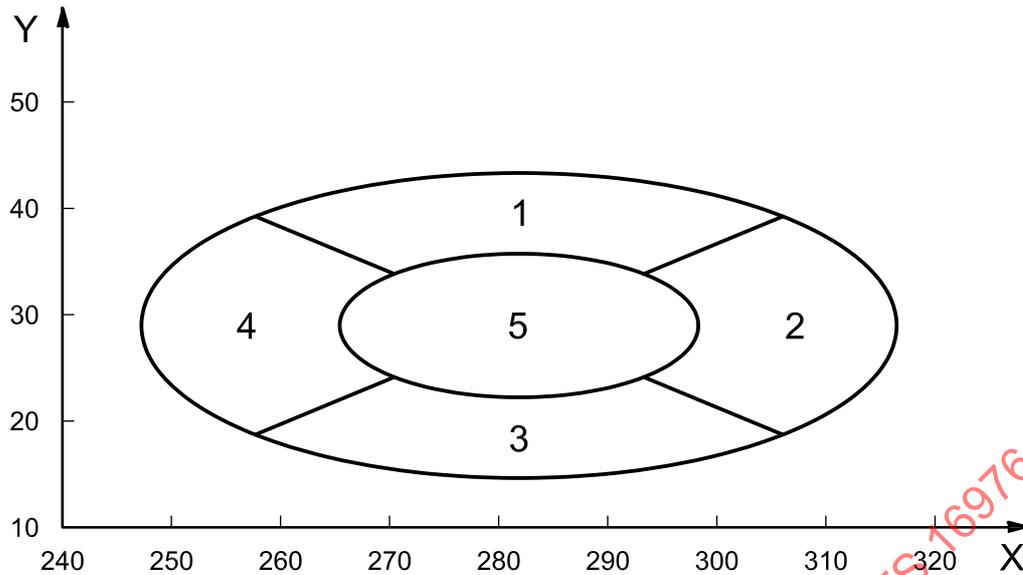
if cell = 6 and $r_2 \leq 1$, then cell = 5.

The measurement of these ten dimensions is described in Annex B. A test panel member should be remeasured when the member has a condition that may interfere with the respirator seal, e.g. a significant change in weight, a change to the face in the sealing area (e.g. scarring, facial surgery) or dental changes.

NOTE A video tape (see Reference [8]) is available which demonstrates the landmarking and measuring techniques with the traditional tools. A computer program (see Reference [9]) is available which provides a tool for recording measurements and determining the cell number for each subject.

9 Models of headforms

This clause shows how collected anthropometric data are used to develop models of headforms. Based on the PCA panel, five models of headforms are developed [10]. Four models (small, short/wide, long/narrow and large) represent subjects in cells 1, 3, 6 and 8 respectively (see Figure 4). Subjects in cells 2, 4, 5, and 7 are represented by one model (medium). Figure 5 shows the distribution of the five headforms. The key dimensions (i.e. the ten facial dimensions used for defining the PCA panel) for each model are obtained by averaging the values for the subjects each model represents, including subjects who fall outside the PCA panel (all five models represent a total of 3 997 subjects) and are summarised in Table 5.



- Key**
- 1 long-narrow
 - 2 large
 - 3 short-wide
 - 4 small
 - 5 medium

Figure 5 — Distribution of the five headforms

Table 5 — Mean values for key facial dimensions of headforms

Dimensions in millimetres

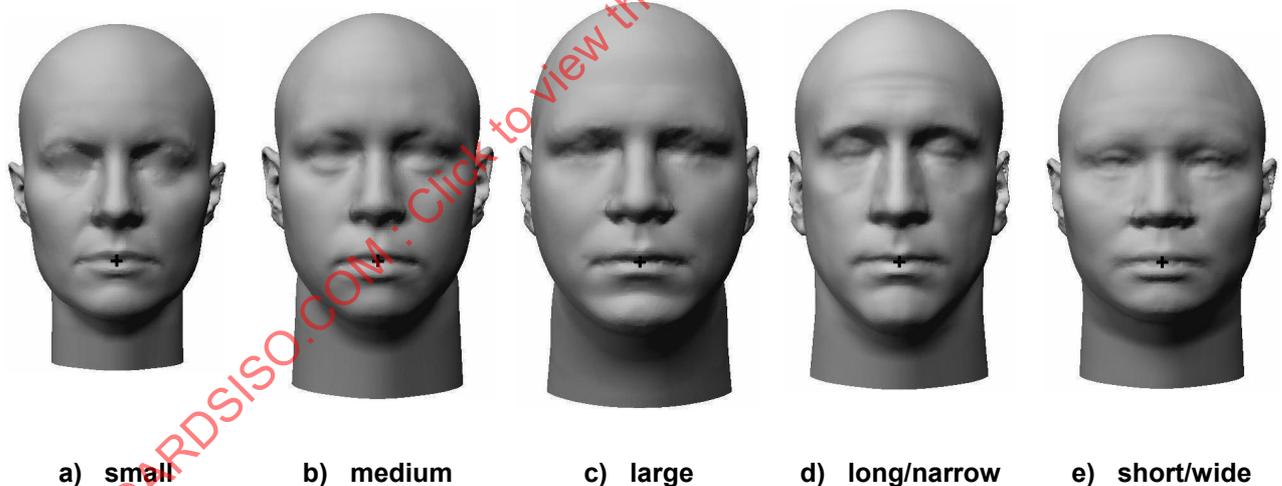
| Facial article | Headform cell 1 (small) | Headform cell 3 (short/wide) | Headform cells 2, 4, 5, 7 (medium) | Headform cell 6 (long/narrow) | Headform cell 8 (large) |
|---------------------------------|-------------------------|------------------------------|------------------------------------|-------------------------------|-------------------------|
| A Minimum frontal breadth | 98 | 106 | 104 | 103 | 110 |
| B Face width | 128 | 141 | 140 | 140 | 151 |
| C Bigonial breadth | 101 | 118 | 115 | 113 | 131 |
| D Face ^a length | 110 | 112 | 119 | 127 | 127 |
| E Interpupillary distance | 59 | 65 | 64 | 63 | 68 |
| F Head breadth | 142 | 149 | 150 | 151 | 158 |
| G Nose protrusion | 19 | 17 | 20 | 23 | 21 |
| H Nose breadth | 32 | 39 | 36 | 35 | 41 |
| J Nasal root breadth | 15 | 17 | 16 | 15 | 18 |
| K Nose ^b length | 47 | 44 | 50 | 56 | 52 |
| ^a Menton-sellion. | | | | | |
| ^b Subnasale-sellion. | | | | | |

Based on the mean values for the ten key facial dimensions, five subjects with facial features close to these mean values for each model were selected. Five scans in each category were chosen based on PCA scores calculated from 3-D scan data and averaged together to construct a representative headform for each size category.

After scanned heads of the appropriate size and shape were identified and selected, the scan data were averaged to develop models of headforms using Polyworks software. Designing a single headform is a multi-step process. After subjects with scanned heads of the appropriate size and shape were selected, their 3-D scans were aligned using Polyworks, a program that allows the user to edit 3-D scans. In order to obtain the optimum average of the five subjects, each head scan was aligned using the Frankfort plane and a vertical symmetry plane constructed from the midpoint between three facial features for each scan. Once in proper alignment, Polyworks was used to create a single averaged headform from all five digital scans.

The resultant averaged headform may contain regions of missing information around important facial features such as the mouth, nose and eye regions. However, the forehead, cheeks and chin regions provide a smooth average. The medium average had holes in the eyes that required a simple patching procedure, but the nose was missing enough information to require an additional step. If necessary, subsequent alignments were used for individual facial features: the nose, lips and each eye. The average of the medium nose was stitched on to the initial average and the remaining holes were patched. Patching the headform included the removal of the noisy ear regions as well as creating a smooth scalp. Once the entire headform was patched, it was duplicated and mirrored so that a symmetric average of the headform could be created. Ears, a neck and a "+" sign at the centre of each mouth were added to complete each headform. The models of the five headforms are shown in Figure 6.

The digital models of headforms for producing physical models are available¹⁾.



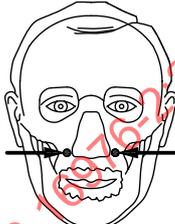
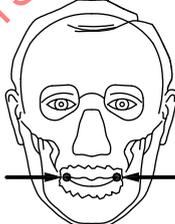
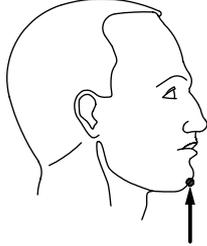
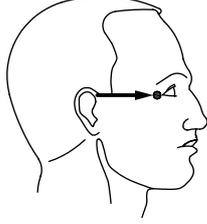
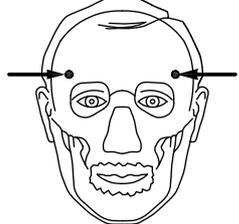
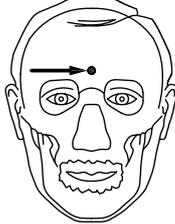
NOTE All headforms are lined up on their reference points, the centre of mouth opening.

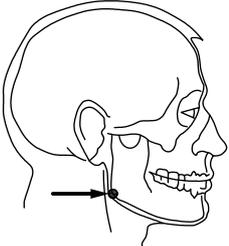
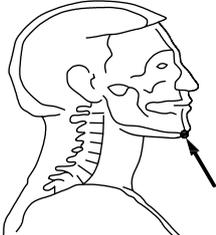
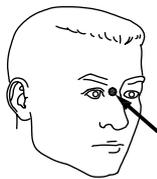
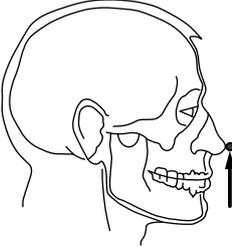
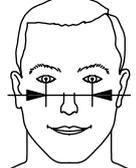
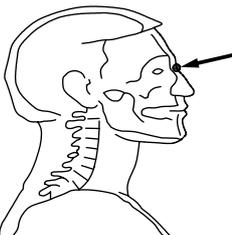
Figure 6 — Models of headforms

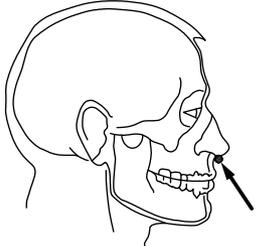
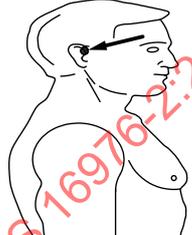
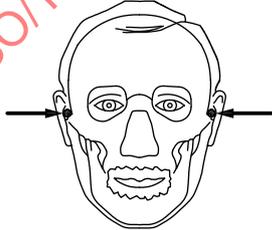
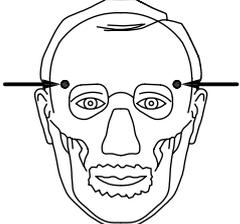
1) Models of headforms are available at the: National Institute for Occupational Safety and Health, National Personal Protective Technology Laboratory, <http://www.cdc.gov/niosh/nppt/default.html>. This information is given for the convenience of users of this Technical Specification and does not constitute an endorsement by ISO of the product named. Equivalent products may be used if they can be shown to lead to the same results.

Annex A
(normative)

Description, definition, and diagrams of selected landmarks

| Description | Definition | Diagram |
|---------------------------------|--|---|
| Alare, right and left | The lateral point on the flare or wing of the nose. Method: It is located by visual inspection. |  |
| Cheilion, right and left | The lateral point of the juncture of the fleshy tissue of the lips with the facial skin at the corner of the mouth. Method: It is located by visual inspection. |  |
| Chin | The most protruding point on the bottom edge of the chin, along the jawline. Method: It is located by visual inspection. |  |
| Ectocanthus, right and left | The outside corner of the eye formed by the meeting of the upper and lower eyelids (unmarked). Method: It is located by visual inspection. |  |
| Frontotemporale, right and left | The point of deepest indentation of the temporal crest of the frontal bone above the brow ridges. Method: It is located by palpation. |  |
| Glabella | The anterior point on the frontal bone midway between the bony brow ridges. Method: It is located by visual inspection and palpation. |  |

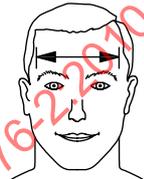
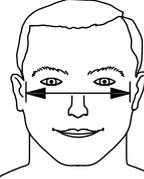
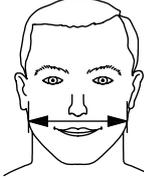
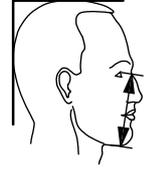
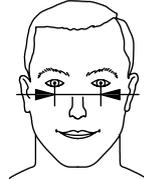
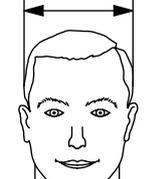
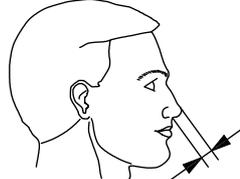
| Description | Definition | Diagram |
|----------------------------------|---|---|
| Gonion, right and left | <p>The most lateral, most inferior, and most posterior point on the angle of the mandible (jawbone).</p> <p>Method: The subject stands with head in the Frankfort plane and with teeth together (lightly occluded). Stand in front of the subject and locate the posterior angles of the mandible by palpation. The landmarks are the most lateral points of these angles.</p> |  |
| Infraorbitale, right and left | <p>The lowest point on the anterior border of the bony eye socket.</p> <p>Method: It is located by palpation.</p> |  |
| Menton | <p>The inferior point of the mandible in the midsagittal plane (bottom of the chin).</p> <p>Method: Subject stands with head in the Frankfort Plane and teeth together. Stand in front of the subject. Locate the landmark by palpation of the lower jawbone just under the chin, and place an adhesive dot on it.</p> |  |
| Nasal root point, right and left | <p>The point on the side of the nasal root at a depth equal to half the distance from the bridge of the nose to the eyes.</p> <p>Method: The subject stands looking straight ahead. Stand to the right side of the subject and locate the nasal root point by inspection.</p> |  |
| Pronasale | <p>The point of the anterior projection of the tip of the nose.</p> <p>Method: It is located by visual inspection.</p> |  |
| Pupil | <p>The centre of the pupil of a subject looking straight ahead.</p> <p>Method: It is not marked on the subject, but is located by visual inspection on the scan.</p> |  |
| Sellion | <p>The point of the deepest depression of the nasal bones at the top of the nose.</p> <p>Method: The subject stands looking straight ahead. Stand to the right of the subject and palpate the point of the deepest depression of the bridge of the nose in the midsagittal plane. On some subjects, however, there is no distinctly deepest point and judgment will have to be used to establish its location. Place an adhesive dot on the bridge of the nose at the landmark.</p> |  |

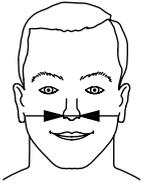
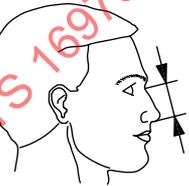
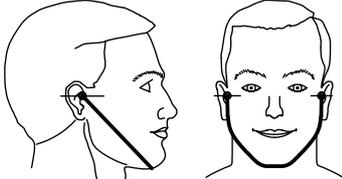
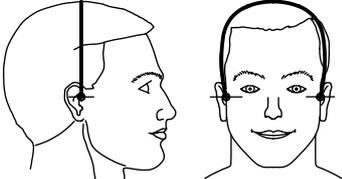
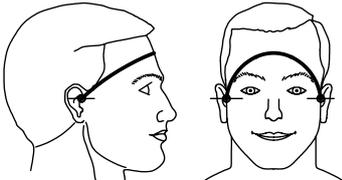
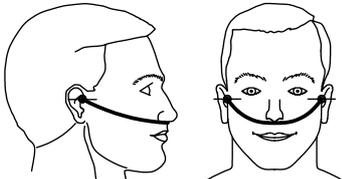
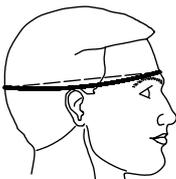
| Description | Definition | Diagram |
|------------------------------|--|---|
| Subnasale | <p>The point of intersection of the philtrum (groove of the upper lip) with the inferior surface of the nose in the midsagittal plane.</p> <p>Method: It is located by visual inspection.</p> |  |
| Tragion, right and left | <p>The superior point on the juncture of the cartilaginous flap (tragus) of the ear with the head.</p> <p>Method: Palpate the tragus to find the superior point of attachment to the head. Place an adhesive dot on each landmark.</p> |  |
| Zygion, right and left | <p>The most lateral point on the zygomatic arch (unmarked).</p> <p>Method: The subject stands, looking straight ahead, with facial muscles relaxed. Stand in front of the subject and locate the most lateral point by palpation. (When unmarked, this is located by movement of the tips of the spreading calliper during measurement.)</p> |  |
| Zygofrontale, right and left | <p>The lateral point of the frontal bone on its zygomatic process.</p> <p>Method: It is located by palpation.</p> |  |

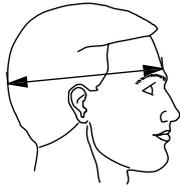
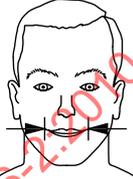
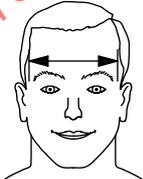
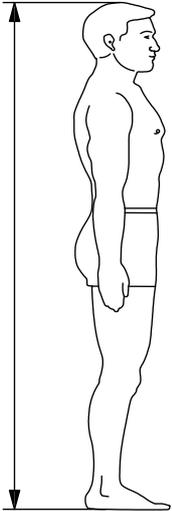
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Annex B (normative)

Description, definition, and diagram of dimensions to be measured

| Description | Definition | Diagram |
|---------------------------|---|---|
| A Minimum frontal breadth | The straight-line distance between the right and left frontotemporale landmarks on the temporal crest on each side of the forehead is measured with a spreading calliper. The subject sits looking straight ahead. Only enough pressure is exerted to ensure that the calliper tips are on the landmarks. |  |
| B Face width | Maximum horizontal breadth of the face as measured with a spreading calliper between the zygomatic arches. The subject sits looking straight ahead and with teeth together (lightly occluded). Only enough pressure is exerted to ensure that the calliper tips are on the zygomatic arches. |  |
| C Bigonial breadth | Straight-line distance measured with a spreading calliper between the right and left gonion landmarks on the corners of the jaw. The subject sits looking straight ahead and with teeth together (lightly occluded). Only enough pressure is exerted to ensure that the calliper tips are on the landmarks. |  |
| D Menton-sellion length | The distance in the midsagittal plane between the menton landmark at the bottom of the chin and the sellion landmark at the deepest point of the nasal root depression is measured with a sliding calliper. The subject sits looking straight ahead and with teeth together (lightly occluded). The fixed blade of the calliper is placed on the sellion. Only enough pressure is exerted to obtain contact between the calliper and the skin is exerted. |  |
| E Interpupillary distance | Distance as measured with a pupillometer at the centre of the right and the centre of the left pupil. |  |
| F Head breadth | Maximum horizontal breadth of the head as measured with a spreading calliper above the level of the ears. The subject sits looking straight ahead. Enough pressure is exerted to obtain contact between the calliper and the skin. |  |
| G Nose protrusion | The straight-line distance between the pronasale landmark at the tip of the nose and the subnasale landmark under the nose is measured with a sliding calliper. The subject sits looking straight ahead. The sliding blade of the calliper is reversed and the base of the calliper is placed on the subnasale landmark. The beam of the calliper is parallel to the line of the protrusion of the nose. |  |

| Description | Definition | Diagram |
|----------------------------|--|---|
| H Nose breadth | Straight-line distance as measured with a sliding calliper between the right and left alare landmarks. The subject sits looking straight ahead. Only enough pressure is exerted to obtain contact between the calliper and the skin. |  |
| J Nasal root breadth | The horizontal breadth of the nose at the level of the deepest depression in the root (sellion landmark) and at a depth equal to half the distance from the bridge of the nose to the eyes is measured with a sliding calliper. The subject sits looking straight ahead. The blunt points of the sliding calliper are used. Only enough pressure is exerted to obtain contact between the calliper and the skin. |  |
| K Subnasale-sellion length | Straight-line distance as measured with a sliding calliper between the subnasale landmark and the sellion landmark. The subject sits looking straight ahead. Only enough pressure is exerted to obtain contact between the calliper and the skin. |  |
| Bitrignon chin arc | The surface distance between the right and left trignon landmarks across the anterior point of the chin is measured with a tape. The subject sits looking straight ahead and with teeth together (lightly occluded). Enough tension is exerted to maintain light contact between the tape and the skin. The chin will be slightly compressed. |  |
| Bitrignon coronal arc | The surface distance between the right and left trignon landmarks across the top of the head in the coronal plane is measured with a tape. The subject sits with head in the Frankfort plane. Enough tension is exerted to compress the hair. |  |
| Bitrignon frontal arc | The surface distance between the right and left trignon landmarks across the forehead just above the ridges of the eyebrows (supraorbital ridges) is measured with a tape. The subject sits looking straight ahead. Enough tension is exerted to maintain light contact between the tape and the skin. |  |
| Bitrignon subnasale arc | The surface distance between the right and left trignon landmarks across the subnasale landmark at the bottom of the nose is measured with a tape. The subject sits looking straight ahead. Enough tension is exerted to maintain light contact between the tape and the skin, but not enough to compress the soft tissue under the nose. |  |
| Head circumference | The maximum circumference of the head just above the ridges of the eyebrows (supraorbital ridges) and the attachment of the ears is measured with a tape. The subject sits looking straight ahead. The plane of the tape will be higher in the front than in the back and the sides should be parallel. Enough tension is exerted to compress the hair. |  |

| Description | Definition | Diagram |
|-------------------------|---|---|
| Head length | The maximum length of the head in the midsagittal plane is measured with a spreading calliper. The subject sits looking straight ahead. One tip of the calliper is placed on the glabella landmark between the brow ridges and the other tip is moved up and down the back of the head until a maximum measurement is obtained. Light pressure is exerted on the glabella and at the back of the head to compress the hair. |  |
| Lip length | The straight-line distance between the right and left chelion landmarks at the corners of the closed mouth is measured with a sliding calliper. The subject sits looking straight ahead with teeth together (lightly occluded). The facial muscles are relaxed, and the mouth is closed. |  |
| Maximum frontal breadth | The straight-line distance between the right and left zygofrontale landmarks at the upper margin of each bony eye socket is measured with a spreading calliper. The subject sits looking straight ahead. Only enough pressure is exerted to ensure that the calliper tips are on the landmarks is exerted. |  |
| Neck circumference | The circumference of the neck at the level of the infrathyroid landmark (Adam's apple) is measured with a tape. The plane of the measurement is perpendicular to the long axis of the neck. The subject stands erect with head in the Frankfort plane. The shoulders and upper extremities are relaxed. |  |
| Stature | The vertical distance between the standing surface and the top of the head is measured with an anthropometer. The subject stands erect with heels together and head in the Frankfort plane. The shoulders and arms are relaxed. Enough pressure is exerted to compress the hair. The measurement is taken at the maximum point of quiet respiration. |  |
| Weight | The weight of the subject is taken to the nearest half kilogram. The subject stands on the centre of the platform looking straight ahead. The heels are together and the weight evenly distributed on both feet. | |