Analysis of the Facial Measurements of Korean Air Force Pilots for Oxygen Mask Design

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Face Anthropometry of Pilots

Abstract
The present study measured the facial dimensions of Korean Air Force (KAF) pilots to design a pilot oxygen mask and compared them with those of Korean civilians and U.S. Air Force (USAF) personnel. Twenty-two facial dimensions were measured for 278 KAF male pilots (KMP) and 58 KAF female pilots and cadets (KFP) using an anthropometer and a 3D scanner. The KMP face measurements were found significantly larger (mean difference, $\bar{d} = 0.7 \sim 26.5$ mm) and less varied (ratio of SDs $= 0.29 \sim 0.82$) than those of Korean male civilians (KMC). The average face length, lip width, and nasal root breadth of the KMP were significantly longer ($\bar{d} = 4.7$ mm), narrower ($\bar{d} = -2.4$ mm), and wider ($\bar{d} = 5.2$ mm), respectively, than those of USAF male personnel (UMP). Lastly, the KMP face measurements were significantly larger ($\bar{d} = 1.8 \sim 26.1$ mm) than those of the KFP.

Keywords: oxygen mask design, face measurement, anthropometer, 3D scanner, Korean pilots

Practitioner Summary
The face measurements of KAF pilots were collected and compared with those of Korean civilians and USAF personnel. The distinct facial features of the populations identified in the present study are applicable to custom design of an oxygen mask for prevention of excessive pressure and oxygen leakage.
1. Introduction

An oxygen mask worn over the face of a fighter pilot supports a steady supply of oxygen and efficient communication for safe and effective mission accomplishment. The pilot oxygen mask encloses the pilot’s nose and mouth for a stable supply of oxygen to the pilot while a mission is conducted at high altitude where oxygen is lacking. The oxygen mask protects the pilot in adverse environments (e.g., decompression, fire, and fumes in the cockpit, windblast during ejection, and ditching) by continuously supplying oxygen to the pilot (Alexander et al., 1979). The oxygen mask also houses a microphone for communication and is securely mounted to a helmet with adjustable straps, bayonet receivers, and connectors.

The MBU-20/P (Gentex Corporation, U.S.A.) pilot oxygen mask, originally designed for U.S. Air Force (USAF) personnel, has been causing excessive pressure and/or leakage of oxygen around the nasal root to a significant number of Korean Air Force (KAF) pilots. The MBU-20/P mask was initially designed using face anthropometric data of 2,420 USAF personnel collected by Churchill et al. (1977) and has been improved by applying the 3D face scan data of 60 (30 males and 30 females) pilots (Gross et al., 1997). A survey conducted by KAF in 2006 on the usability of the MBU-20/P mask identified that a significant percentage of KAF pilots suffered from excessive pressure and/or oxygen leakage around the nasal root due to the lack of fit of the oxygen mask to the face, which is most likely caused by a significant difference in facial shape and size between KAF pilots and USAF personnel.

Facial measurements have been collected and applied for ergonomics design of half-face masks including pilot oxygen mask and industrial dustproof mask. Previous research on half-face mask design has measured the dimensions of the head (e.g., head height, head breadth, head length, and head circumference), face (e.g., face length, face width, and
bitragion-subnasale arc), nose (e.g., nose length, nose width, and nose protrusion), lip (e.g.,
lip width), and chin (e.g., supramentale-to-menton length, chin width, and bizygomatic-
menton arc). For example, Han et al. (2004) measured 10 facial dimensions (face length,
lower face length, nose length, nose protrusion, face width, chin width, nose width, lip width,
bitragion-menton arc, and bitragion-subnasale arc) of 50 (26 males and 24 females) civilians
to develop a half-mask respirator for Koreans. Gross et al. (1997) measured 15 facial
dimensions (head breadth, head length, head circumference, face length, lower face length,
sellion-to-supramentale length, nose length, nose protrusion, face width, bi-inframalar
breadth, bizygomatic breadth, lip width, nasal root breadth, nose width, and bitragion-
subnasale arc) of 60 USAF pilots for the design of MBU-20/P mask. Lastly, both Hack and
McConville (1978)’s study on the design of an industrial respirator and Young (1966)’s study
on the design of an oxygen mask for children measured detailed nose dimensions (e.g., nasal
root breadth, maximum nasal bridge breadth, rhinion-to-menton length, and rhinion-to-
promentale length), which are useful for an ergonomics design of the nasal part of an oxygen
mask.

The anthropometric information of KAF pilot faces is needed to develop an
ergonomics design of pilot oxygen mask. Facial data collected by a national anthropometric
survey for Korean civilians (KATS, 2004) and a small scale study (50 civilians) by Han et al.
(2004) for an industrial mask design are available. However, the applicability of these facial
anthropometric measurements of Korean civilians is quite limited for design of an oxygen
mask because some nose-related measurements such as nasal root breadth, nasal bridge
breadth, and rhinion-to-menton length, which are crucial for oxygen mask design, were not
measured. Furthermore, anthropometric measurements often significantly differ between
military personnel and civilians (Lee et al., in press, Zhuang et al., 2007). Jeon (2011)
reported significant mean differences in various body dimensions between KAF pilots (1,238
males) and Korean civilians (1,741 males)—for example, the average leg length of KAF male pilots (101.1 ± 4.4 cm) was significantly shorter than that of Korean male civilians (105.8 ± 4.8 cm) at $\alpha = .01$.

The present study measured the faces of KAF pilots in 3D for design of an oxygen mask and analyzed their characteristics in comparison with those of Korean civilians and USAF personnel. Twenty-two facial dimensions were selected in the present study as those applicable to the design of an oxygen mask. Then, the faces of KAF pilots were captured using a 3D scanner and the facial dimensions were measured using the 3D face scan data. Lastly, the facial measurements of KAF pilots were compared with those of Korean civilians and USAF personnel.

2. Methods

2.1. Selection of Facial Dimensions

For the design of an oxygen mask, 22 facial dimensions were selected through a review of literature and the recommendation of a panel of experts. Fifteen journal papers (Ahn and Shu, 2004, Alexander et al., 1979, Clauser et al., 1988, Hack and McConville, 1978, Han and Choi, 2003, Hughes and Lomaev, 1972, Kim, 2004, Kim, 2005, Kim et al., 2004, KATS, 2004, Oestenstad et al., 1990, Oh and Park, 2010, Yokota, 2005, Young, 1993, Zhuang and Bradtmiller, 2005) were reviewed which measured facial dimensions for the design of a half-face mask. Through the literate review 107 facial dimensions (length dimensions: 45; depth dimensions: 24; width dimensions: 17; circumference/arc dimensions: 21) were identified. Of these facial dimensions, 22 dimensions (length dimensions: 9; depth dimensions: 2; width dimensions: 7; circumference/arc dimensions: 4) were selected by a panel of three
ergonomists and three clothing experts as those applicable to design of an oxygen mask and their importance in designing an oxygen mask was classified into one of three categories (low, medium, and high) as shown in Figure 1. For measurement of the selected facial dimensions, 14 landmarks (Figure 2) were identified by referring to Alexander et al. (1979), Buikstra and Ubelaker (1994), Clauser et al. (1988), Hack and McConville (1978), and Young (1966).

2.2. Measurement of Facial Dimensions

2.2.1. Participants

336 KAF male pilots (KMP) and KAF female pilots and cadets (KFP) were measured in the present survey. The minimum sample size requirement of each facial dimension was identified by considering the age distribution of KAF pilots and applying the Korean civilian data (KATS, 2004) to Equation 1 (ISO, 2006):

\[
n = (1.96 \times \frac{CV}{k})^2 \times 1.534^2
\]

(Equation 1)

where: \( CV \) = coefficient of variation,
\( k \) = precision level

The sample mean and sample SD of a facial dimension of the KAF pilot population mixed in gender and age were estimated by applying corresponding Korean citizen data to Equations 2 and 3, respectively:
\[
\overline{X} = \frac{\sum_{i=1}^{j} \overline{X}_i \times n_i}{\sum_{i=1}^{j} n_i} \quad \text{(Equation 2)}
\]

where: \( \overline{X} \) = sample mean of a composite population,
\( \overline{X}_i \) = sample mean of population \( i \),
\( n_i \) = sample size of population \( i \)
\( j \) = the number of populations

\[
s = \sqrt{\frac{\sum_{i=1}^{j} [n_i \times \overline{X}_i^2 + (n_i - 1) \times s_i^2] - \sum_{i=1}^{j} n_i \times \overline{X}^2}{\sum_{i=1}^{j} n_i - 1}} \quad \text{(Equation 3)}
\]

where: \( s \) = sample SD of a composite population,
\( \overline{X} \) = sample mean of a composite population,
\( \overline{X}_i \) = sample mean of population \( i \),
\( s_i \) = sample standard deviation of population \( i \),
\( n_i \) = sample size of population \( i \),
\( p_i \) = proportion of population \( i \)
\( j \) = the number of populations

Of the 22 facial dimensions, 10 dimensions (head height, head breadth, head length, head circumference, face length, lower face length, nose length, nose protrusion, nose width, and lip width) were measured in the 2004 Size Korea anthropometric survey (KATS, 2004). The minimum sample size requirements of the facial dimensions were calculated for two levels of
precision \((k = \text{sampling error/sample mean} = 3\% \text{ and } 4\%\) as shown in Figure 3. Lastly, the sample size for the facial anthropometric survey on KAF pilots in the present study was determined by the prioritized facial dimensions, sample size requirement analysis results, and sampling errors (SEs). The SEs of the four high-importance facial dimensions (face length, rhinion-to-promentale length, nose width, and lip width) measured in the Korean national anthropometric survey were further calculated as shown in Table 1 for \(k = 3\% \text{ and } 4\%\). It was agreed upon by the expert panel in the present study that \(k = 3\% \text{ (maximum SE = 3.4 mm in face length) is acceptable in oxygen mask design, resulting in } n = 166\) as the minimum sample size of the facial anthropometric survey. However, 278 KMPs and 58 KFPs were measured during the available study period to apply facial data to various applications and accommodate a change in the gender composition of the KAF pilot population in the future.

[Figure 3 about here]

[Table 1 about here]

2.2.2 Measurement Protocol

Direct and 3D measurement methods were used to measure the facial dimensions. The face measurement process consisted of four phases: (1) orientation of the study purpose and measurement process; (2) attachment of stickers to the designated landmark locations on the face; (3) direct measurement using a Martin-type anthropometer; and (4) 3D measurement using a 3D scanner. In the orientation phase, the purpose and process of face measurement were explained to the participant. In the landmarking phase, the landmarks (see Figure 2) were marked using stickers. In the direct measurement phase, four facial dimensions (head height, head breadth, head length, and head circumference) were measured using a Martin-
type anthropometer. Lastly, in the 3D measurement phase, the face was captured using a Rexcan 560 (Solutionix Co., South Korea) 3D scanner and then the face scan was processed using the ezScan (Solutionix Co., South Korea) image processing program. The face was captured in a darkroom tent (150 cm × 150 cm × 200 cm, see Figure 4) for a proper contrast to obtain 3D scan images with high quality. The face was scanned at five different positions (front, 30° and 60° degrees to the left and to the right).

[Figure 4 about here]

After 3D facial scans were post-processed in five phases (alignment, merging, editing, landmark refinement, and measurement extraction; Figure 5) using the ezScan software, the facial dimensions were measured using a program developed in the present study. In the alignment and merging phases, the five facial images of the participant scanned at different angles were aligned and merged. In the editing phase, the merged 3D facial image was edited by applying hole-filling, smoothing, and abnormal surface cleaning functions provided by the image processing software. In the landmark refinement phase, landmarks which were not captured during 3D scanning or lost in the alignment and merging phases were marked manually. After the image post-processing was completed, a program developed with Matlab (MathWorks, Inc., USA) in the study was used to automatically measure the facial dimensions that were not measured by the direct measurement method. Of the facial dimensions, length and width dimensions were measured by calculating Euclidian distances between corresponding landmarks and arc dimensions were measured by creating a virtual plane passing corresponding three landmarks and forming the arc which intersects the plane and the facial image. Figure 6 illustrates that the lip width is measured by calculating the
Euclidian distance between the left and right cheilions and the bitragion-menton arc by measuring the length of the arc intersecting the facial image and the cross-sectional plane passing the left tragion, menton, and right tragion.

[Figure 5 about here]

[Figure 6 about here]

The integrity of facial measurements using 3D facial scans was assured by an outlier checking process. Measurements of each facial dimension exceeding the range of mean ± 3SD were examined and repeated measurement was made for accuracy.

2.3. Analysis Method

The facial measurements of KAF pilots were compared with those of Korean civilians (KATS, 2004) and USAF personnel (Churchill et al., 1977). Of the 22 facial dimensions, 10 dimensions were comparable with the Korean civilian anthropometric study and 13 with the USAF personnel anthropometric study. Note that nose length (sellion-to-pronasale length) in the Korean civilian anthropometric study was measured differently from that (sellion to subnasale length) of the USAF personnel anthropometric study. Also note that, of the USAF facial measurements, those of nasal root breadth and maximum nasal bridge breadth were collected by the Los Alamos National Laboratory (LANL) survey data by Hack et al. (1973). t-test and F-test were conducted using MINITAB v. 14 (Minitab Inc., USA) to examine the statistical significance of the differences in mean and SD, respectively, between the KAF pilots, Korean civilians, and USAF personnel.
3. Results

3.1. Facial Measurements of KAF Male Pilots and KAF Female Pilots and Cadets

The descriptive statistics (mean, SD, min, max, and percentiles) of the KMP facial measurements and that of the KFP facial measurements are presented in Tables 4 and 5, respectively. For example, the descriptive statistics of KMP face width (unit: mm) in Table 4 shows mean ± SD = 156.4 ± 5.2, min = 143.4, max = 171.5, \( p_{.01} = 145.0 \), \( p_{.05} = 148.3 \), \( p_{.95} = 164.7 \), and \( p_{.99} = 168.8 \).

3.2. Comparison of KAF Male Pilots and Korean Male Civilians

A comparison in mean and SD between the KMP and Korean male civilians (KMC) presented in Table 6 and Figure 7 reveals that the KMP had a significantly lager head and a more protruded nose (ratio of means > 1.05) and was less varied in all the facial dimensions than the KMC. The KMP was found significantly larger than the KMC in all the head-related dimensions (head height, head breadth, head length, face length, and lower face length; \( \bar{d} = 6.6 \sim 26.5 \), ratio of means = 1.05 to 1.12) except head circumference (\( \bar{d} = -6.5 \); ratio of means = 0.99). Next, the KMP was found having a longer, higher, but slightly narrower nose.
(\(\bar{d} = 1.2\) in nose length, \(1.8\) in nose protrusion, and \(-1.4\) in nose width) and a slightly wider lip \((\bar{d} = 0.7\) in lip width). The SD ratio analysis results indicate that the facial measurements of the KMP were significantly less dispersed than those of the KMC in all the facial dimensions \((\text{ratio of SDs} = 0.29\) to \(0.82\)).

3.3. Comparison of KAF Male Pilots and USAF Male Personnel

A comparison in mean and SD between the KMP and the USAF male personnel (UMP) presented in Table 7 and Figure 8 indicates that the KMP had a significantly longer, wider, but flatter head and a longer and wider nose, and was less varied in the length and width dimensions of the head, nose, and lip, but more varied in chin width, nasal root breadth, bitragion-menton arc, and bitragion-subnasale arc than the UMP. The mean length differences between the KMP and the UMP decreased in the following order for the head \((\bar{d} = 13.3;\) ratio of means = \(1.06\)), face \((\bar{d} = 4.7;\) ratio of means = \(1.04\)), and lower face \((\bar{d} = 1.0;\) ratio of means = \(1.01\)). The KMP width measurements of the face, chin, nasal root, and nose were found significantly larger than the corresponding UMP measurements \((\text{ratio of means} = 1.09\) to \(1.34\)), but the opposite was found in maximum nasal bridge breadth \((\text{ratio of means} = 0.90\)) and lip width \((\text{ratio of means} = 0.95\)). The mean head length of the KMP was found significantly smaller than that of the UMP \((\text{ratio in mean} = 0.95\)), indicating the KMP had a flatter head than the UMP. The mean nose length of the KMP was found significantly longer than that of the UMP \((\bar{d} = 3.7;\) ratio in mean = \(1.07\)). Lastly, the SD ratio analysis results indicate that the facial measurements of the KMP were less varied in the length and width.
dimensions of the head, nose, and lip (ratio of SDs = 0.75 to 0.97), but more varied in chin width, nasal root breadth, bitragion-menton arc, and bitragion-subnasale arc (ratio of SDs = 1.05 to 1.33) than those of the UMP.

[Table 7 about here]

[Figure 8 about here]

3.4. Comparison of KAF Male Pilots and KAF Female Pilots and Cadets

A comparison in mean and SD between the KMP and the KFP presented in Table 8 and Figure 9 shows that the KMP was larger in all the facial dimensions (ratio of means = 1.02 ~ 1.20) except promentale-to-menton length (ratio of means = 0.93) and more varied in all the facial dimensions (ratio of SDs = 1.03 ~ 1.33) except face width, bitragion-subnasale arc, and chin-related dimensions (supramentale-to-menton length, promentale-to-menton length, bizygomatic-menton arc) than the KFP. Of the facial dimensions, relatively large mean differences ($\bar{d} > 10.0$ mm or ratio of means > 1.10) between the KMP and the KFP were found in head height, bitragion-menton arc, bitragion-subnasale arc, bizygomatic-menton arc, nasal root breadth, and maximum nasal bridge breadth. Lastly, significant SD differences (ratio of SDs > 1.2) between the KMP and the KFP were found mainly in the width-related dimensions (head breadth, rhinion-to-promentale length, chin width, maximum nasal bridge breadth, and nose width).

[Table 8 about here]

[Figure 9 about here]
4. Discussion

The present study selected 22 facial dimensions as those required to design a pilot’s oxygen mask by a comprehensive review of existing face anthropometric studies and the recommendations of a panel of experts. Of the 107 facial dimensions identified by reviewing 15 studies on face anthropometry and mask design, 22 dimensions (vertical length dimensions: 9; horizontal length dimensions: 2; width dimensions: 7; circumference or arc dimensions: 4) were systematically selected as those pertinent to half-face mask design. The facial measurements collected in the present study can be utilized effectively for the design of a half-face oxygen mask.

The facial measurements were efficiently extracted from 3D face scan data using the semi-automatic facial measurement extraction program developed in the present study. Once landmarks on the face scan are confirmed by the analyst, the facial measurement program coded by Matlab automatically extracts measurements for facial dimensions. A Euclidian distance between landmarks was calculated for length and width dimensions and an arc intersecting the facial image and a plane passing designated three landmarks was measured for arc dimensions. Note that the 3D face measurement method is superior to the conventional method which uses a tape measure for arc-related facial dimensions.

Since the facial measurements of the KMP are significantly different from those of the KMC and the UMP, the shape and sizing system of an oxygen mask need to be custom designed for Korean pilots. The largest mean difference at the nasal root area between the KMP and the UMP was found in nasal root breadth ($\bar{d} = 5.2$, ratio of means = 1.34), which can be the main cause of excessive pressure being experienced by most of Korean pilots wearing MBU-20/P masks. This significant difference at the nasal root area indicates that the
corresponding area of the existing oxygen mask design should be widened by about 5 mm on average for a better fit to Korean pilots. Lastly, the significant differences in mean and SD between the KMP and the UMP indicate that a customized sizing system needs to be developed for Korean pilots.

The facial characteristics of the KFP should be reflected in the oxygen mask sizing system and mask design because of their significant differences in mean and SD from the KMP. The faces of the KFP were found significantly smaller than the KMP (e.g., at nasal root breadth $\bar{d} = 3.4$ and ratio of means = 1.20) and less dispersed. A composite population of Korean pilots needs to be formed for oxygen mask design by reflecting an increasing rate of the KFP in the future.

The KMP was found significantly larger than the KMC in all head-related dimensions except head circumference. Demographic factors such as occupation and age commonly affect the anthropometric characteristics of a population. It is likely that the face of the KMP is larger than that of the KMC because of physical requirements such as height, weight, and physical fitness for pilots. However, the opposite occurs in head circumference, which is likely caused by the relatively short hair of pilots.

Lastly, use of the 3D scanning method was effective to collect not only facial measurements but also 3D facial images that are applicable to computer-aided design and virtual fit evaluation of an oxygen mask. For instance, the nasal contact area of an oxygen mask can be designed using not only facial measurements (e.g., nasal root breadth) but also the curved-surface shape of a 3D face scan image. Also, a 3D face scan can be used to compare a new design with the existing design by virtually applying various oxygen mask designs to the pilot's 3D facial scan and analyzing the magnitude of infiltration of an oxygen mask into the virtual face to estimate contact pressure due to wearing of an oxygen mask as illustrated in Figure 10. A virtual fit analysis and an ergonomics oxygen mask design have
been conducted as follow-up research of the present study.

[Figure 10 about here]

Acknowledgments

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Table 1. Maximum sampling error (SE; unit: mm) and sample size (n) requirement by precision (k) for facial dimensions of high importance for design of an oxygen mask

<table>
<thead>
<tr>
<th>k</th>
<th>Category</th>
<th>Face length</th>
<th>Rhinion-to-promentale length</th>
<th>Nose width</th>
<th>Lip width</th>
<th>Max</th>
</tr>
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<tbody>
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<td>3%</td>
<td>SE</td>
<td>3.4</td>
<td>1.9</td>
<td>1.2</td>
<td>1.5</td>
<td>3.4</td>
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<td></td>
<td>n</td>
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<td>165</td>
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</tr>
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<td>1.6</td>
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</tr>
<tr>
<td></td>
<td>n</td>
<td>93</td>
<td>93</td>
<td>40</td>
<td>63</td>
<td>93</td>
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Table 2. Facial anthropometric studies compared in the present study

<table>
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<tr>
<td></td>
<td>Males</td>
<td>Females</td>
<td></td>
</tr>
<tr>
<td>Sample size</td>
<td>278</td>
<td>58</td>
<td>803 (2,568*)</td>
</tr>
<tr>
<td>Age</td>
<td>25 ~ 43</td>
<td>20 ~ 28</td>
<td>25 ~ 49 (8 ~ 75*)</td>
</tr>
<tr>
<td>Number of facial dimensions</td>
<td>22</td>
<td>10 (40*)</td>
<td>13 (48*)</td>
</tr>
<tr>
<td>Remarks</td>
<td>- 278 pilots</td>
<td>- 6 pilots</td>
<td></td>
</tr>
<tr>
<td></td>
<td>- 52 cadets</td>
<td>- 1187 pilots</td>
<td></td>
</tr>
<tr>
<td></td>
<td>- 505 navigators</td>
<td>- 505 student pilots</td>
<td></td>
</tr>
<tr>
<td></td>
<td>- 118 student navigators</td>
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<td></td>
</tr>
</tbody>
</table>

* The information of original data; face measurements matching in age with the present study and facial dimensions corresponding to the present study were used for comparison.
Table 3. Facial dimensions of Korean civilians and U.S. Air Force (USAF) personnel compared with those of Korean Air Force (KAF) pilots

<table>
<thead>
<tr>
<th>No.</th>
<th>Facial dimensions measured for Korean Air Force pilots</th>
<th>Size Korea (KATS, 2004)</th>
<th>USAF personnel (Churchill et al., 1977)</th>
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<tbody>
<tr>
<td>1</td>
<td>head height</td>
<td>☑</td>
<td>☑</td>
</tr>
<tr>
<td>2</td>
<td>head breadth</td>
<td>☑</td>
<td>☑</td>
</tr>
<tr>
<td>3</td>
<td>head length</td>
<td>☑</td>
<td>☑</td>
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† As for nose length Churchill et al. (1977) measured the length of sellion to subnasale, while KATS (2004) measured the length of sellion-to-pronasale. Two measurements were collected for nose length using both of the methods in the present study.

‡ The data of nasal root breadth and maximum nasal bridge breadth were obtained from an anthropometric survey report by Los Alamos National Laboratory (Hack et al., 1973).
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Table 6. Comparison of KAF male pilots (KMP) and Korean male civilians (KMC) (unit: mm)

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<th>SDKMP/MSDKMC</th>
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* p < .05; ** p < .01
Table 7. Comparison of KAF male pilots (KMP) and USAF male personnel (UMP) (unit: mm)

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* \( p < .05 \); ** \( p < .01 \)
Table 8. Comparison of KAF male pilots (KMP) and KAF female pilots and cadets (KFP)  
(unit: mm)

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<td>14</td>
<td>face width</td>
<td>156.4</td>
<td>5.2</td>
<td>147.0</td>
<td>6.0</td>
<td>9.4**</td>
</tr>
<tr>
<td>15</td>
<td>chin width</td>
<td>132.0</td>
<td>8.1</td>
<td>122.2</td>
<td>6.1</td>
<td>9.8**</td>
</tr>
<tr>
<td>16</td>
<td>nasal root breadth</td>
<td>20.6</td>
<td>2.5</td>
<td>17.2</td>
<td>2.2</td>
<td>3.4**</td>
</tr>
<tr>
<td>17</td>
<td>maximum nasal bridge breadth</td>
<td>31.3</td>
<td>2.4</td>
<td>27.0</td>
<td>1.9</td>
<td>4.3**</td>
</tr>
<tr>
<td>18</td>
<td>nose width</td>
<td>38.1</td>
<td>2.5</td>
<td>35.0</td>
<td>2.0</td>
<td>3.2**</td>
</tr>
<tr>
<td>19</td>
<td>lip width</td>
<td>49.9</td>
<td>3.4</td>
<td>45.4</td>
<td>3.2</td>
<td>4.4**</td>
</tr>
<tr>
<td>20</td>
<td>bitragion-menton arc</td>
<td>318.2</td>
<td>13.0</td>
<td>292.1</td>
<td>12.1</td>
<td>26.1**</td>
</tr>
<tr>
<td>21</td>
<td>bitragion-subnasale arc</td>
<td>285.8</td>
<td>11.1</td>
<td>269.8</td>
<td>12.4</td>
<td>16.0**</td>
</tr>
<tr>
<td>22</td>
<td>bizygomatic-menton arc</td>
<td>309.0</td>
<td>11.0</td>
<td>284.6</td>
<td>12.1</td>
<td>24.5**</td>
</tr>
</tbody>
</table>

*p < .05; ** p < .01
Figure 1. Facial dimensions and their importance for design of a pilot oxygen mask
<table>
<thead>
<tr>
<th>No.</th>
<th>Landmark</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Alare (left/right)</td>
<td>The most laterally positioned point on the nasal aperture in a transverse plane.</td>
</tr>
<tr>
<td>2</td>
<td>Cheilion (left/right)</td>
<td>The lateral junction point of the upper and lower lips with the facial skin at the corner of the mouth with no facial expression.</td>
</tr>
<tr>
<td>3</td>
<td>Dacryon (left/right)</td>
<td>The intersection point of the maxillary bone, lacrimal bone, and frontal bone on the side of the nasal root between sellion and endocanthion.</td>
</tr>
<tr>
<td>4</td>
<td>Gonion (left/right)</td>
<td>The most posterior-inferior midpoint of the rounded gonial angle between the mandibular body and ramus.</td>
</tr>
<tr>
<td>5</td>
<td>Menton</td>
<td>The most inferior midsagittal point of the mandible (bottom of the chin).</td>
</tr>
<tr>
<td>6</td>
<td>Nasal ala (left/right)</td>
<td>The most lateral point on the surface of the nostril.</td>
</tr>
<tr>
<td>7</td>
<td>Promentale</td>
<td>The most anterior midsagittal point on the chin prominence.</td>
</tr>
<tr>
<td>8</td>
<td>Pronasale</td>
<td>The most anterior midsagittal point on the tip of the nose.</td>
</tr>
<tr>
<td>9</td>
<td>Rhinion</td>
<td>The most anterior midsagittal osseocartilaginous junction point at the nasal bone.</td>
</tr>
<tr>
<td>10</td>
<td>Sellion</td>
<td>The most posterior midsagittal point of the nasal bone at the top of the nasal bridge.</td>
</tr>
<tr>
<td>11</td>
<td>Subnasale</td>
<td>The midsagittal point at the junction of the inferior surface of the nose and the superior aspect of the philtrum.</td>
</tr>
<tr>
<td>12</td>
<td>Supramentale</td>
<td>The most posterior midsagittal point in the concavity between the lower lip and promentale.</td>
</tr>
<tr>
<td>13</td>
<td>Tragion (left/right)</td>
<td>The most anterior of the ear notch just superior edge of the tragus flap.</td>
</tr>
<tr>
<td>14</td>
<td>Zygion (left/right)</td>
<td>The most lateral point on the zygomatic arch.</td>
</tr>
</tbody>
</table>

Figure 2. Facial landmarks for measurement of facial dimensions
Figure 3. Minimum sample size requirements by precision ($k$) for face anthropometric survey
Figure 4. Face capturing in a darkroom tent
Figure 5. Post-processing of 3D facial scan images
Figure 6. Illustration of face dimension measurement: lip width and bitragion-menton arc
Figure 7. The mean differences of facial measurements between KAF male pilots (KMP) and Korean male civilians (KMC) (unit: mm)
Figure 8. Illustration of differences of KAF male pilots (KMP) and USAF male personnel (UMP) (unit: mm)
Figure 9. Illustration of differences of KAF male pilots (KMP) and KAF female pilots and cadets (KFP) (unit: mm)
Figure 10. Illustration of a virtual fit analysis of an oxygen mask design to a pilot's face (the area in which the oxygen mask infiltrates into the virtual face is colored red, which indicates the area of a high contact pressure on the face due to lack of fit of the mask to the face)