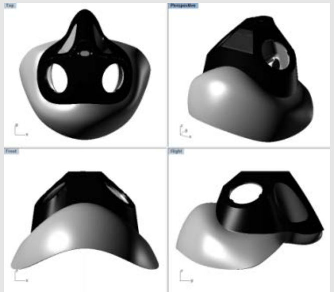
INDUSTRIAL AND MANAGEMENT ENGINEERING, POSTECH

Ergonomic Design Technology Lab

Ergonomic Design and Evaluation of a Pilot Oxygen Mask






Wonsup Lee[1], Hee-Eun Kim[2], Daehan Jung[3], Seikwon Park[4], and Heecheon You[1]

[1] Department of Industrial and Management Engineering, Pohang University of Science and Technology (POSTECH), South Korea

[2] Department of Clothing and Textiles, Kyungpook National University, South Korea

[3] Department of Mechanical Engineering, Korea Air Force Academy, South Korea

[4] Department of Systems Engineering, Korea Air Force Academy, South Korea

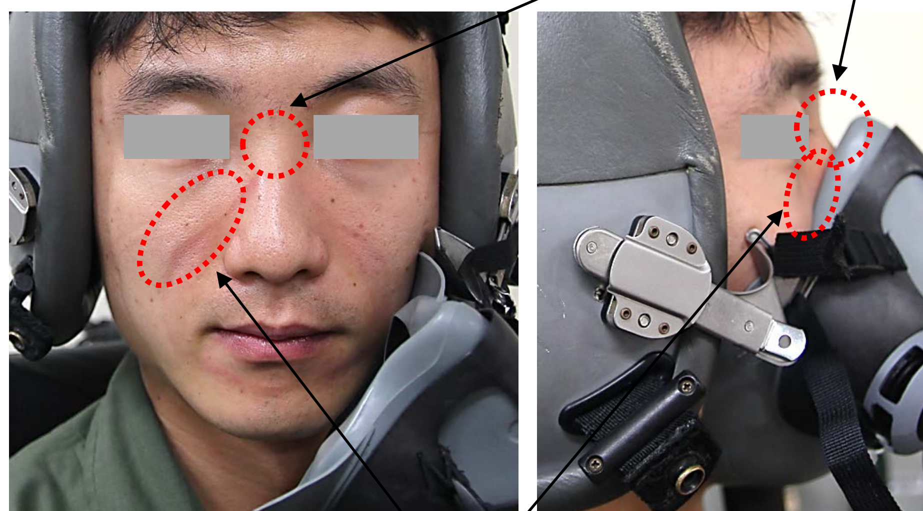
Contents

Motivation

- MBU-20/P pilot oxygen masks (OM) designed based on USAF facial measurements and shape are worn by Korean F-15/F-16 pilots
- Unfit to a significant percentage of Korean Air Force (KAF) pilots
  ⇒ Excessive pressure and/or oxygen leakage at the nasal root
  ⇒ High level of discomfort during flight operation

⇒ Required a new OM design which is better fit to KAF pilots

MBU-20/P pilot oxygen mask
(Gentex Corp., USA)



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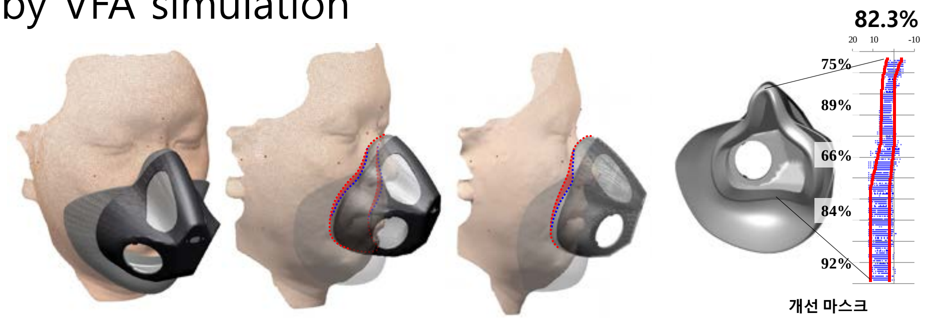
Research Objectives

Development of an Ergonomic Design and Evaluation Methods of a Pilot Oxygen Mask

1. **Development and application of OM design method**
   - ✓ Development of OM design method based on virtual fit assessment (VFA)
   - ✓ Identification the OM shape proper to KAF pilots
   - ✓ Evaluation of design improvement effect by VFA simulation

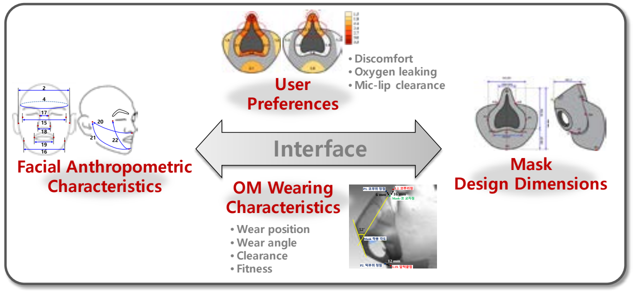


2. **Validation of the proposed OM design**
   - ✓ Development of usability evaluation protocol
   - ✓ Evaluation of discomfort, pressure, and suitability for military equipment

Approach

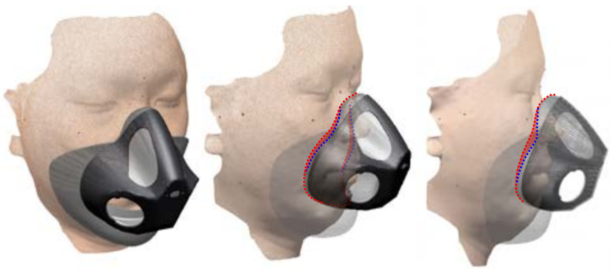
S1 Face-Mask Interface Analysis

- Analysis of face, oxygen mask, and face-mask interface
- Identification of OM design characteristics



S2 Mask Design Based on Virtual Fit Assessment

- Development of virtual fit assessment (VFA) method
- Improvement of OM design through VFA method
- Evaluation of OM design improvement effect

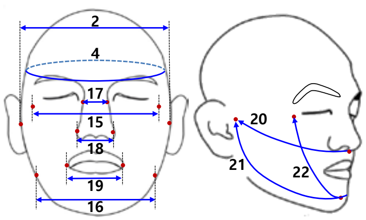


S3 Oxygen Mask Evaluation

- Development of evaluation protocols
- Evaluation of the proposed OM designs

S1. Face-Mask Interface Analysis

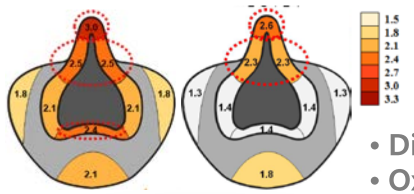
- **Identified comprehensive characteristics** among **face, oxygen mask, and their interface**



Facial dimensions

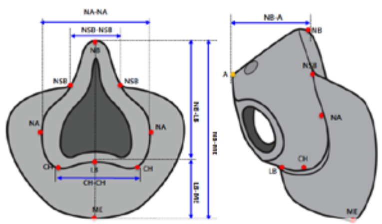

3D shape

Facial Anthropometric Characteristics



User Preferences

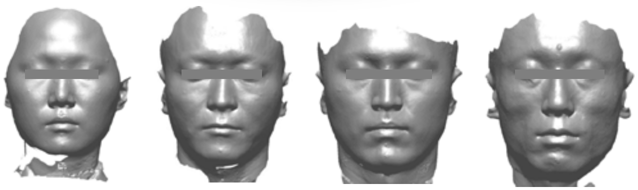
- Discomfort
- Oxygen leaking
- Microphone-lip clearance
- Overall satisfaction



OM design dimensions

Interface

Oxygen Mask Characteristics

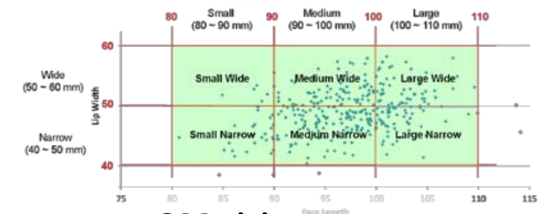


Representative face models

OM Wearing Characteristics

- Wear position
- Wear angle
- Clearance
- Fit

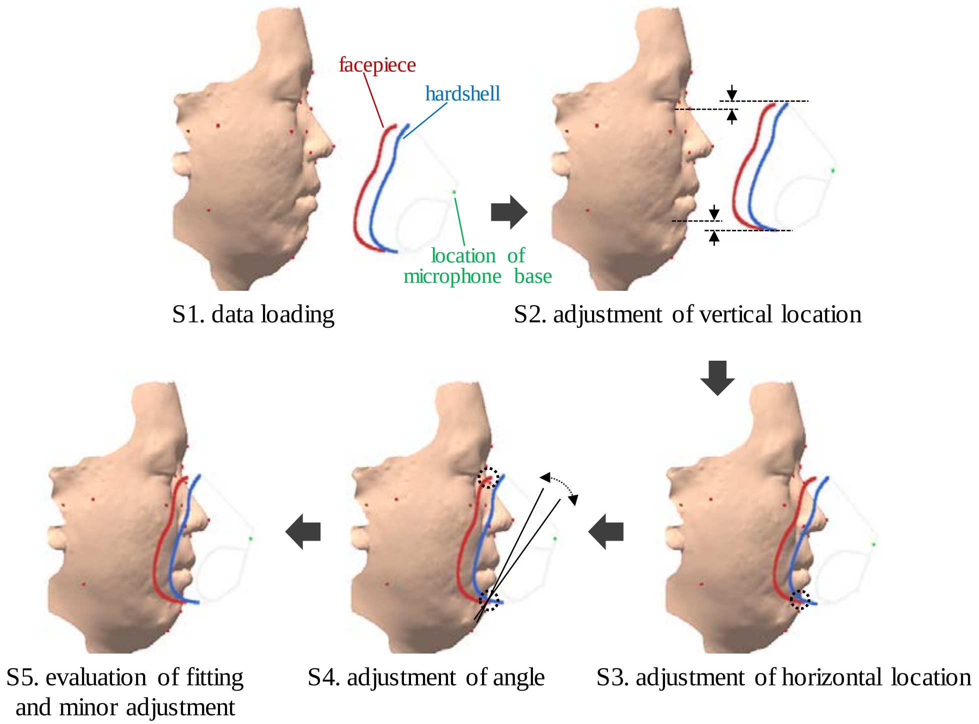
Oxygen mask fit characteristics to the face

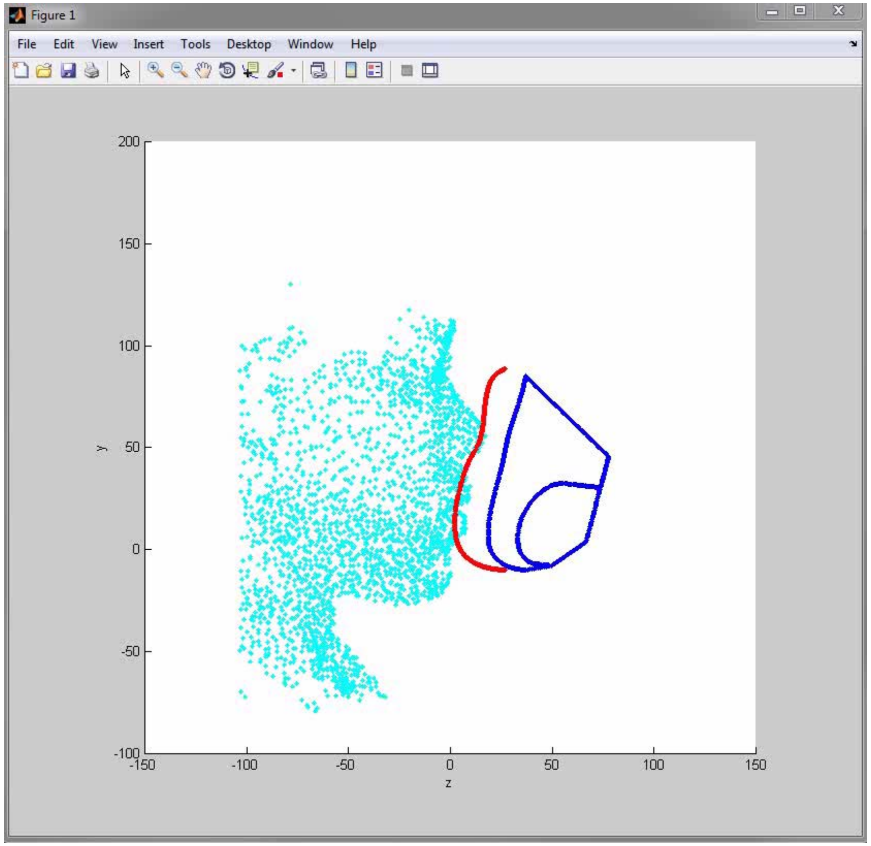


OM sizing system

S2. Mask Design Based on Virtual Fit Assessment

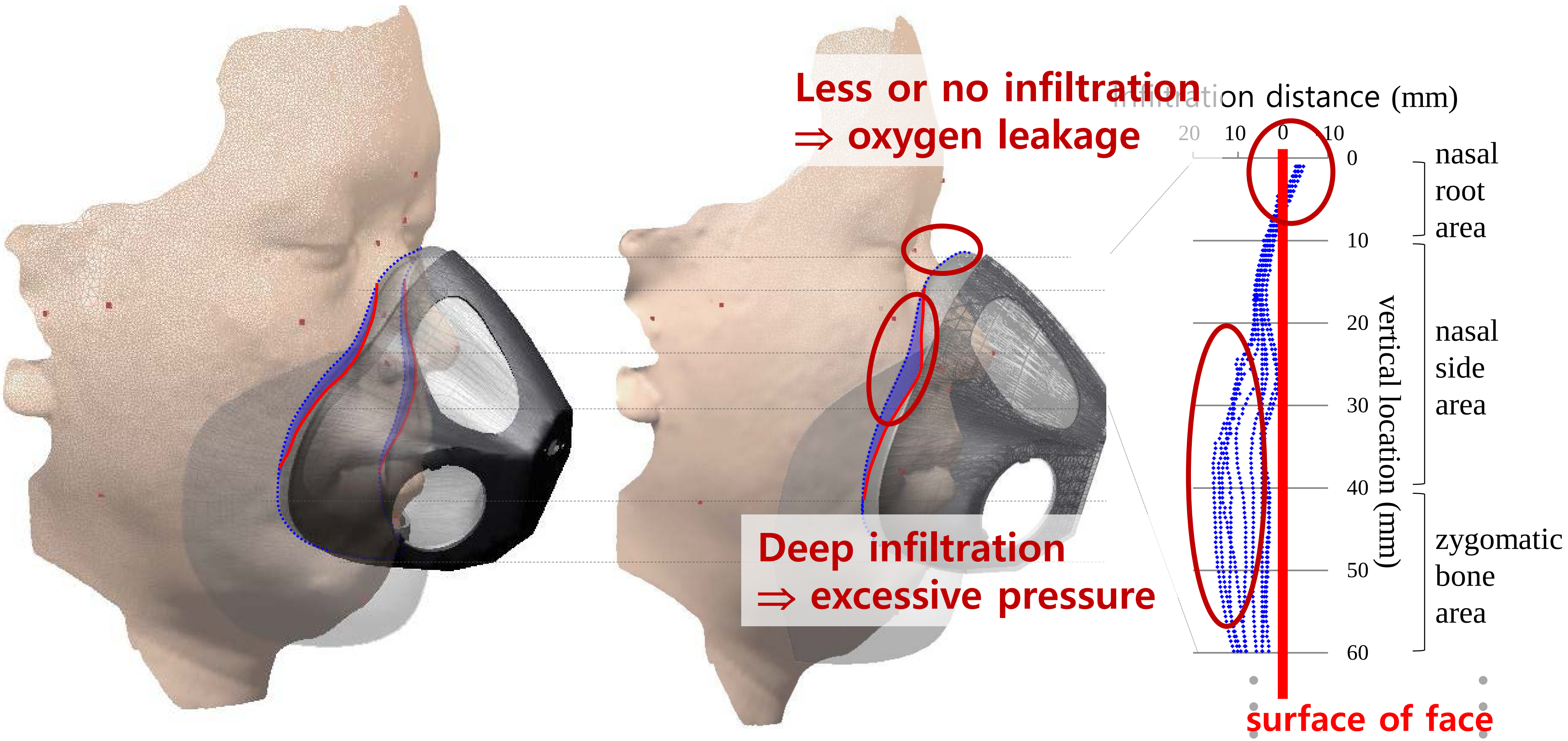
- **Used various 3D face images (*n* = 336) and simplified OM CADs**
- **Virtually aligned OM CAD to 3D faces based on the OM wearing characteristics**
  (wearing position, wearing angle)
- **Automatically aligned and analyzed through the VFA system**





Virtual Fit Assessment

- Identified **infiltration distance** as fit of OM design to the face



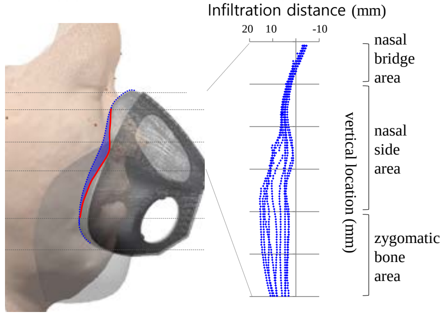
Iterative Design Improvement Using VFA System

S1. Design **initial OM shape** based on RFMs

S2. Evaluation of **design improvement effect using VFA**

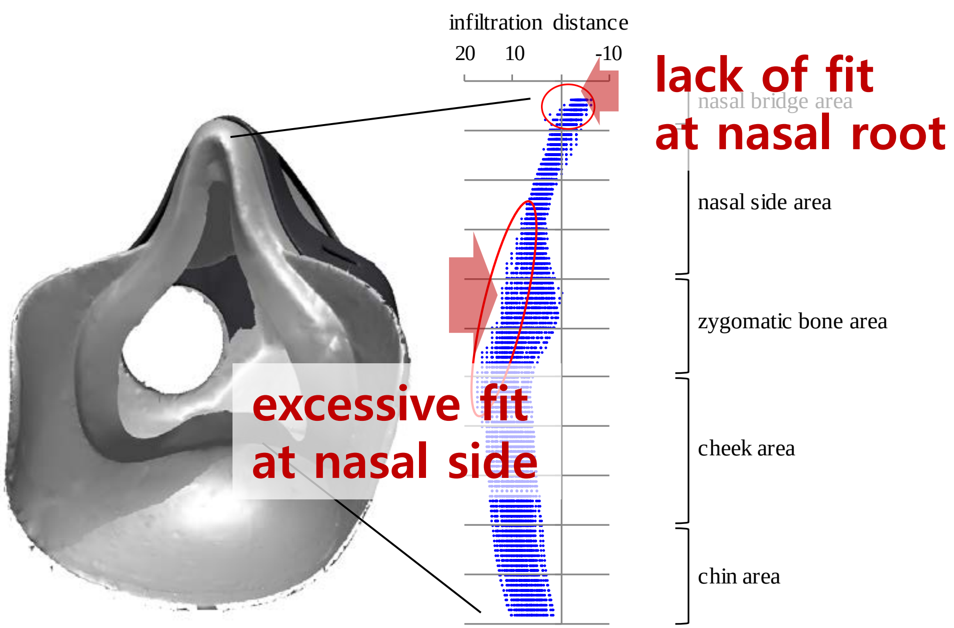
S3. **Adjustment of OM shape**

Iteration

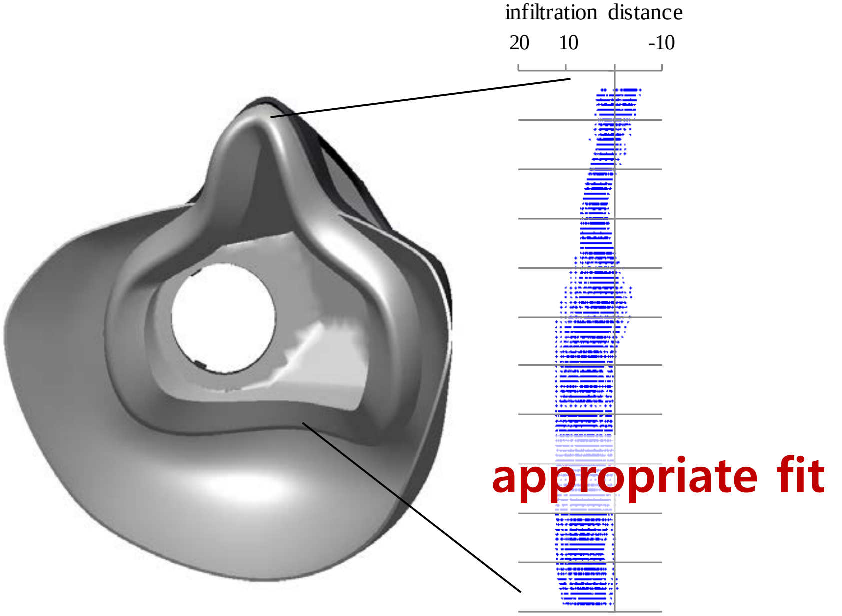


virtual fit assessment

(n = 336)



existing

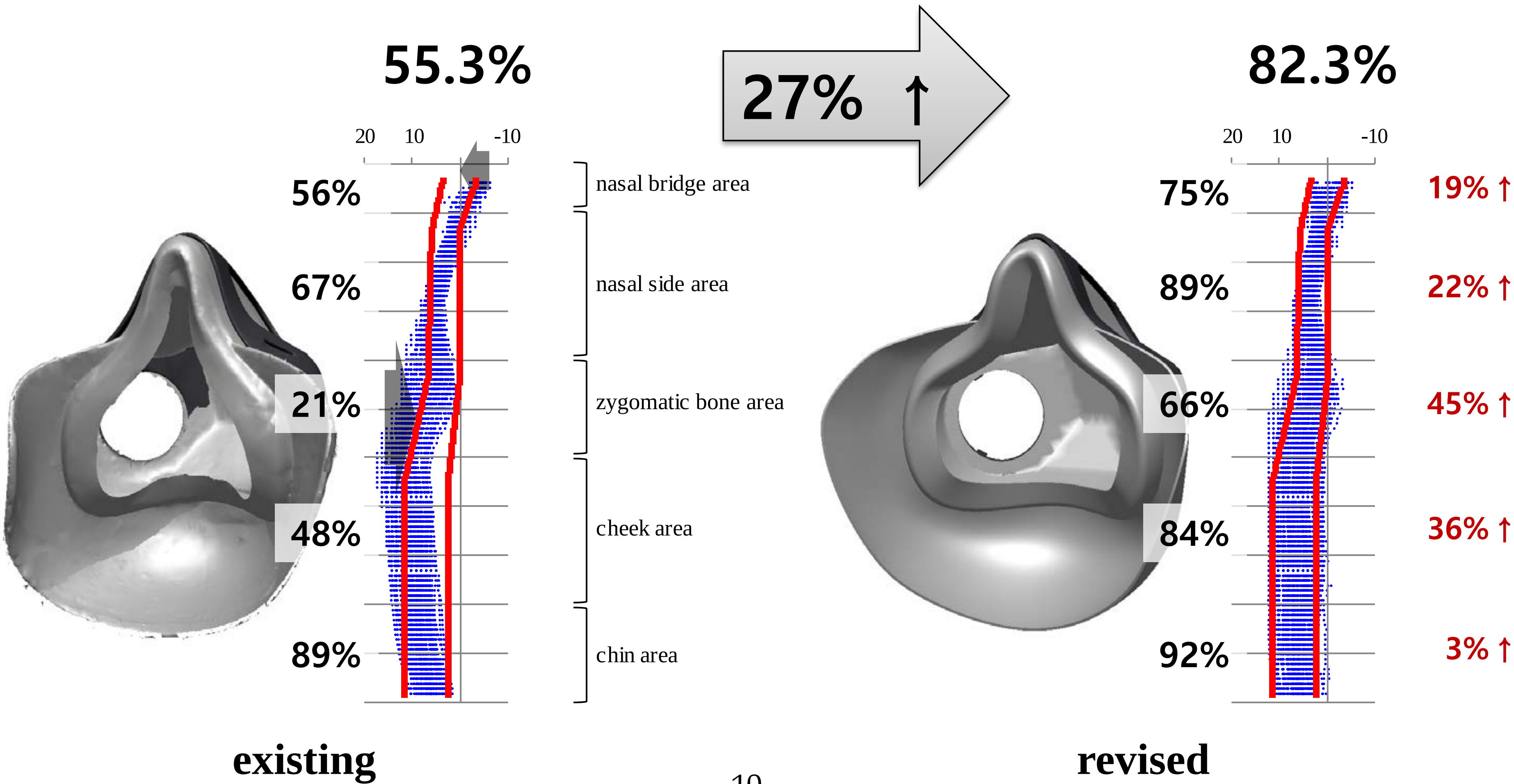


revised

Design Improvement Effect Analysis

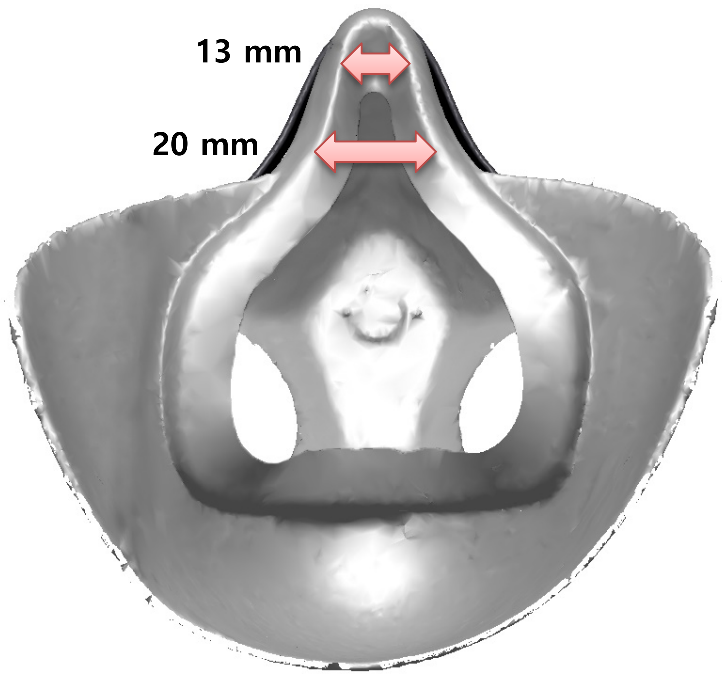
(*n* = 336)

- Evaluated the pilot accommodation percentage of OM design
- Increased fit of OM by 3% ~ 45% (mean = 27%) at the facial area

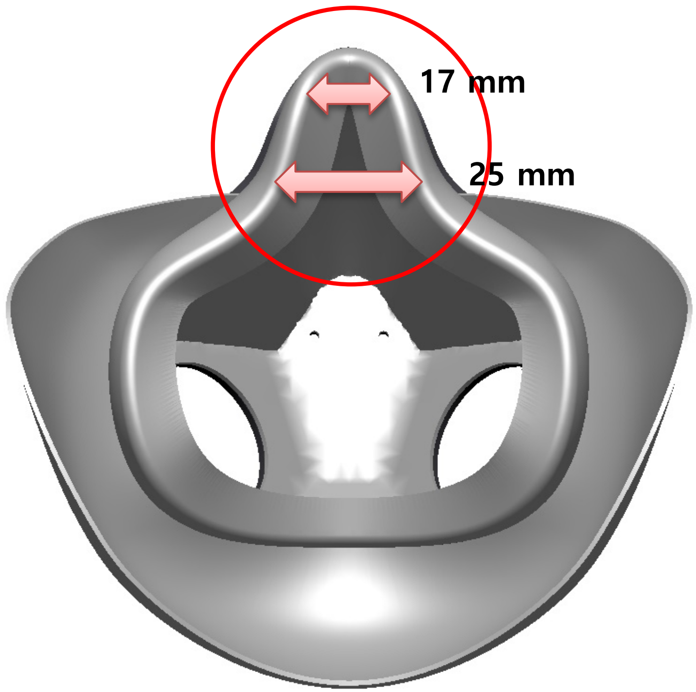


Comparison of OM Shape: Front View

- **Widened the nasal area of OM** (4 ~ 5 mm) for **better fit**



existing

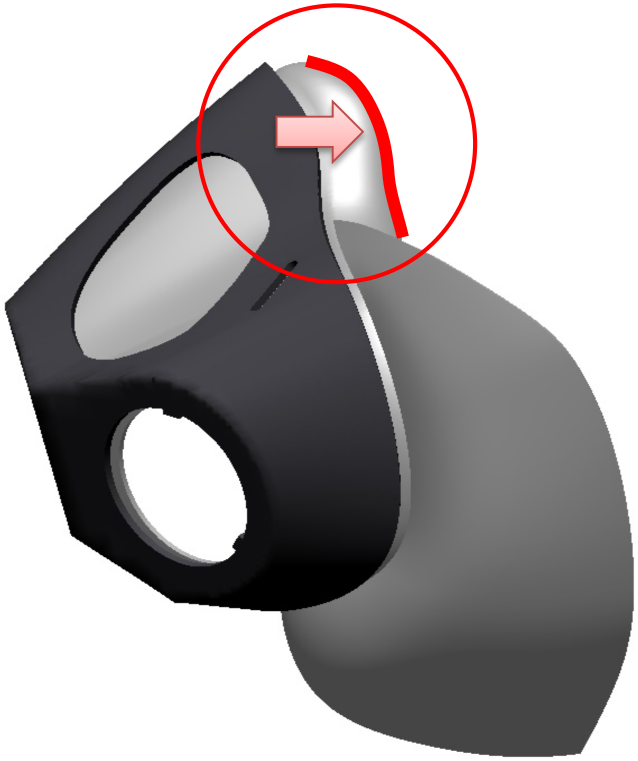


revised

Comparison of OM Shape: Side View

- **Revised the nose shape of OM to enclose the nasal area to prevent oxygen leakage**

existing



revised

Comparison of OM Shape

existing

revised

Evaluation of Oxygen Mask

OM Evaluation Protocol

- **Participants**
  - ✓ **83 KAF pilots** (M: 81, F: 2) currently using MBU-20/P
- **Evaluation methods**
  - ✓ **Subjective evaluation**
  - ✓ **Pressure evaluation** using pressure film
  - ✓ **Suitability evaluation for military equipment**: PBG* mode, low atmospheric pressure, and high-G situations

Subjective evaluation	Pressure evaluation	Suitability evaluation of for military equipment

PBG mode

Low atmospheric pressure

High-G

*pressure breathing for gravity (PBG): Supplying oxygen with high pressure in high-G situation

OM Evaluation Procedure: Subjective & Pressure Evaluation

S1. **Introduction**

Selection and fitting of the revised mask → (applies before the evaluation of the revised mask)

S2.

Evaluation on the **existing mask**	Evaluation on the **revised mask**

(counter-balanced)

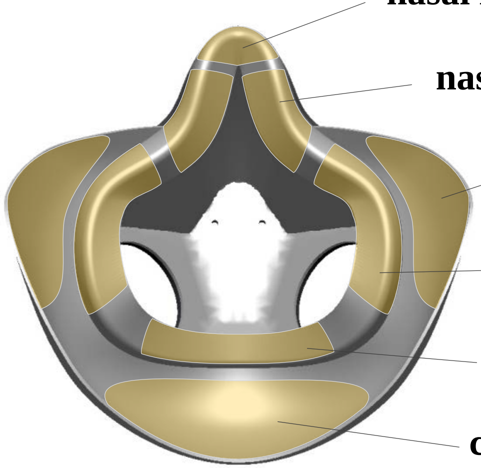
- Questionnaire
- Pressure measurement

S3. **Debriefing**

Subjective Evaluation

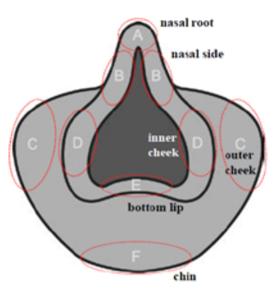
- Wear OM for 10 min, then answer the questionnaire
- Evaluation items
    1) Discomfort due to pressure (by facial area)
    2) Oxygen leakage (by facial area)
    3) Slippage of OM
    4) Microphone-lip contact
    5) Overall satisfaction

- **Facial area**: nasal root, nasal side, inner- and outer-cheek, bottom lip, chin
- **7-point scale** (0: not at all; 1: rarely; 7: extremely)



Oxygen Mask Usability Evaluation	Evaluation Mask	☐ Existing Mask ☐ Revised Mask

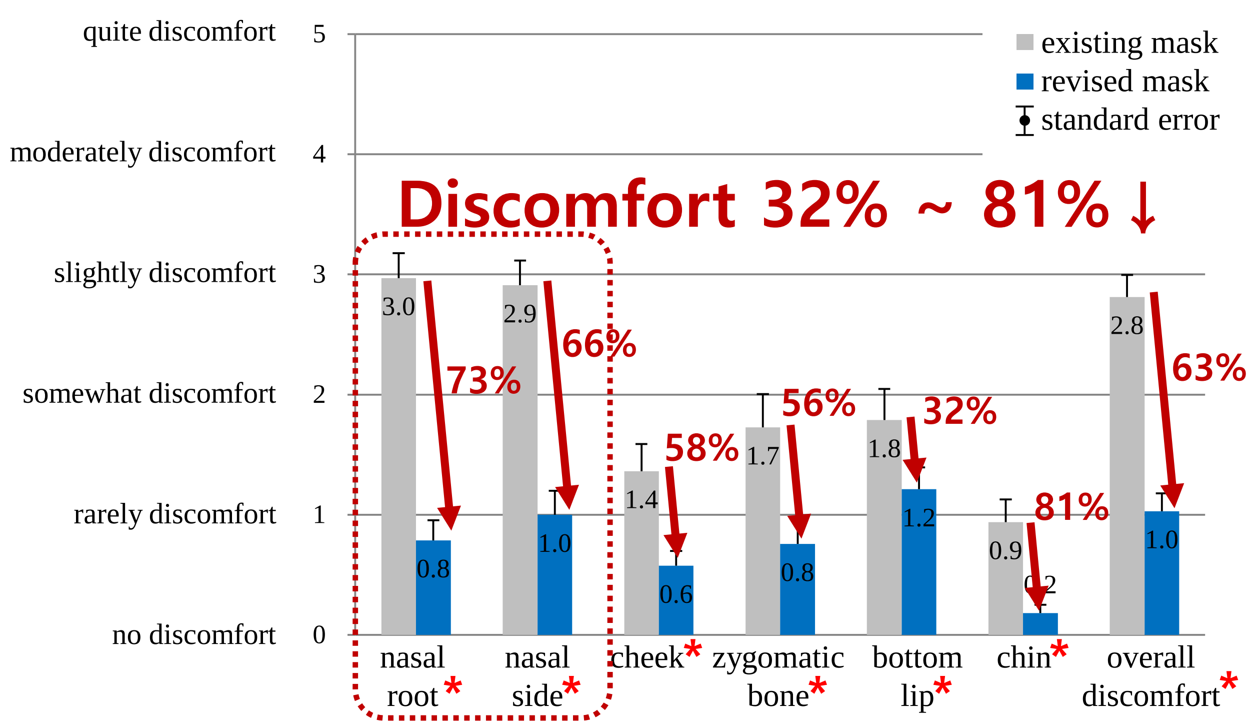
1. Check (√) how much you feel discomfort by facial area.



Facial area	no discomfort	rare discomfort	somewhat discomfort	slight discomfort	moderate discomfort	quite discomfort	very discomfort	extreme discomfort
	0점	1점	2점	3점	4점	5점	6점	7점
A: nasal root	☐	☐	☐	☐	☐	☐	☐	☐
B: nasal side	☐	☐	☐	☐	☐	☐	☐	☐
C: outer cheek	☐	☐	☐	☐	☐	☐	☐	☐
D: inner cheek	☐	☐	☐	☐	☐	☐	☐	☐
E: bottom lip	☐	☐	☐	☐	☐	☐	☐	☐
F: chin	☐	☐	☐	☐	☐	☐	☐	☐
overall discomfort	☐	☐	☐	☐	☐	☐	☐	☐

Results: Discomfort

- In-depth analysis on 32 pilots showing discomfort ≥ 3 at nasal root or nasal side with the existing mask
- Discomfort of the revised mask was decreased by 32% ~ 81%



*significant at $\alpha = 0.05$

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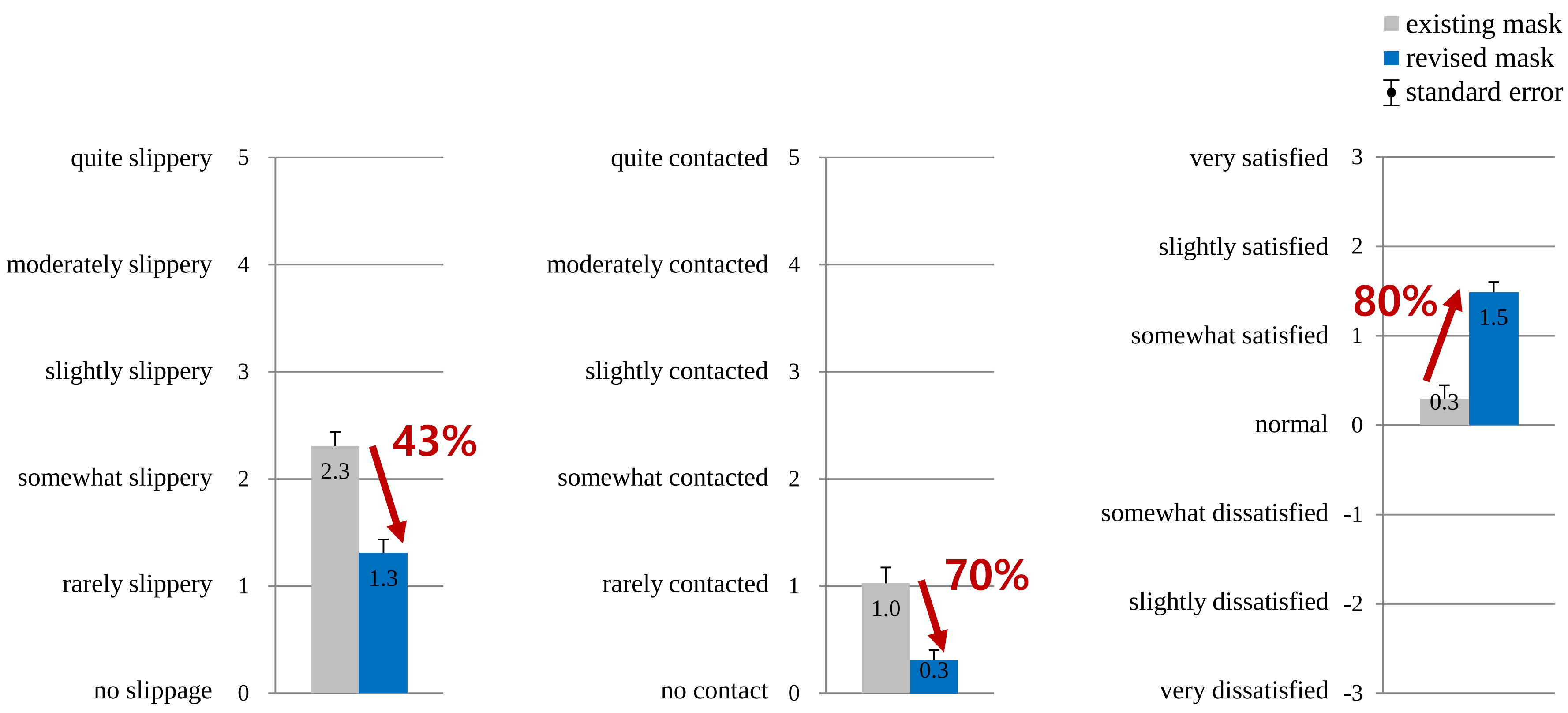
Results: Subjective Evaluation

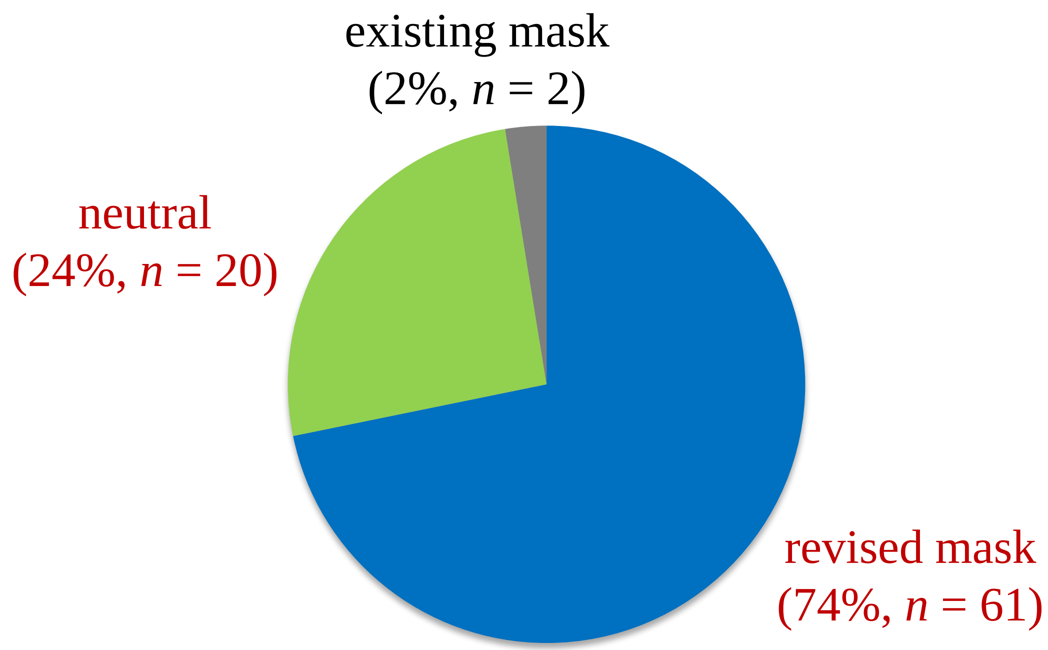
- **The revised mask was significantly preferred to the existing mask in terms slippage, microphone-lip contact, and overall satisfaction**



Slippage of oxygen mask* **Microphone-lip contact*** **Overall satisfaction***

***significant at $\alpha = 0.05$**

Results: Preference



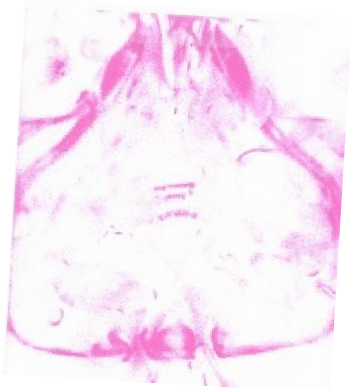
KAF Pilots (*n* = 83)

Pressure Evaluation Protocol

- **Used Prescale™ pressure film (Fujifilm, Japan) for pressure measurement**

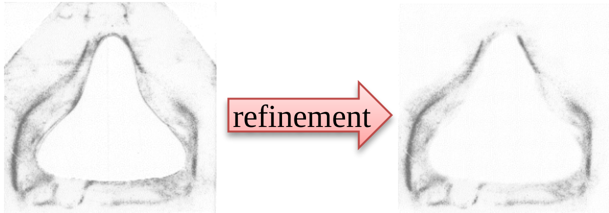
S1. **Preparation of pressure film**

S2. **Measurement of pressure (10 sec)**

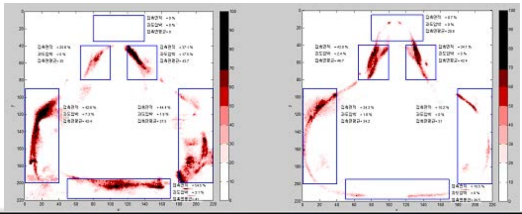


S3. **Scanning of pressure film**

S4. **Processing of pressure film scan image using Photoshop**



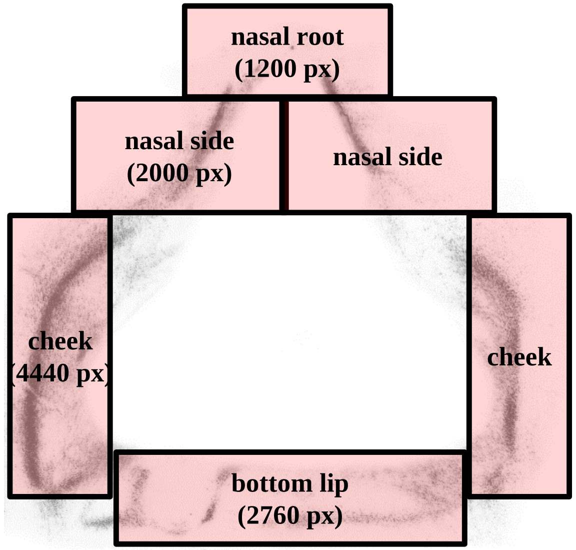
S5. **Analysis of pressure distribution**

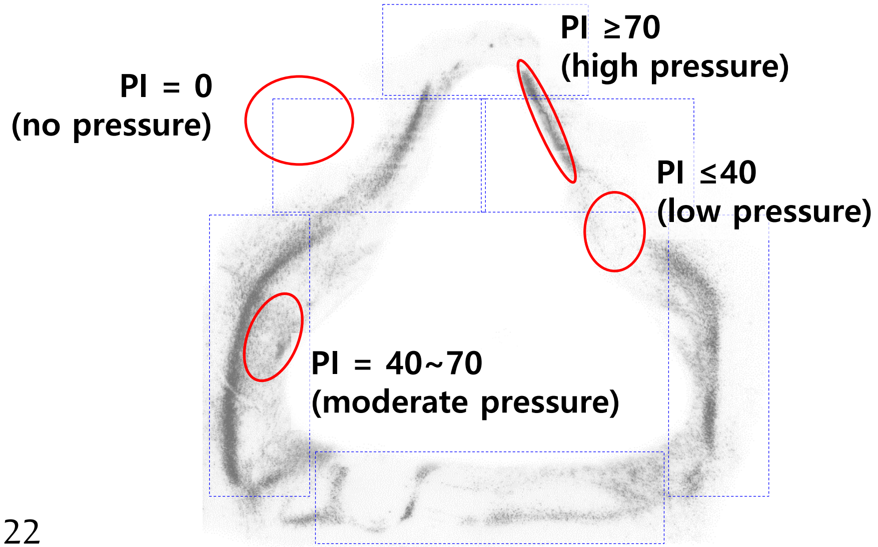


Pressure Index (PI)

- **PI**: 0-to-100 scale (0 = white, 100 = black)
- **Pressure category**: no (PI = 0), low (PI ≤ 40), moderate (40 ≤ PI < 70), and high pressure (PI ≥ 70)
- **Facial area**: nasal root, nasal side, cheek, and bottom lip
- **Analysis criteria**
  - ✓ Average of PI: mean value of pressed area where PI > 0
  - ✓ Moderately pressed area: number of pixels where 40 ≤ PI < 70
  - ✓ Excessively pressed area: number of pixels where PI ≥ 70

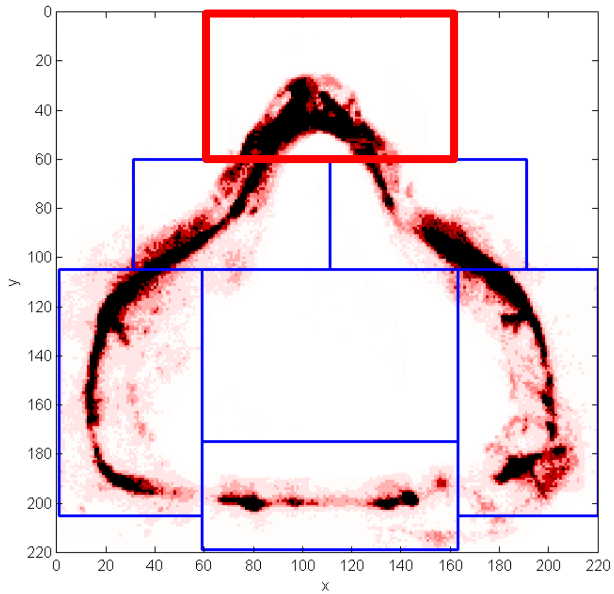
PI	Mpa	psi
40	0.10	14
70	0.17	25
100	0.20	29





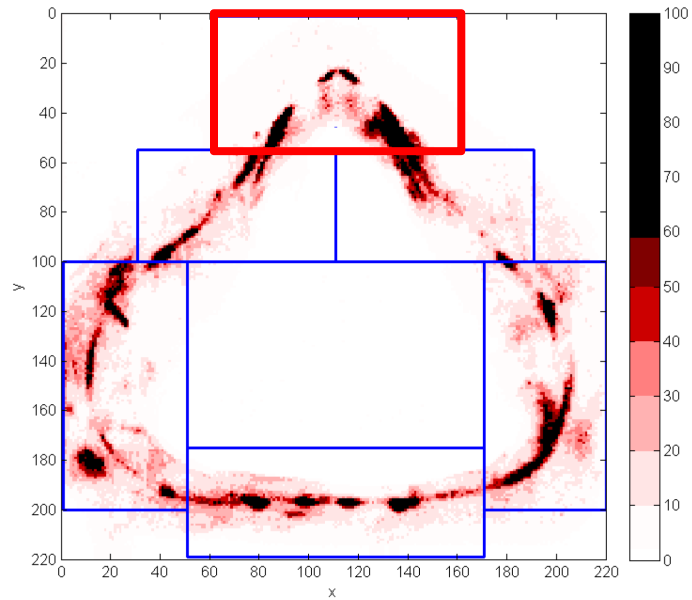
Pressure Analysis: Nasal Root Area (illustration)

- Average of PI: 25.2
- Moderately pressed area: 948 px
- Excessively pressed area: 476 px



Existing mask (size: small narrow)

- Average of PI: 10.0 **(60%↓)**
- Moderately pressed area: 170 px **(82%↓)**
- Excessively pressed area: 82 px **(83%↓)**

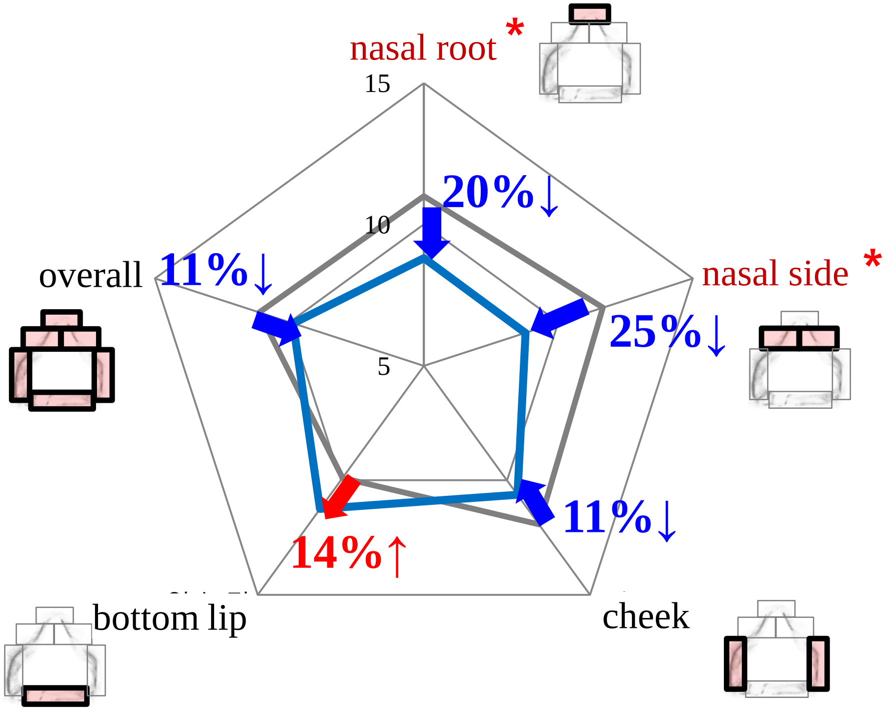


Revised mask (size: medium wide)

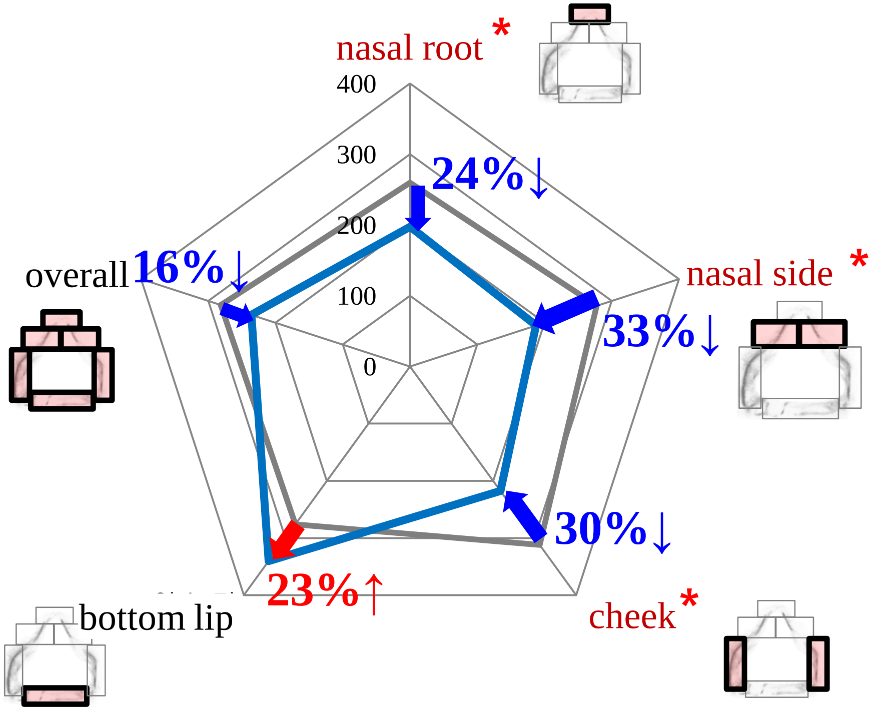
Results

- Pressure of the revised mask was **decreased by 11% ~ 25%**
- Moderately pressed area (40 ≤ PI < 70) of the revised mask was **decreased by 24% ~ 33%**
- Bottom lip: discomfort score was lower ⇒ **comfortable fit**

Average of PI



Moderately Pressed Area



*significant at α = 0.05

Suitability Evaluation for Military Equipment

- **Evaluated OM suitability in the extreme environments of OM usage**

	PBG mode	Low atmospheric pressure	High-G
Evaluation facility	**Combined Aircrew Systems Tester (CAST; Gentex Corp., USA)**	**aviation physiology training chamber**	**high-G training simulator**
# participants	20	5	5
Evaluation method	**Subjective evaluation**	**Subjective evaluation**	• **Subjective evaluation** • **Video analysis of mask slippage**
Image			

[*] **pressure breathing for gravity (PBG)**: **Supplying oxygen with high pressure in high-G situation**

Results: PBG and Low Pressure Situation

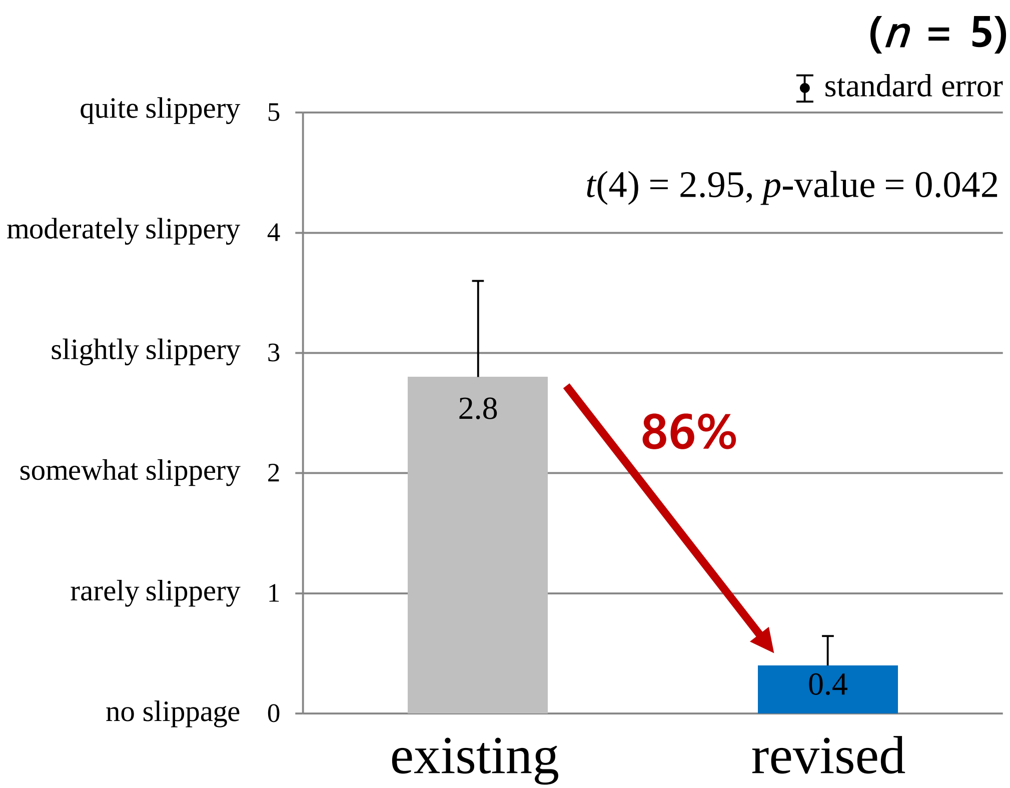
- The revised oxygen mask was found stable and secure in PBG mode and low atmospheric pressure situation
- Any noticeable usability problem was not reported on the revised oxygen mask

PBG mode (n = 20)

low atmospheric pressure (n = 5)

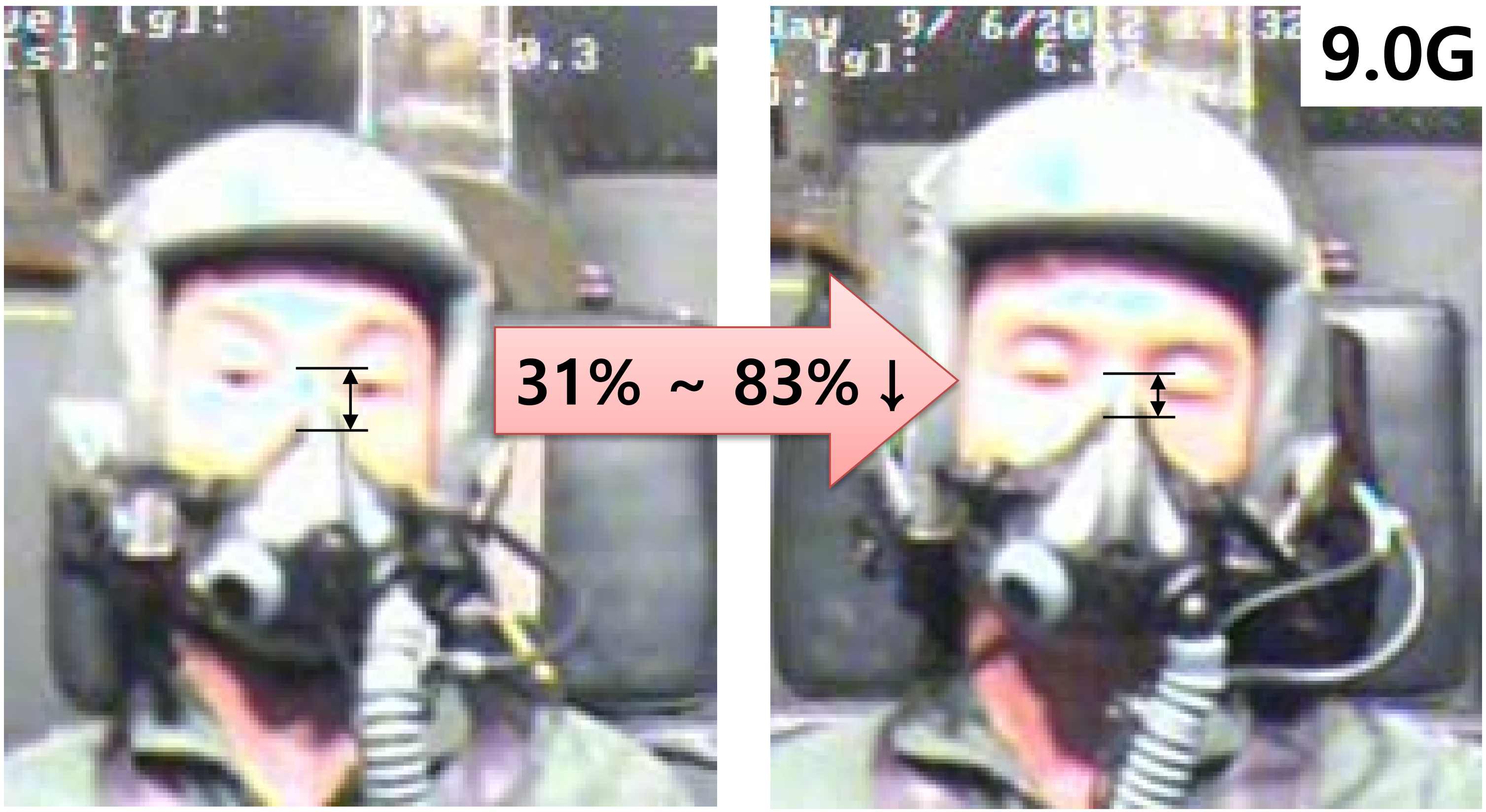
Results: High-G, Subjective Slippage

- **Subjective slippage** of the revised mask was **significantly decreased by 86%**



Results: High-G, Slippage Distance

- **The slippage distance** of the revised mask was **decreased by 31% ~ 83% (mean = 47%)**

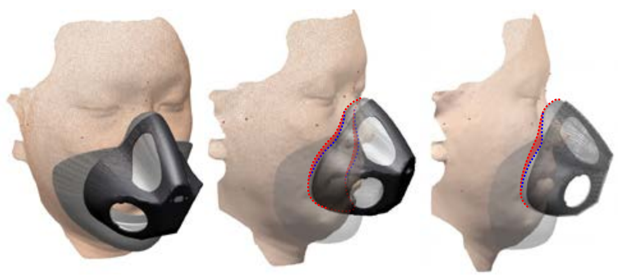


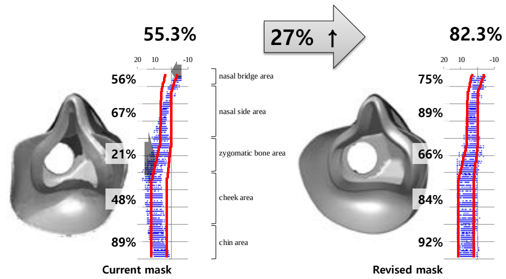
Existing　　　　　　Revised

Discussion (1/2)

- Designed OMs for various face shapes of KAF pilots by virtual fit assessment

  ⇒ Quantitatively evaluated design improvement effects before prototyping



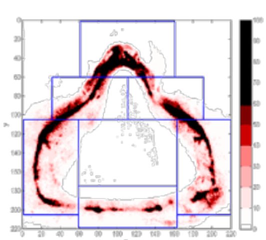


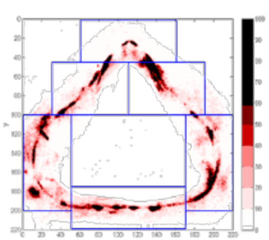
- Validated OM design with OM users

  ⇒ Proposed quantitative evaluation of pressure using pressure film

  ⇒ Introduced suitability evaluation in the simulated OM usage environment

  ⇒ Validated the OM design method





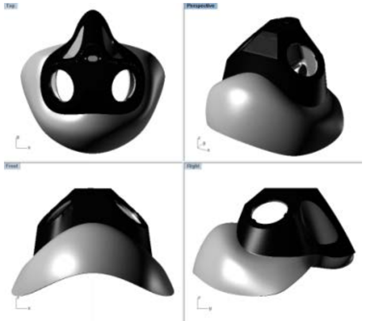
Discussion (2/2)

- **Support more comfortable and safe flight**
  - ✓ Reduce discomfort due to excessive pressure & oxygen leakage
  - ✓ Improve satisfaction
  - ✓ Increase combat power

- **OM design method using 3D facial scan and virtual fit assessment applicable to ergonomic product designs**
  - ✓ Other types of mask: military gas filter mask, industrial dust-proof mask, industrial gas filter mask, firefighter's full-face mask, and diver's mask
  - ✓ Wearable products: goggles, helmets, gloves, shoes, and clothing

Q & A

Thank you for your attention!

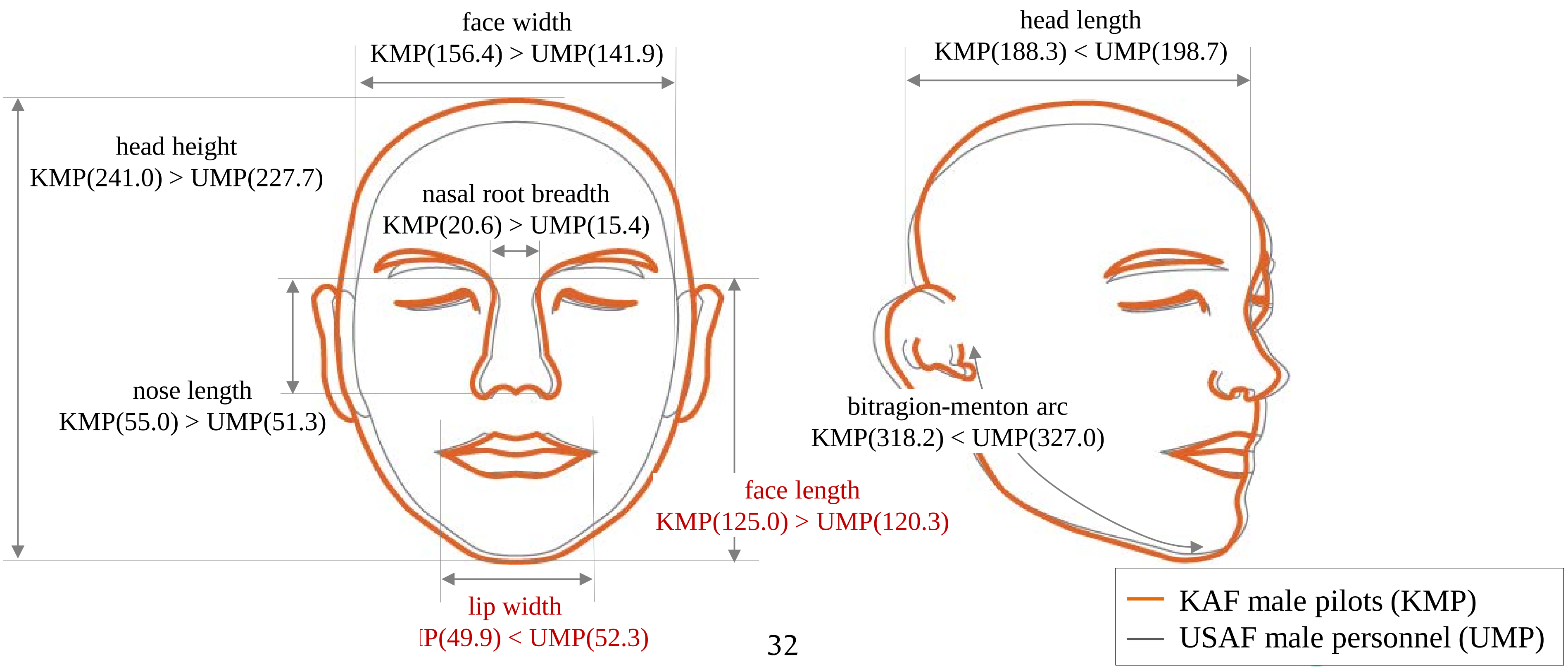


Korean Male Pilots (KMP) vs. USAF Male Personnel (UMP)

2011 KAF 3D facial anthropometric data (Lee et al., in press) 1967-1968 USAF facial anthropometric data

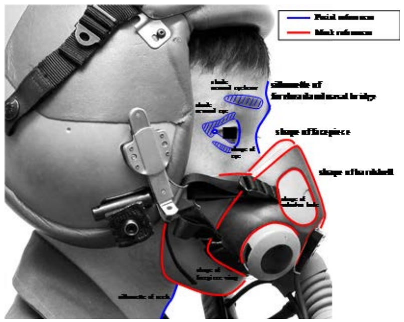
- **Mean** - Lengths: KMP > UMP ($\bar{d}$ = 1.0 ~ 13.3 mm)
  - Widths: KMP > UMP ($\bar{d}$ = 3.1 ~ 14.7 mm)
  - Nasal root breadth: KMP > UMP ($\bar{d}$ = 5.2 mm) ⇒ high pressure

⇒ **The size and designs of OM need to be custom designed to KAF pilots**

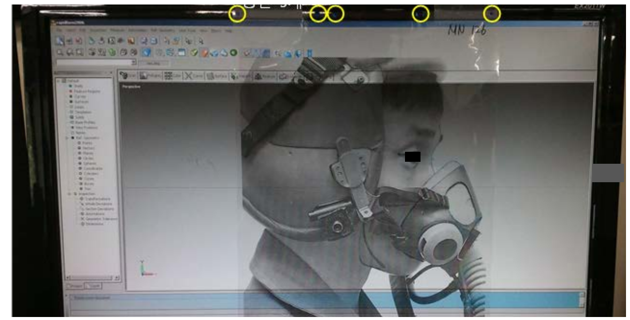


OM Wearing Characteristics Analysis

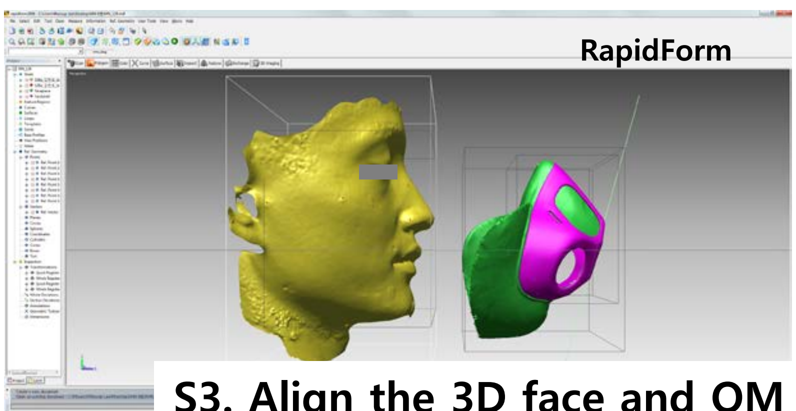
- Analyzed **OM wearing characteristics** using **photos of pilots wearing OM and 3D scan data of pilots**

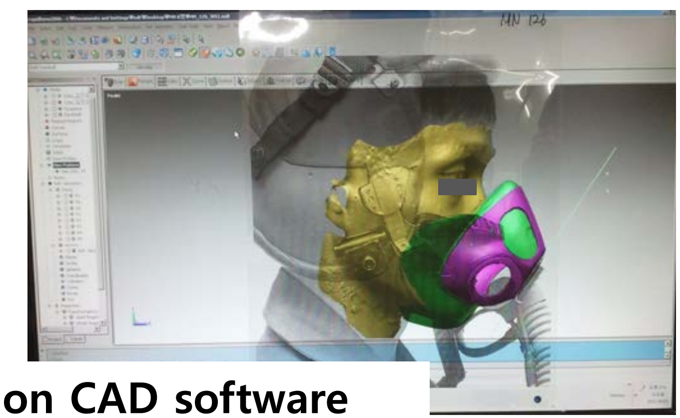


S1. Mark key features of the face & OM on a photo of a pilot wearing OM



S2. Attach the photo film to a monitor

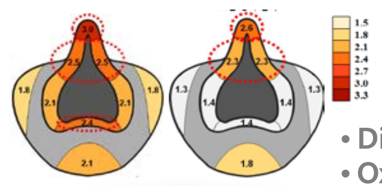




S3. Align the 3D face and OM on CAD software with those on the photo by referring to the marked features

Correlation Analysis Between FMI Factors

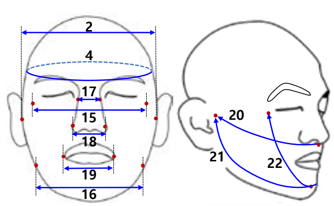
- **Analyzed the correlation between facial characteristics, OM wearing characteristics, and user preferences**
- **Identified characteristics highly related to the OM design by considering correlation coefficient (*r*), *p*-value, and plot**
  - Highly correlated: $r \geq 0.7$
  - Normally correlated: $0.4 \leq r < 0.7$
  - Lowly correlated: $r < 0.4$



User Preferences

- Discomfort
- Oxygen leaking
- Mic-lip clearance

Face



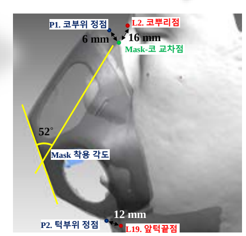
Facial Anthropometric Characteristics

- 22 facial dimensions

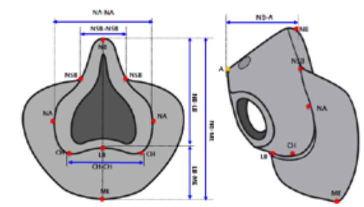
Interface

OM Wearing Characteristics

- Wear position
- Wear angle
- Clearance
- Fitness



Mask

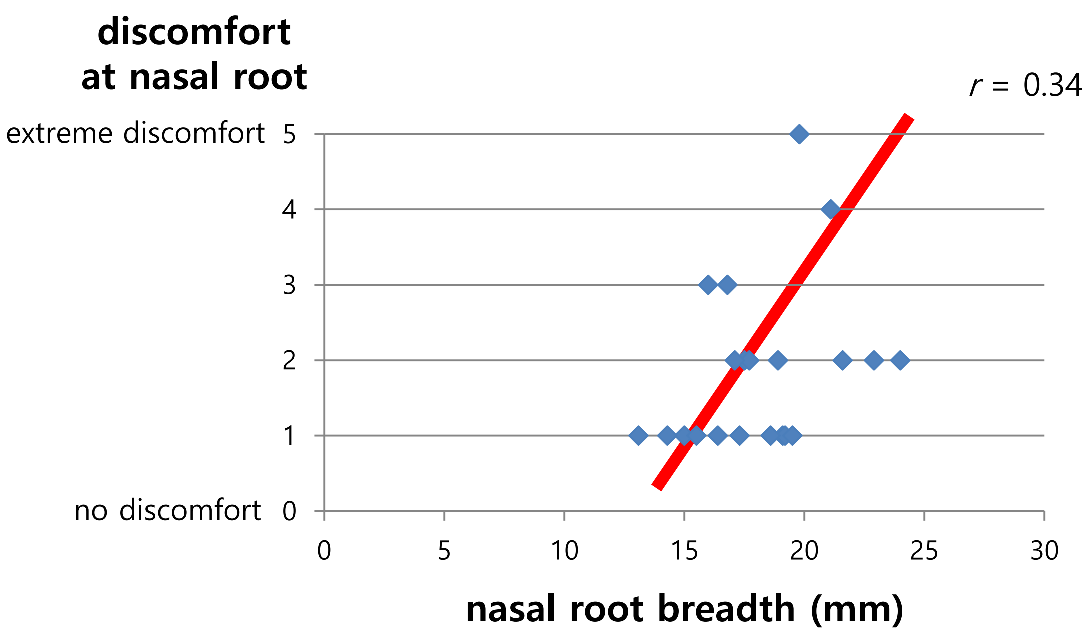


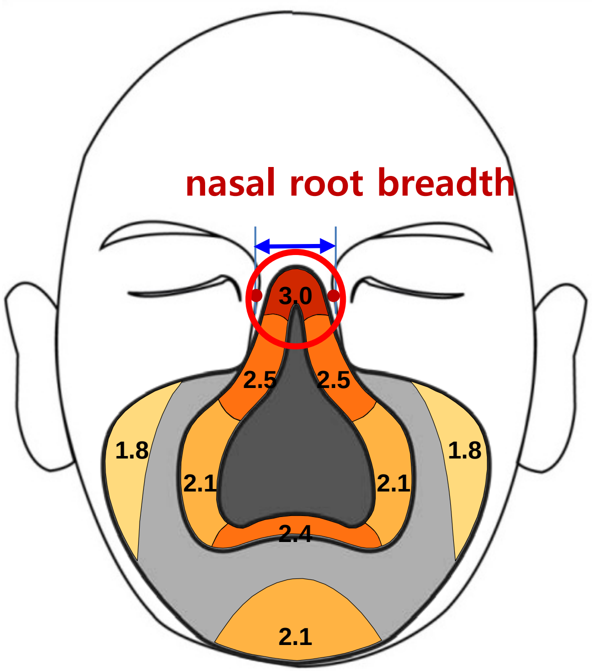
Mask Design Dimensions

OM Design Strategies: Nasal Width

- Wider nasal root breadth (↑) ⇒ higher discomfort at nose (↑)

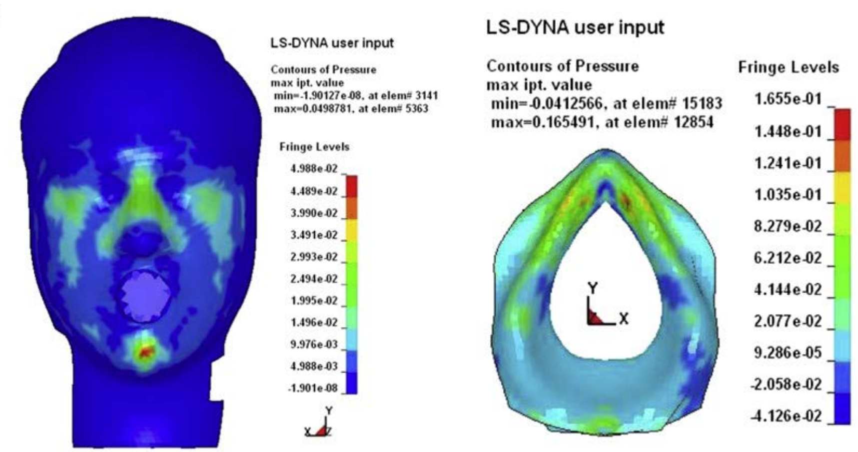
⇒ Application to OM design: Widen the nasal area of OM (5 mm) considering the difference of nasal root breadth between KAF pilots (20.6 mm) and USAF personnel (15.4 mm)



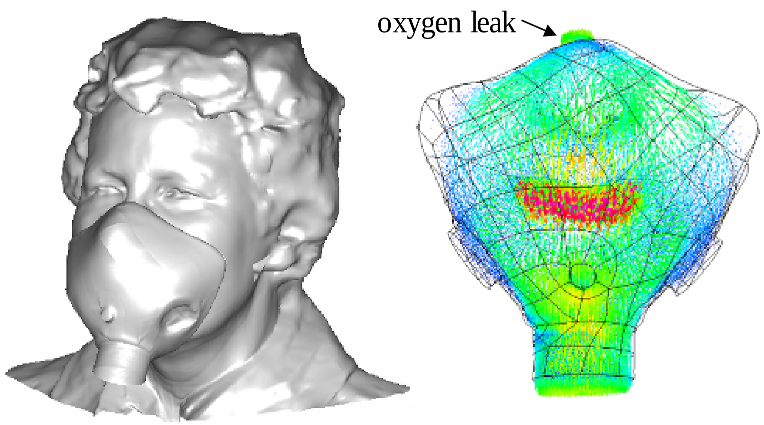


Discussion (3/3)

- **Improve the VFA system considering material properties of face and mask by referring to previous research on mask fit based on finite element method** (Butler, 2009; Yang et al., 2009; Dai et al., 2011; Lei et al., 2012)
- **Improved VFA method can be validated by comparing to pressure measurements**
- **Results of the improved VFA can be more accurately applied to design OM**



Analysis of pressure between face and mask (Dai et al., 2011)



Analysis of air flow in mask (Butler, 2009)