



# 3D Scan to Product Design: Methods, Techniques, and Cases



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- **Discussion**



# S1. Establishment of 3D Scan Images

## Heads and faces

**Korean Air Force pilot**  
( $N = 336$ )



**oxygen mask**



**N95 mask**

**CAESAR North American**  
( $N = 2,299$ )



**head-related products**

**Dutch children**  
( $N = 307$ )



**medical mask**

## Ear

**Korean and Caucasian** ( $N = 296$ )



**earphones**

## Body (torso)

**Size Korea elderly woman** ( $N = 271$ )



**hip protector**

# Korean Air Force Pilots

$N = 336$

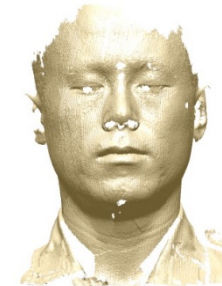
- Rexcan 560 (2006; Solutionix, South Korea), white light projection scanner
  - ✓ High resolution
  - ✓ Required a dark room
  - ✓ Time consumed for processing
- Edited, measured, then compared to US Air Force facial measurements
- For pilot oxygen mask design



**3D scanned images**  
(>15 min/person)



**image alignment**



**merging**



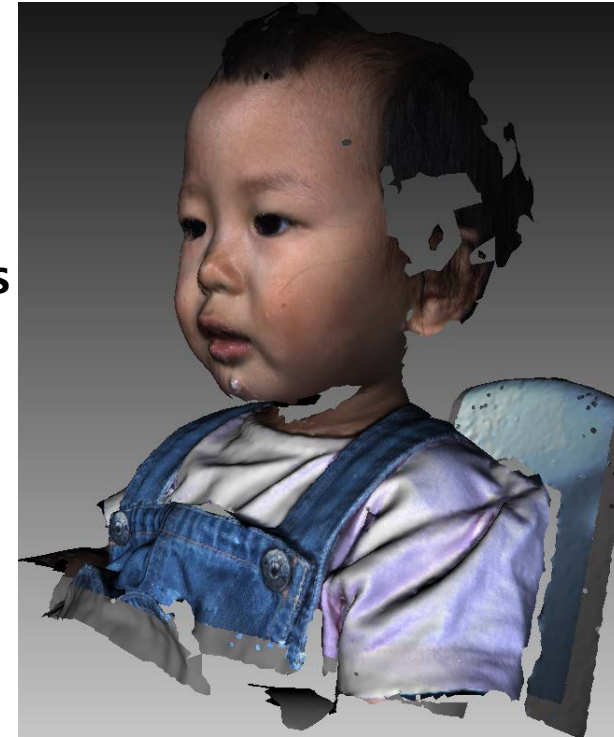
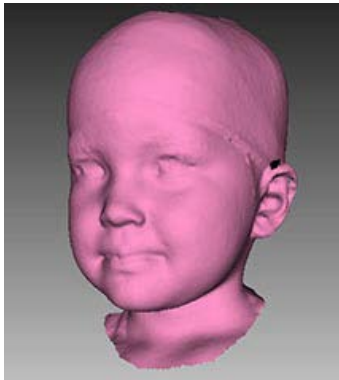
**data editing**

(>60 min/person)

# Dutch Children

$N = 307$

- Applied 3dMD face scanner
  - ✓ Very fast (<1s)
  - ✓ Colored
- Merged and edited by Artec Studio
- Identified landmarks by 3dMD software
- Measured and analyzed by MATLAB
- Compared to existing children facial measurements by statistic tools
- For medical mask design for Dutch children



<http://www.tudelft.nl/en/current/latest-news/article/detail/tu-delft-ontwerpt-beademingsmaskers-voor-kinderen-met-spierziekten/>

Lỳe Goto & prof. Johan Molenbroek

# Ear Scanning

$N = 296$

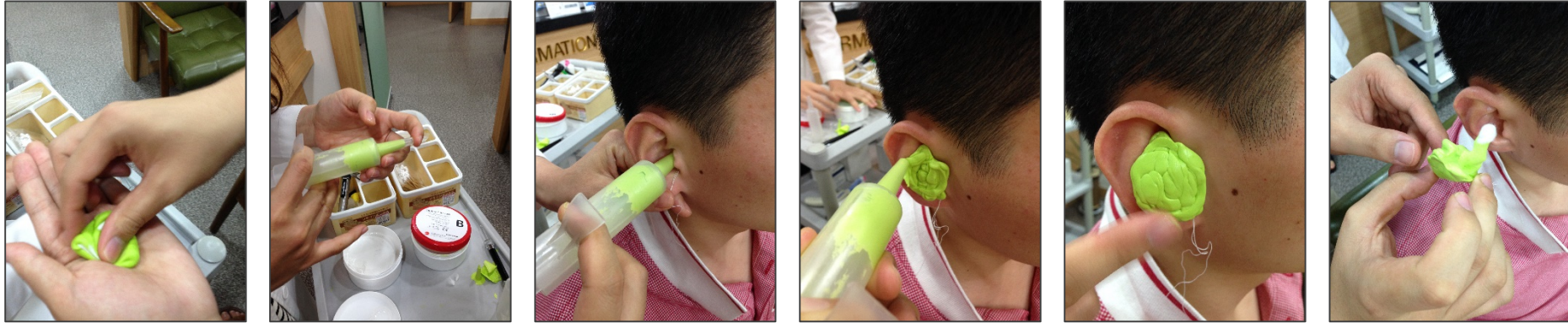
- Artec Eva scanner



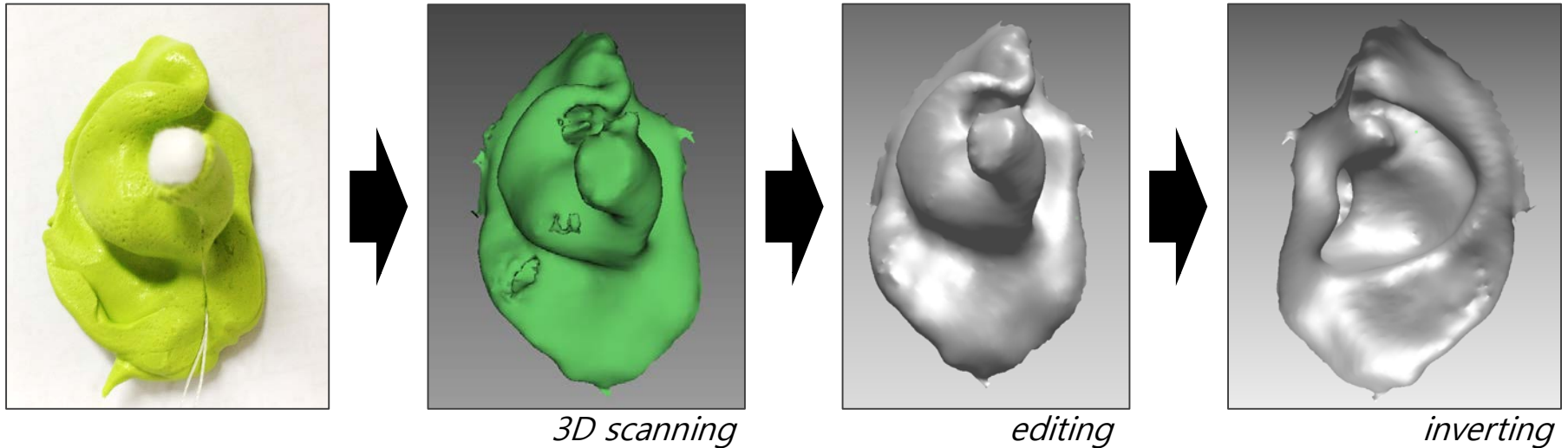
# Ear Casting & Scanning

$N = 296$

- Casting concha & ear canal (<5 min)



- 3D scanning of cast (20 ~ 40 min)

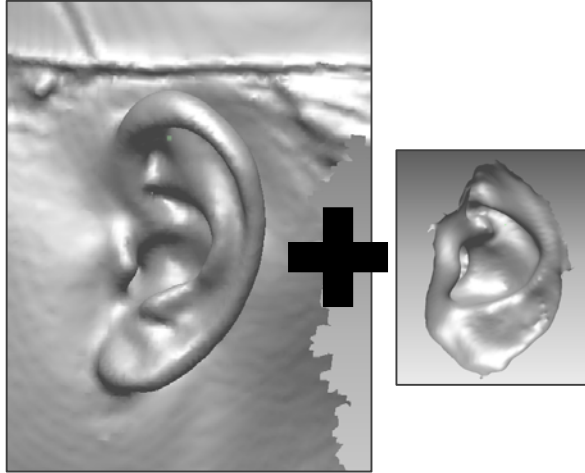




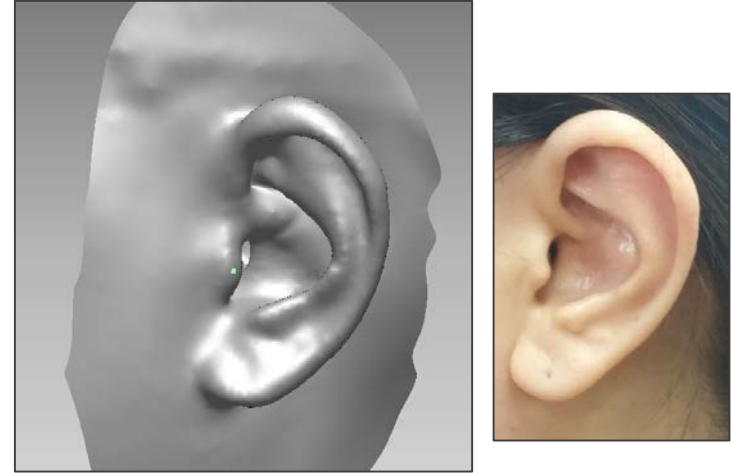
# Detailed 3D Ear

$N = 296$

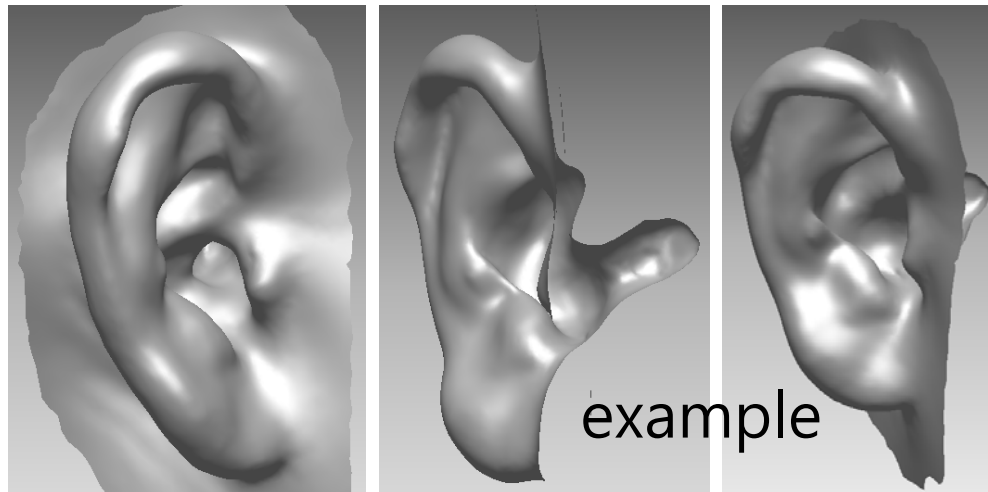
Overall ear + concha/ear canal part



Merged ear



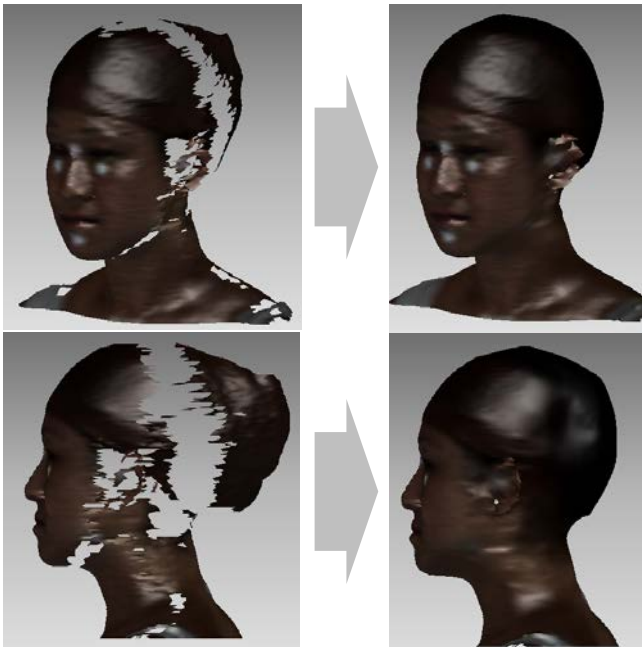
200 Koreans & 96 Caucasians (aged 20~50s, 1:1 gender ratio)



# Manual Editing of Existing 3D Scan DB

- Hole-filling
- Smoothing/Defeaturing
- Rotation/Alignment

CAESAR heads ( $N = 2,299$ )  
for head product designs



(processing time: 260h)

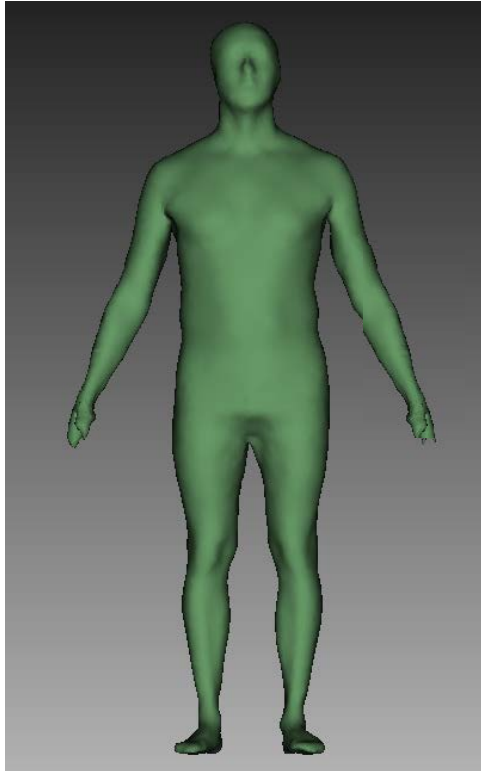
- Elimination of unnatural features
  - hair style,
  - beard,
  - clothes, etc.

Size Korea elderly woman ( $N = 271$ )  
for hip protector design



# Automatic Editing by Template Fitting (on-going)

**Template 3D model**  
(**automatically edited**)



**Target 3D image**  
(**required to be edited**)



- **Features of template model**

- Automatic landmark identification
- Automatic measurement & feature extraction
- Calculation of area/volume of body parts
- Posture change

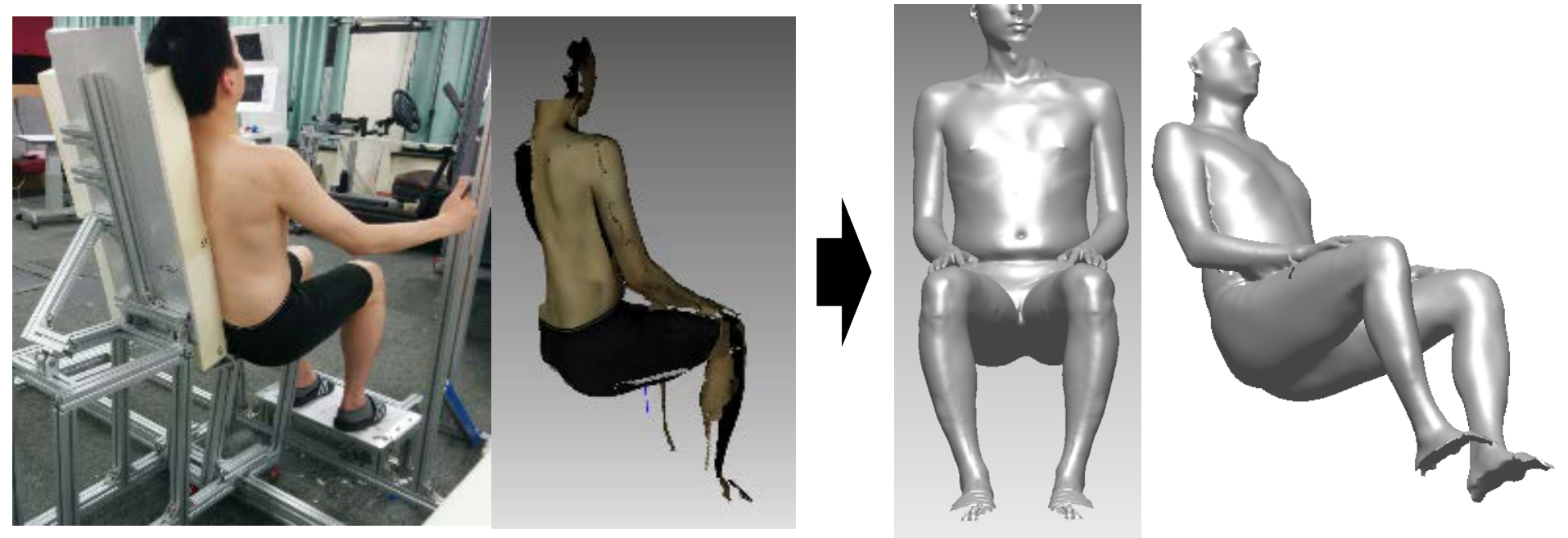


- **Applications**

- Design considered skin deformation
- Pressure estimation
- Parametric design

# Specialized Scans: Seated Posture

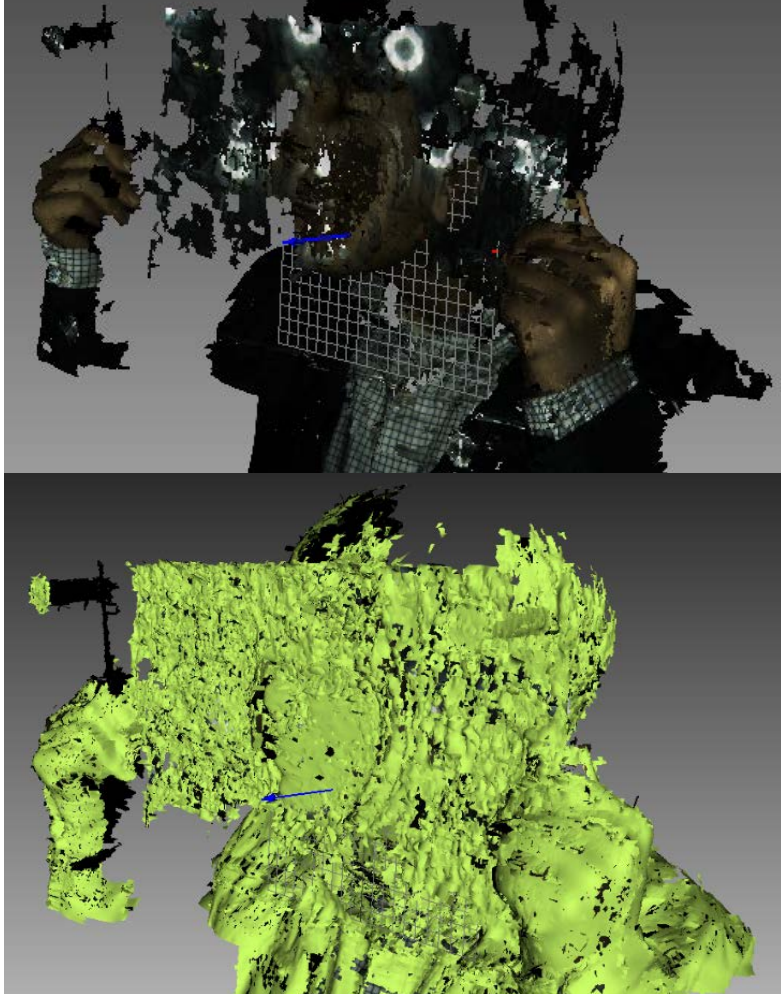
- Developed specialized equipment for scanning
- Scanned left and right side separately, then merged (Artec)



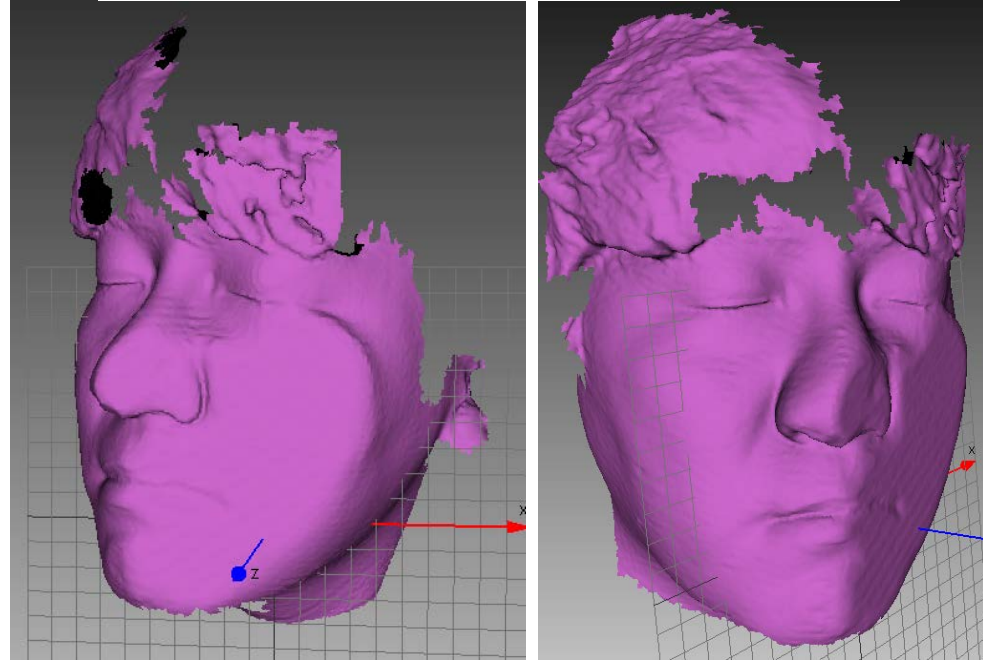
# Specialized Scans: Deformed Skin

- 3D scanning for **skin deformation** study (Artec)

scanning through glass pushing face

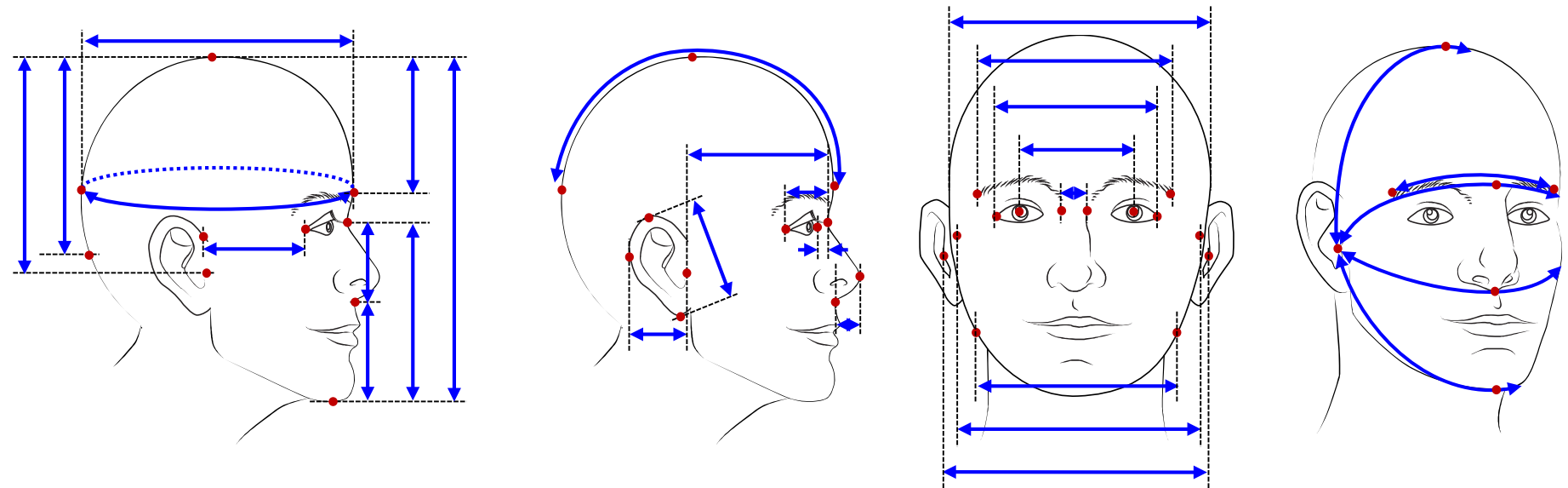


noise filtering & editing



## S2. Anthropometric Dimensions: Head and Face

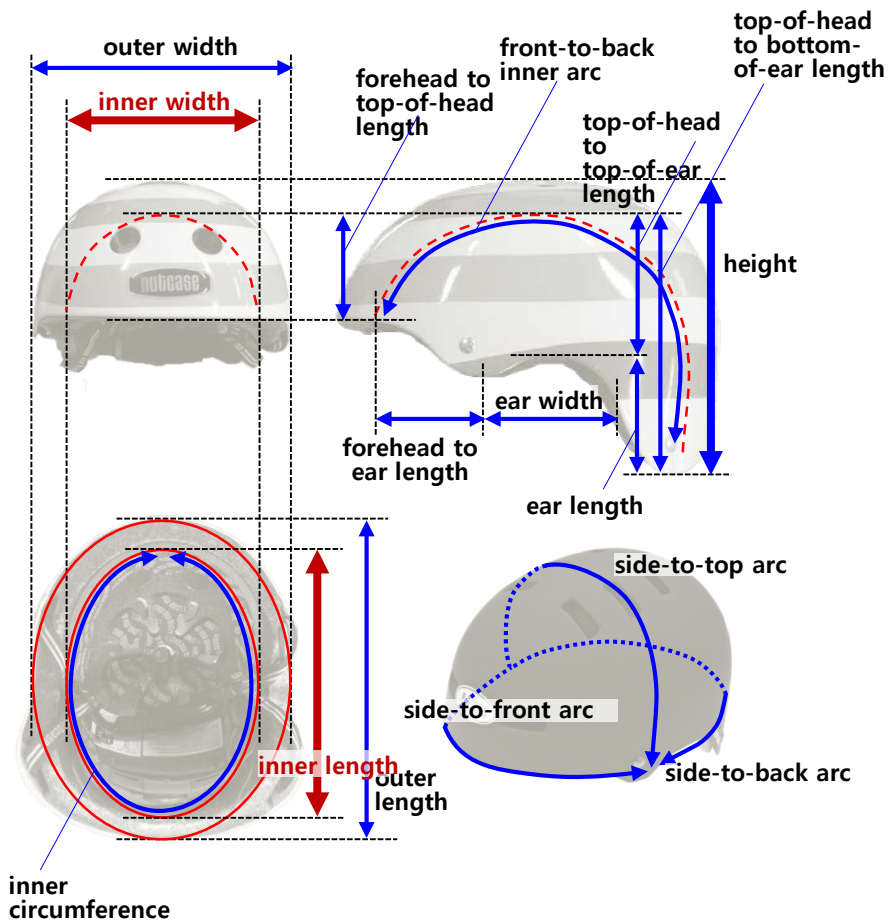
- Identified **122 head dimensions** by referring to 18 previous studies
  - ✓ Length dimensions: 53
  - ✓ Depth dimensions: 29
  - ✓ Width dimensions: 18
  - ✓ Circumference/arc dimensions: 22
- Selected dimensions related to product design
- Identified **new dimensions** based on existing facial landmarks



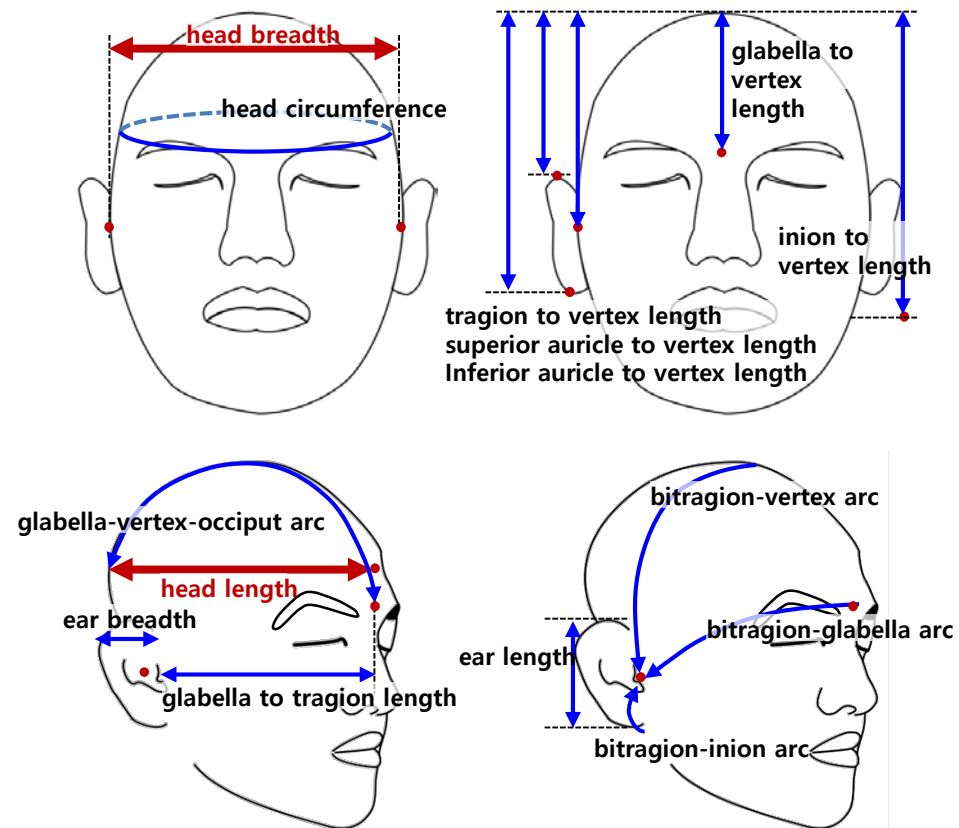
# Selection of Anthropometric Dimensions: Helmet

- By analysis of **design dimensions** and **related head dimensions**

Design dimensions (16)



Head dimensions (18)

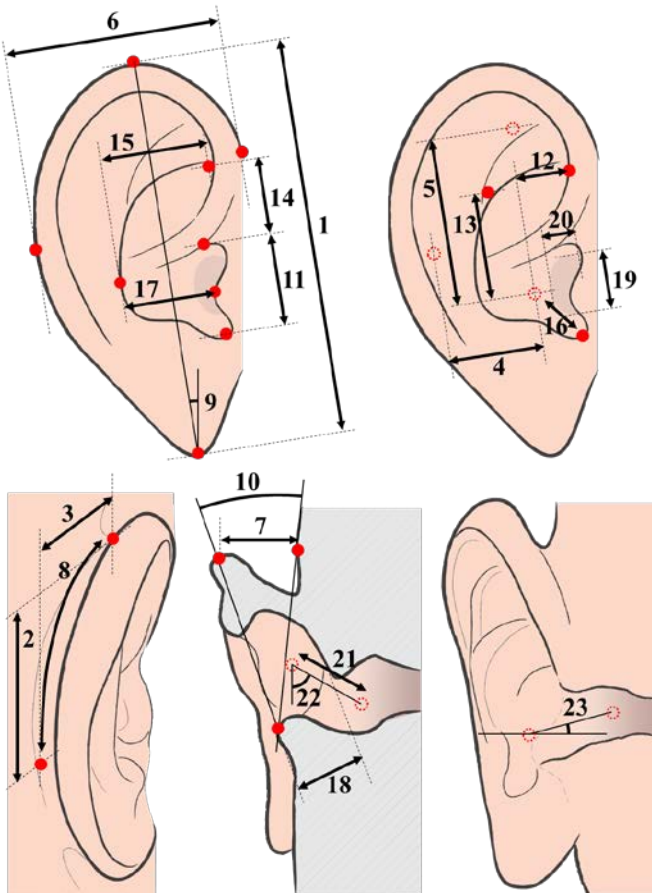


red: key dimensions

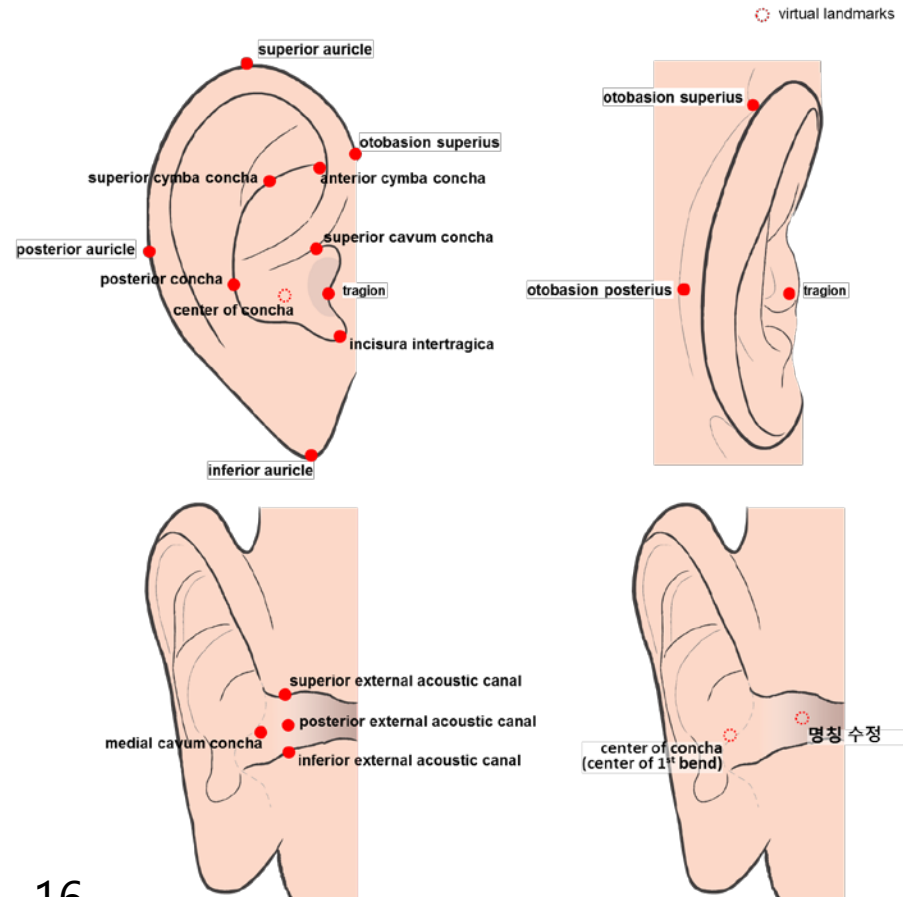
# Anthropometric Dimensions: Ear

- Identified **22 ear dimensions** by referring to 15 previous studies
- Proposed additional **14 ear dimensions** for **earphone design**

Ear dimensions for earphone design



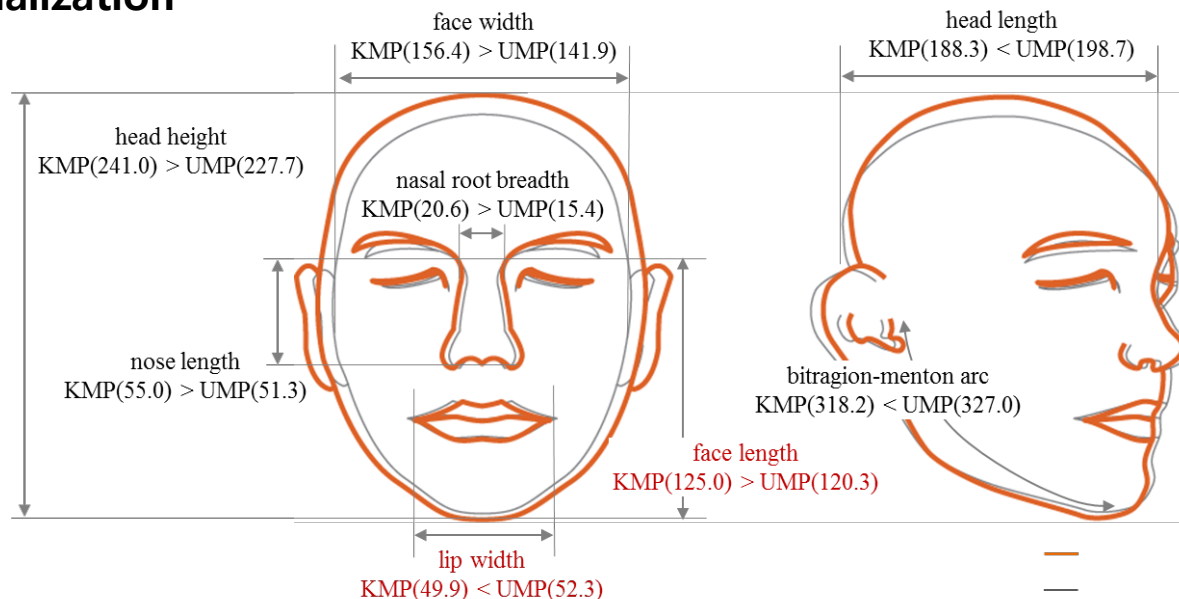
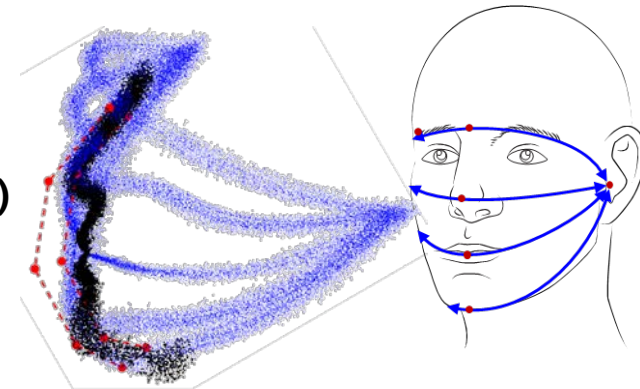
Related ear landmarks





# Measurement & Comparison

- Automatic measurement & analysis by an in-house software developed using MATLAB
  - Automatic alignment
  - Landmark classification
  - Measurement (dimensions, curvature, area, volume)
  - Shape analysis (e.g., curvature extraction)
  - Comparison of measurement
  - Visualization



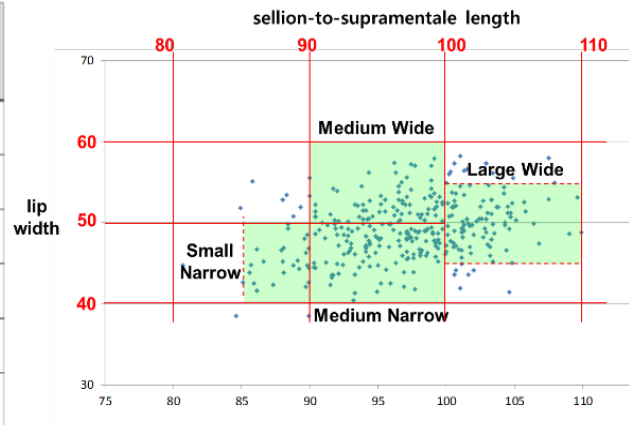
Korean Air Force pilots vs. US Air Force personnel

# S3. Sizing System

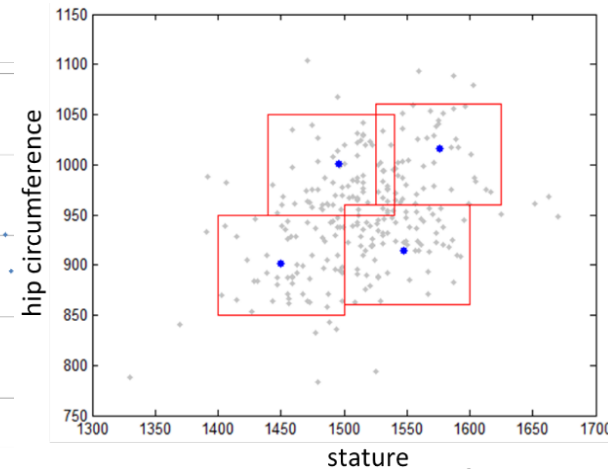
- Statistic-based sizing system generation

Stature	Small < 168	Medium < 173	Large < 178	Special < 183	Special large < 190
85 (82.5~87.4)	0.9 %	3.2 %	2.1 %		
90 (87.5~92.4)	1.6 %	7.2 %	8.1 %	2.9 %	
95 (92.5~97.4)	1.9 %	10.1 %	12.2 %	5.5 %	1.1 %
100 (97.5~102.4)	0.9 %	5.3 %	10.8 %	6.8 %	2.1 %
105 (102.5~107.4)		2.2 %	4.2 %	3.5 %	1.2 %
110 (107.5~112.4)			1.5 %	1.2 %	

Korean Air Force pilots  
flight suit (23 sizes)



Air Force pilot oxygen  
mask (4 sizes)

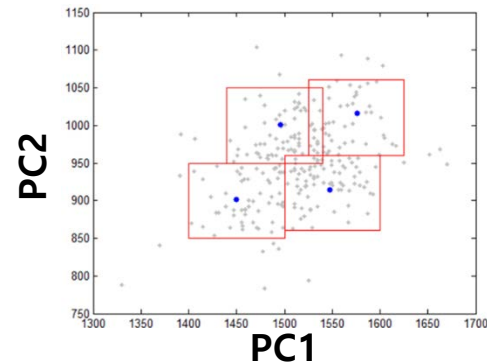
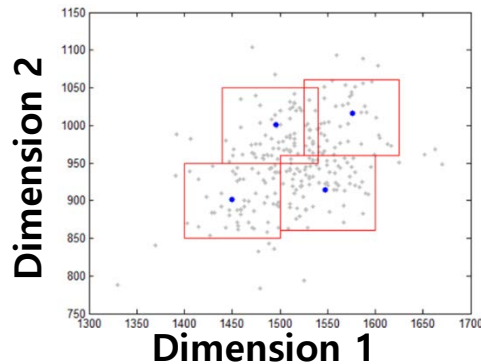


hip protector for  
Korean elders (4 sizes)

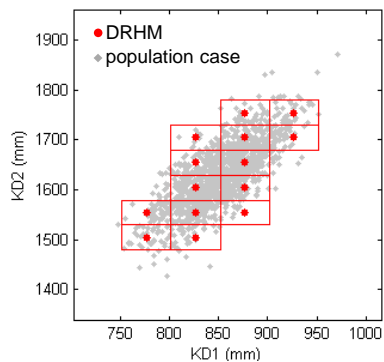
# Considerations for Sizing System Generation

- **Key dimensions selection** method

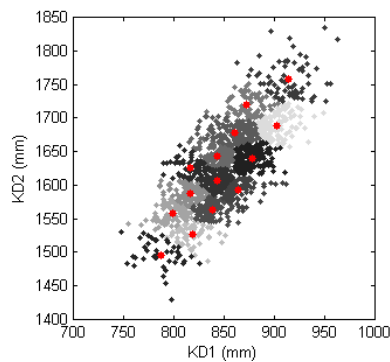
- Selection by designer
- Selection through statistical analysis (e.g., factor analysis, PCA, regression)



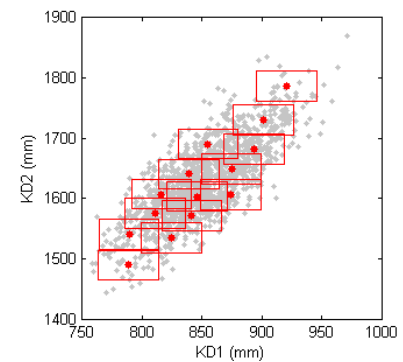
- **Grid formation** method



**Lattice method**  
(traditional method  
for apparel design)



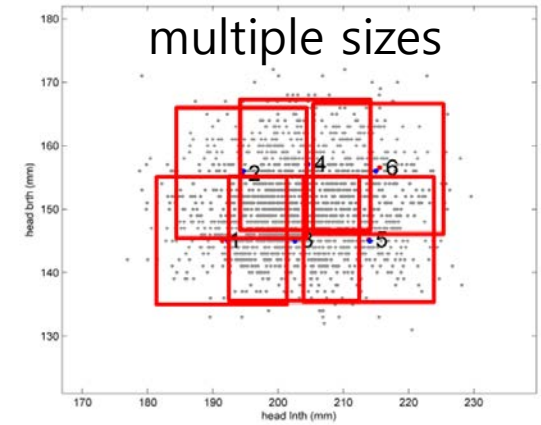
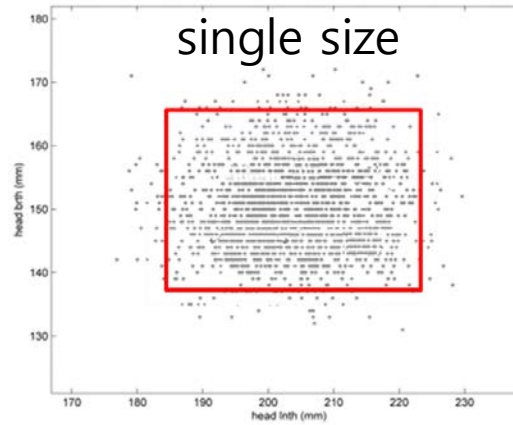
**clustering method**  
(Laing et al., 1999)



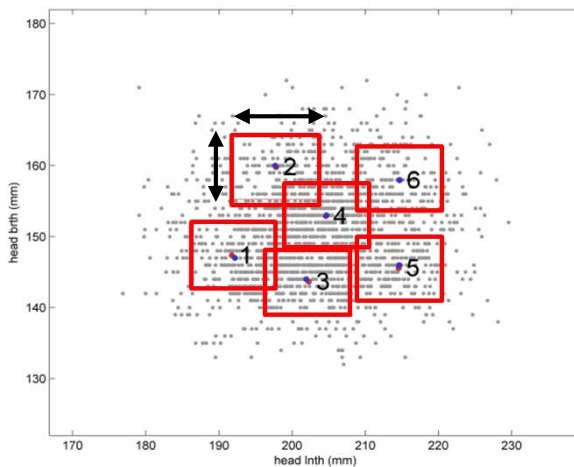
**optimization method**  
(McCulloch et al., 1998)

# Considerations for Sizing System Generation (cont'd)

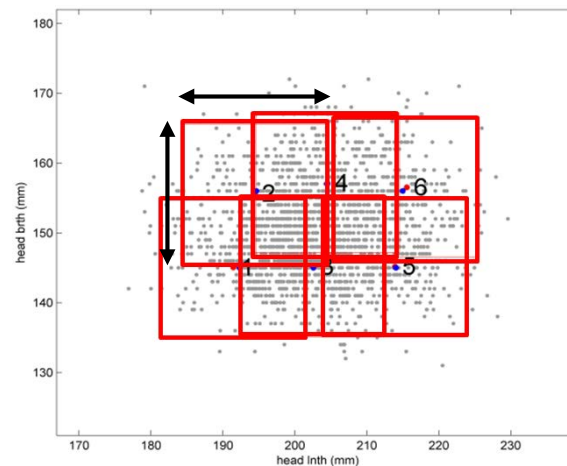
- **Number of size categories**



- **Accommodation** percentage
- **Tolerance** of each category (static product vs. flexible/adjustable product)



20



# Computerized Program for Sizing System Analysis

- To make **statistical analyses easy and simple**

**1 Target Population Characterization**

Database: **US Army (1988)**

Gender: Male, Female, Composite (%)

Age: Number of Age Groups: **2**

Ages: 10s, 20s, 30s, 40s

Ratio (%): **60** / **40**

**2 Anthropometric Variable Selection**

Selection

**3 Key Dimension Selection**

Analysis-Based | User-Defined

Regression Analysis (RA) | Factor Analysis (FA) | Principal Component Analysis (PCA)

**4 Grid Formation**

Lattice (Robinette and Annis, 1986) | Clustering (Laing et al., 1999) | Optimization (McCulloch et al., 1998)

**5 DRHM Determination**

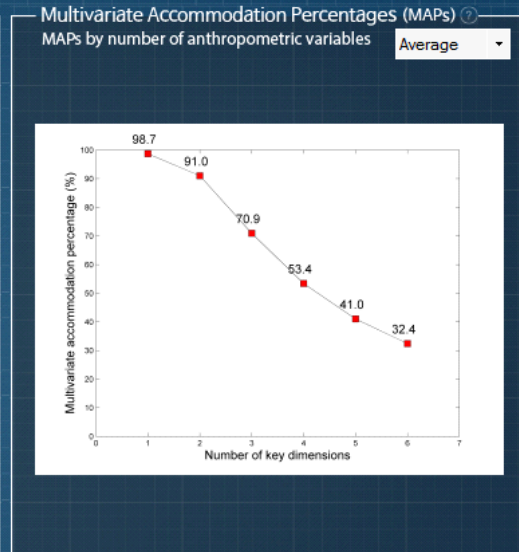
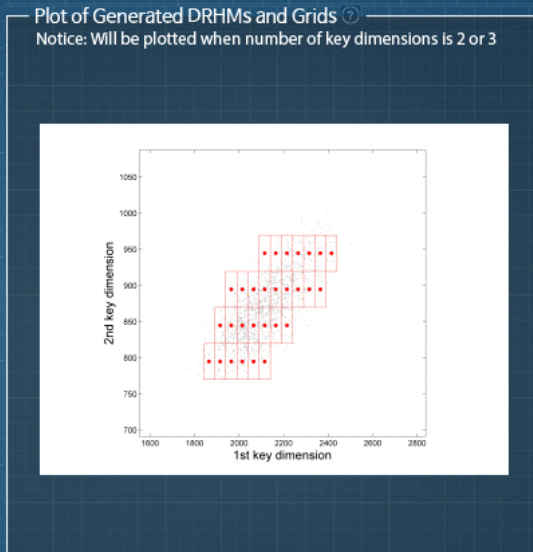
Estimated Case | Real Case

Generation | Initialization | Exit

Accommodation Percentage for key dimensions

**95.4 %**

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**Generated DRHMs**

Body Sizes of DRHMs (Number of DRHMs: 29, Number of target anthropometric Variables: 6)

No.	Overhe...	Sitting ...	Buttoc...	Overhe...	Overhe...	Stature
1	2114.7	944.9	828.4	2211.8	1389.3	1716.3
2	2364.7	894.9	967.1	2457.2	1489.3	1812.4
3	1864.7	794.9	762.3	1952.7	1212.4	1493.4
4	1964.7	894.9	774.2	2059.1	1298.5	1608.0
5	2414.7	944.9	973.0	2510.4	1532.3	1869.6
6	2114.7	794.9	882.9	2201.6	1331.6	1621.2
7	2164.7	944.9	852.5	2261.6	1413.1	1741.9
8	2314.7	894.9	943.0	2407.5	1465.4	1786.8
9	2314.7	944.9	924.8	2410.9	1484.6	1818.5

Sample size (n) : 1767

	Female	Male	Total
Group 1	742	318	1060
Group 2	495	212	707
Group 3	0	0	0
Group 4	0	0	0
Total	1237	530	1767

Statistical Information

Regression Equation

FA or PCA Loadings and Scores

# Development of 3D Anthropometric Sizing Analysis System

- Simplified version of sizing analysis program for designers in SAMSUNG
- Based on CAESAR head measurements

3D Anthropometric Sizing Analysis System

**Target Product**

Helmet  
 Glasses  
 Goggles  
 HMD  
 Headband Type  
 Neckband Type  
 Necklace type

New Sizing System  
 Existing Sizing System

**Target Population**

**Ethnicity**  
 Caucasian  
 African American  
 Asian  
 Hispanic

**Gender**  
 Male  
 Female

**Age**  
 20s  18 to 19  
 30s  over 50s  
 40s  
 50s

**Sizing System**

Number of sizes:  1  2  3  4  5  6

**Key Dimension (KD) Selection**

KD 1  
 head length  
 KD 1 Modification

KD 2  
 head breadth  
 KD 2 Modification

**Sizing System for Helmet Design**

head breadth (mm)

head length (mm)

Accommodation (%) **72.0%**

**Sizing System Modification**

Modification by Each Size  
 Modification for All Sizes

x  mm

**Modification by Each Size**

Size no.	Representative Head no.	KD 1	KD 2	Range of KD1 (head length)		Range of KD2 (head breadth)	
(1)	1061	192.2	147.0	186.0	197.6	142.8	151.9
(2)	667	197.7	160.0	192.0	203.6	155.2	164.4
(3)	1908	202.0	144.0	196.5	208.1	13.91	
(4)	2744	204.7	153.0	198.8	210.5	148.3	
(5)	58	214.7	146.0	208.8	220.4	141.0	
(6)	2035	214.7	158.0	208.9	220.5	153.4	162.5

**Representative Heads**

(1) (2) (3) (4) (5) (6)

기술통계치	변수1	변수2	대표1	대표2	대표all
평균	203.6	150.5	382	59	1612
표준편차	8.9	6.9	0	0	0
최소	176.9	132.0	2585	2838	2585
최대	229.6	172.0	2439	2	629
범위	52.7	40.0	0	0	0
1퍼센타일	183.8	136.0	1167	321	1869
5퍼센타일	188.7	140.0	1556	219	1249
10퍼센타일	192.3	142.0	142	14	2359
25퍼센타일	197.7	145.0	653	15	1955
50퍼센타일	203.4	150.0	429	59	1612
75퍼센타일	209.9	155.0	1966	27	1542
90퍼센타일	215.5	160.0	1598	16	1598
95퍼센타일	218.3	163.0	1080	57	2044
99퍼센타일	223.3	167.0	1533	73	493

# User Interface: Input

The screenshot shows a multi-step user interface for generating a sizing system. It is divided into four main sections, each highlighted with a colored border and a corresponding callout:

- Target Product:** A grid of product images with radio buttons for selection. The selected product is 'Helmet'.
- Target Population:** A form with three columns: Ethnicity (Caucasian, African American, Asian, Hispanic), Gender (Male, Female), and Age (20s, 30s, 40s, 50s, 18 to 19, over 50s). All options are checked.
- Sizing System:** A row of radio buttons labeled 'Number of sizes' with values 1, 2, 3, 4, 5, and 6. The value 6 is selected.
- Key Dimension (KD) Selection:** Two sections for defining key dimensions. KD 1 is 'head length' and KD 2 is 'head breadth'. Each has a 'Modification' button and a 'Delete' button.

At the bottom, there are buttons for 'Generation of Sizing System', 'Default', and 'Exit'.

**S1. Selection of target product**

**S2. Selection of target population**

This detailed view shows the 'Target Population' section. It contains three columns of checkboxes:

- Ethnicity:**  Caucasian,  African American,  Asian,  Hispanic
- Gender:**  Male,  Female
- Age:**  20s,  30s,  40s,  50s,  18 to 19,  over 50s

**S3. Selection of number of size categories in sizing system**

This detailed view shows the 'Sizing System' section. It features a row of radio buttons labeled 'Number of sizes' with values 1, 2, 3, 4, 5, and 6. The radio button for '1' is selected.

**S4. Selection of key anthropometric dimensions**

# User Interface: Output

## Representative heads related to the sizing system

Sizing system suggested by the software

3D Anthropometric Sizing Analysis System

Sizing System for Helmet Design

head breadth (mm)

head length (mm)

Representative Heads

기술통계지	변수1	변수2	대표1	대표2	대표all
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95퍼센타일	218.3	163.0	1080	57	2044
99퍼센타일	223.3	167.0	1533	73	493

Accommodation (%)

72.0%

Sizing System Modification

Modification by Each Size

Modification for All Sizes

mm

Save Database

Save as Excel File

Save as PNG

Modification by Each Size

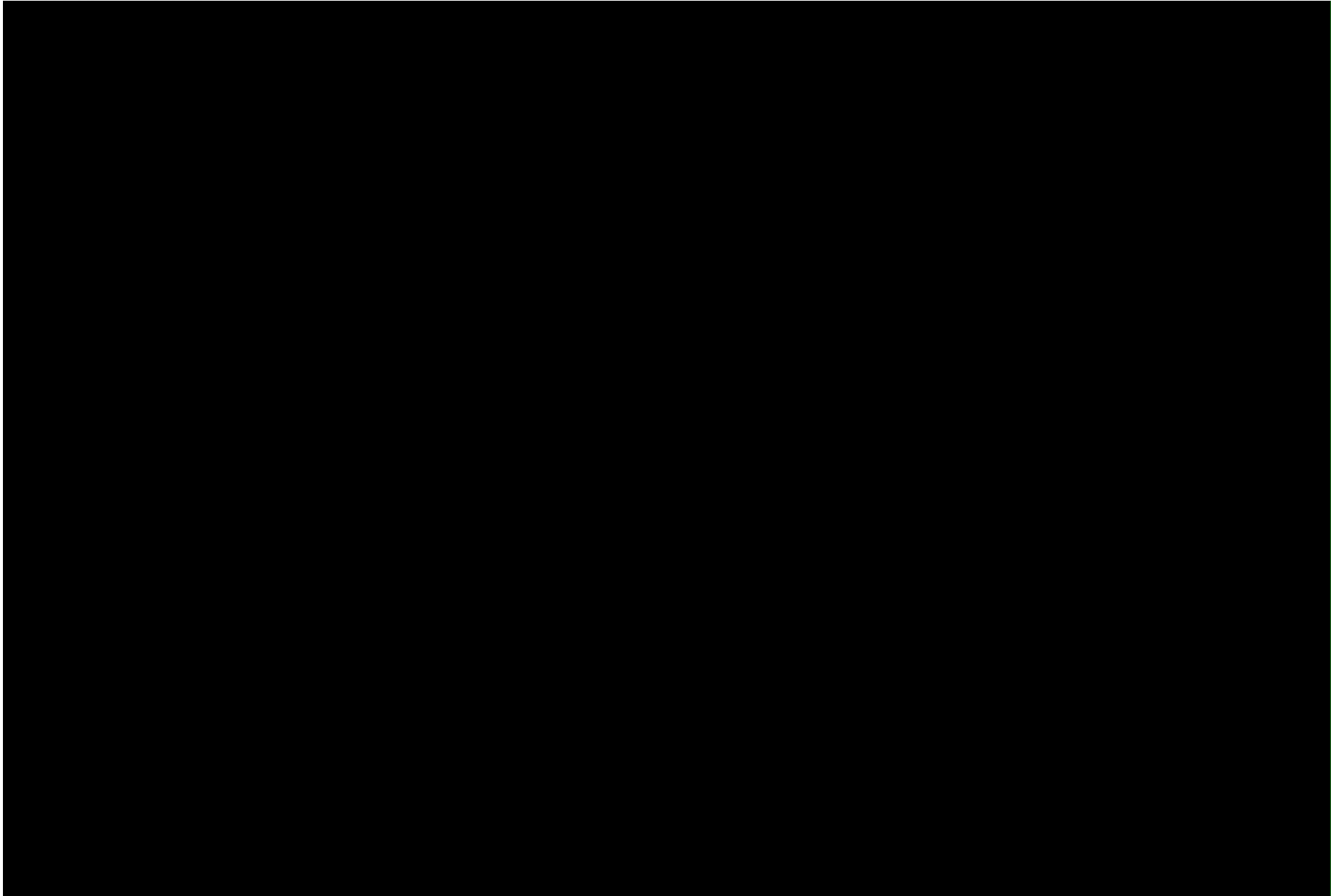
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(4)	2744	204.7	153.0	198.8	210.5	148.3	157.5
(5)	58	214.7	146.0	208.8	220.4	141.0	150.1
(6)	2035	214.7	158.0	208.9	220.5	153.4	162.5

Accommodation percentage of the generated sizing system

User interface for adjustment of the sizing system



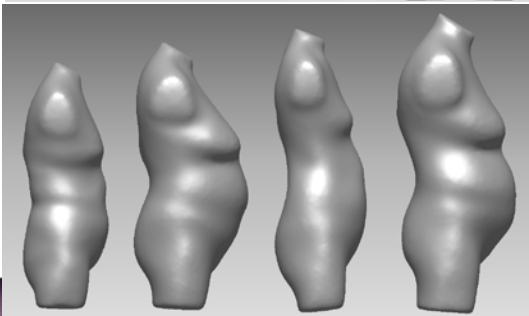
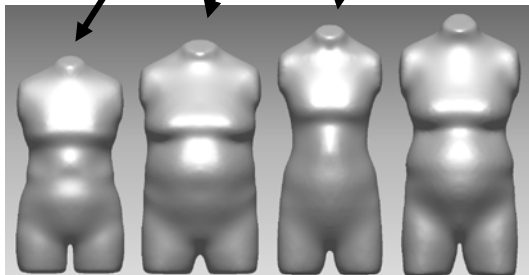
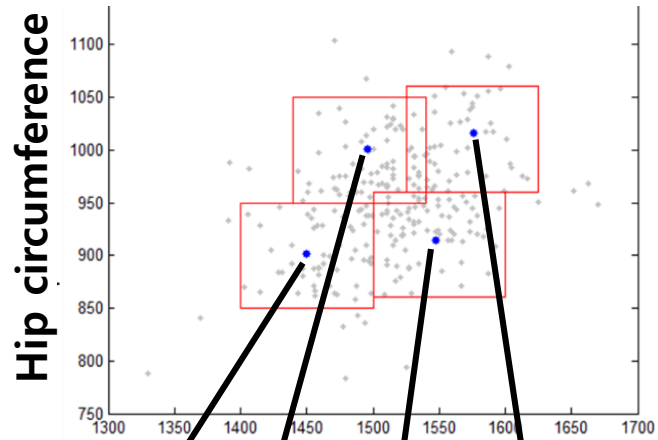
# Demonstration of 3D-ASAS



# S4. Representative Human Models (RHMs)

- Usually RHMs are **centroid of sizing system**

hip protector for Korean elders (4 sizes)

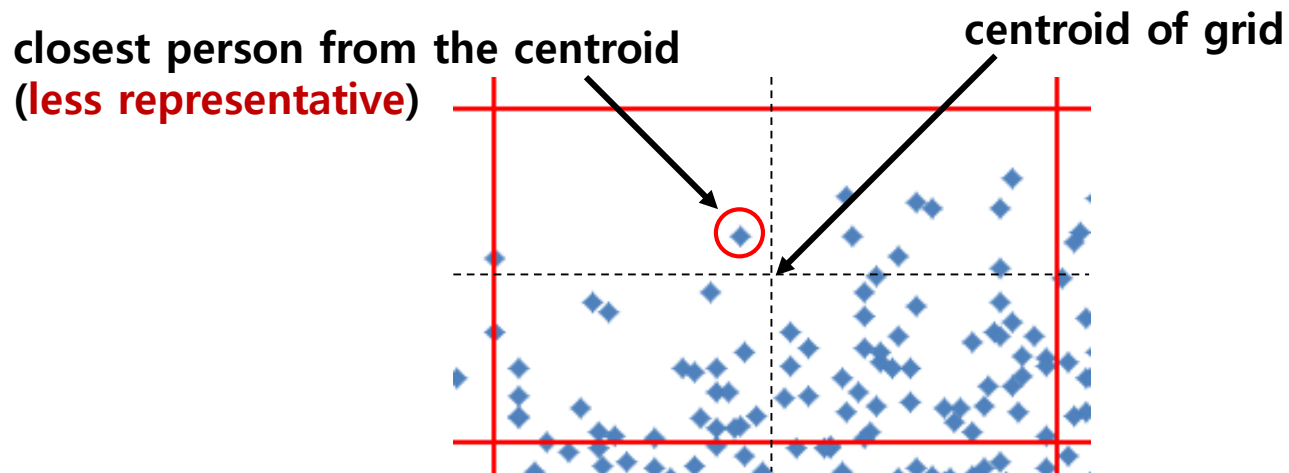


3D-ASAS

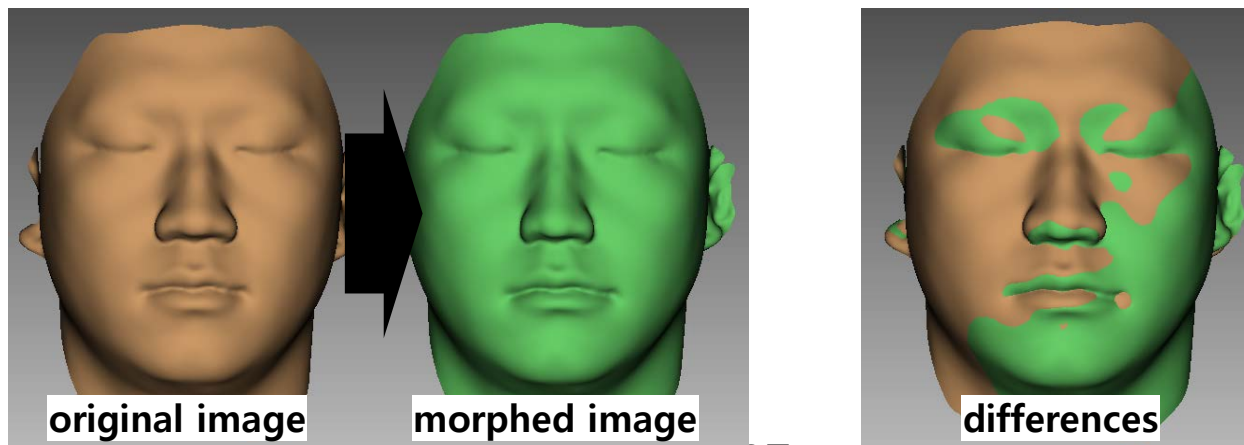
Size no.	Representative Head no.	KD 1	KD 2	Range of KD1 (head length)	Range of KD2 (head breadth)
(1)	3061	192.2	147.0	186.0	142.8
(2)	667	197.7	160.0	192.0	155.2
(3)	1908	202.0	144.0	196.5	133.9
(4)	2744	204.7	153.0	198.8	148.3
(5)	58	214.7	146.0	208.8	141.0
(6)	2035	214.7	158.0	208.0	153.4

# Improvement of Representativeness

- Representative model **can be different from centroid**



- Minor **adjustment for dimensions matching** by **morphing technique**



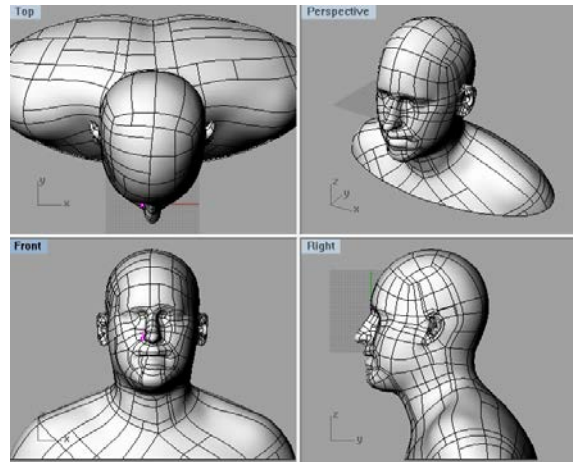
# Headforms for Head-Related Product Designs

- **Digital** and **3D-printed** headforms
- 15 general representative heads (5 ethnic group × 3 gender group)
- Developed **based on RHMs** extracted through **3D-ASAS** system

Original CAESAR scan  
(format: point cloud mesh)



Edited model  
(format: NURBS)



3D printed model



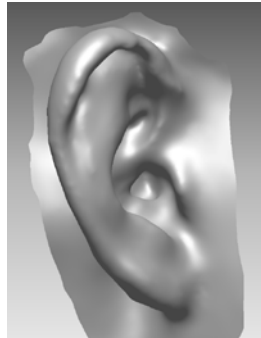
# Representative 3D Ear and Torso Models

- **Ear models** of Korean and Caucasian for earphone designs

**Smallest**  
(2.5%ile)



**Small**  
(25%ile)



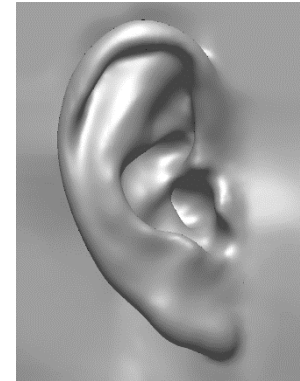
**Medium**  
(50%ile)



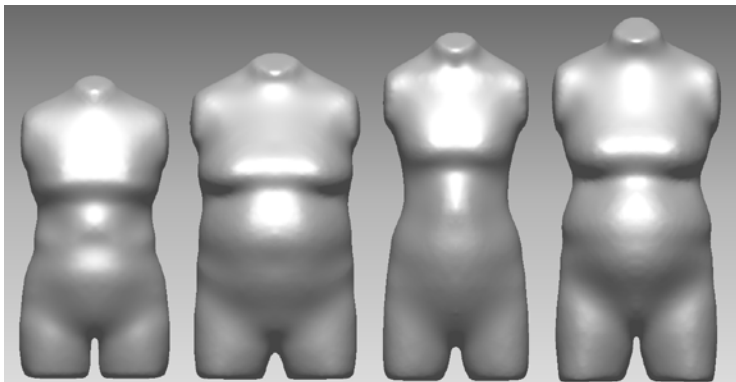
**Large**  
(75%ile)



**Largest**  
(97.5%ile)



- **Physical mannequins** of Korean elderly woman for **draping** of hip protector



# S5. Product Design Methods

## Design based on RHM/individual scans

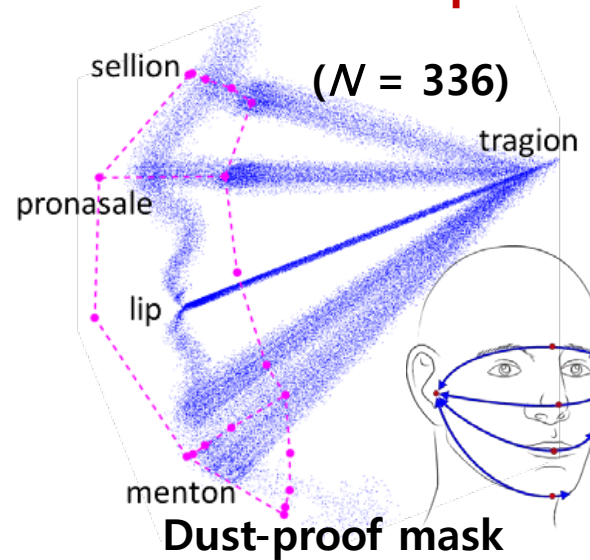


Hip protector

Earphone

- loose fit product
- adjustable/flexible product
- product with many sizes
- for less varied/simplely shaped body part
- e.g., clothes, shoes, helmet, earphone, smart watch
- traditional approach

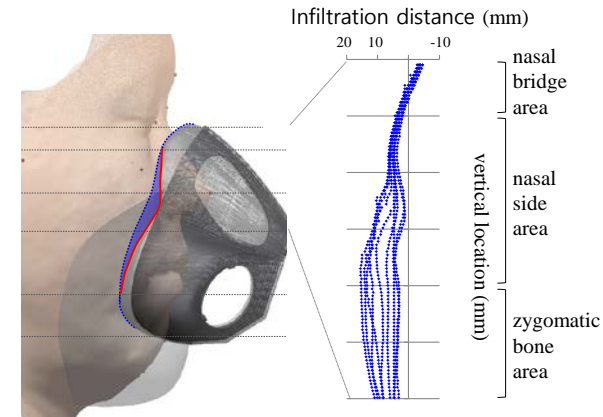
## Design based on massive 3D shapes



Dust-proof mask

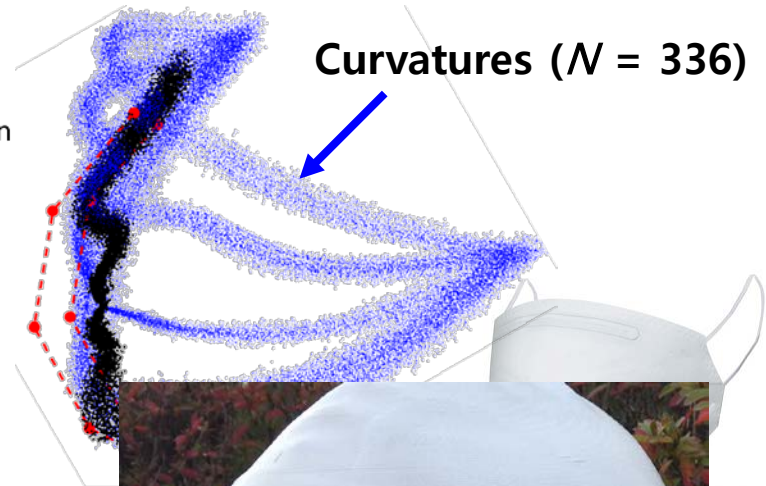
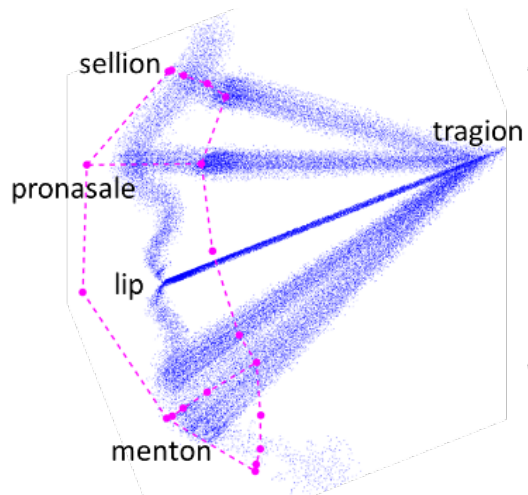
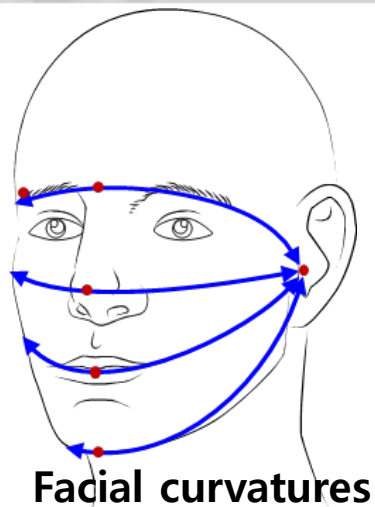
- if fit is important
- product with precise shape
- less adjustable/flexible product
- product with a few sizes
- for complexly shaped body part
- e.g., mask, car seat

## Design based on virtual fit simulation



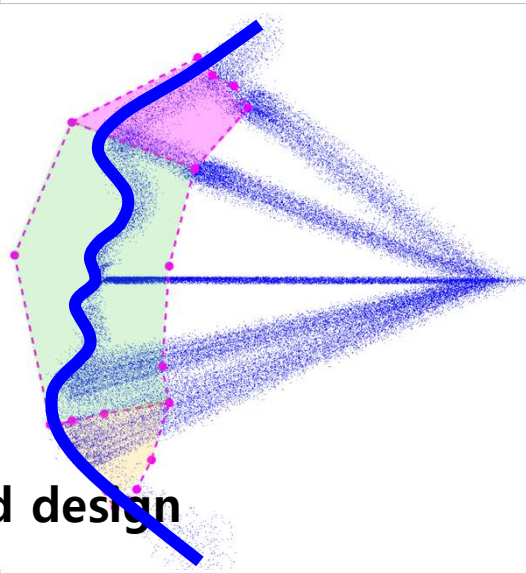
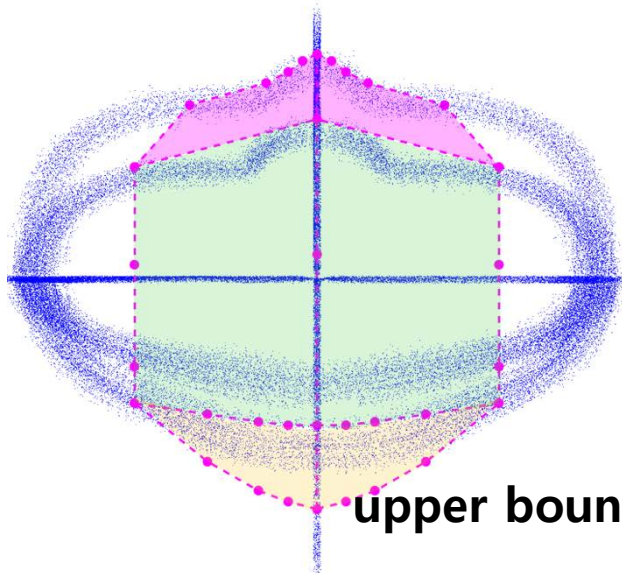
Pilot oxygen mask

# Design Based on 3D Shapes: Dust-Proof Mask

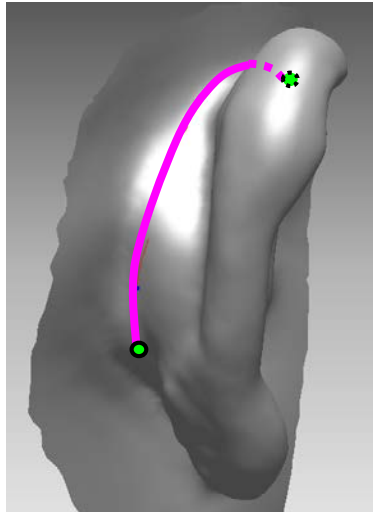


front view

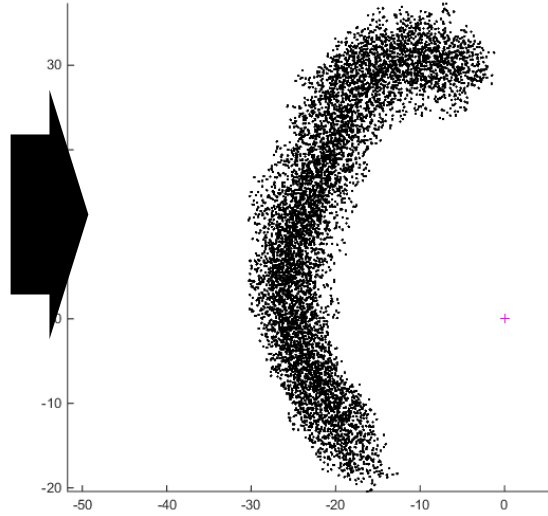
side view



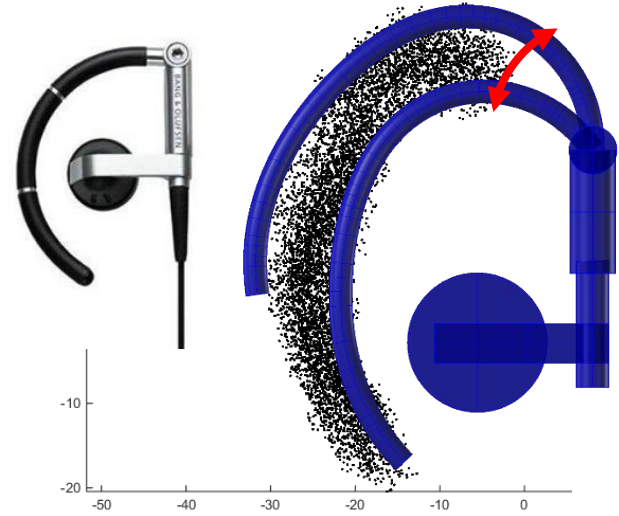
# Design Based on 3D Shapes: Earphone Components



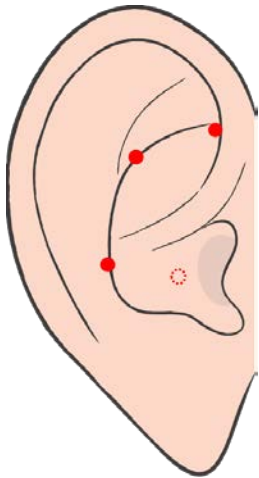
Ear root curvature



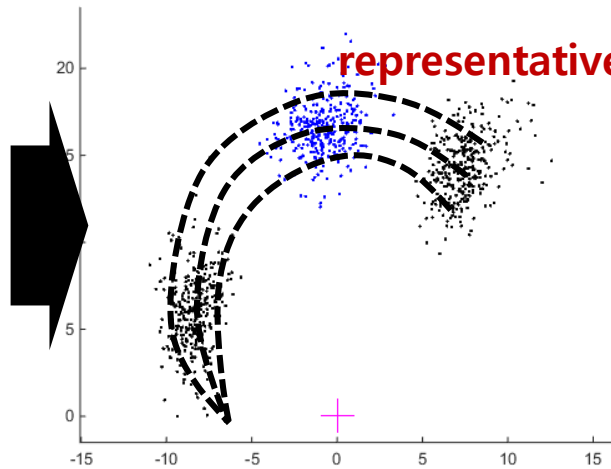
Curvatures ( $N = 296$ )



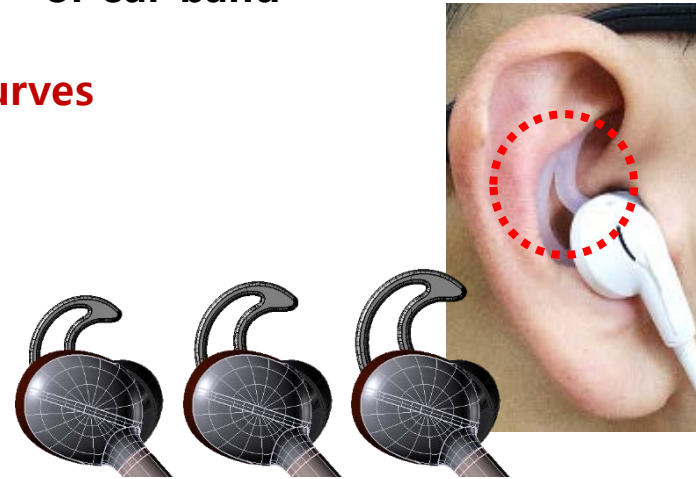
design of **adjustment range** of ear-band



Ear landmarks



Scatter plot of landmarks

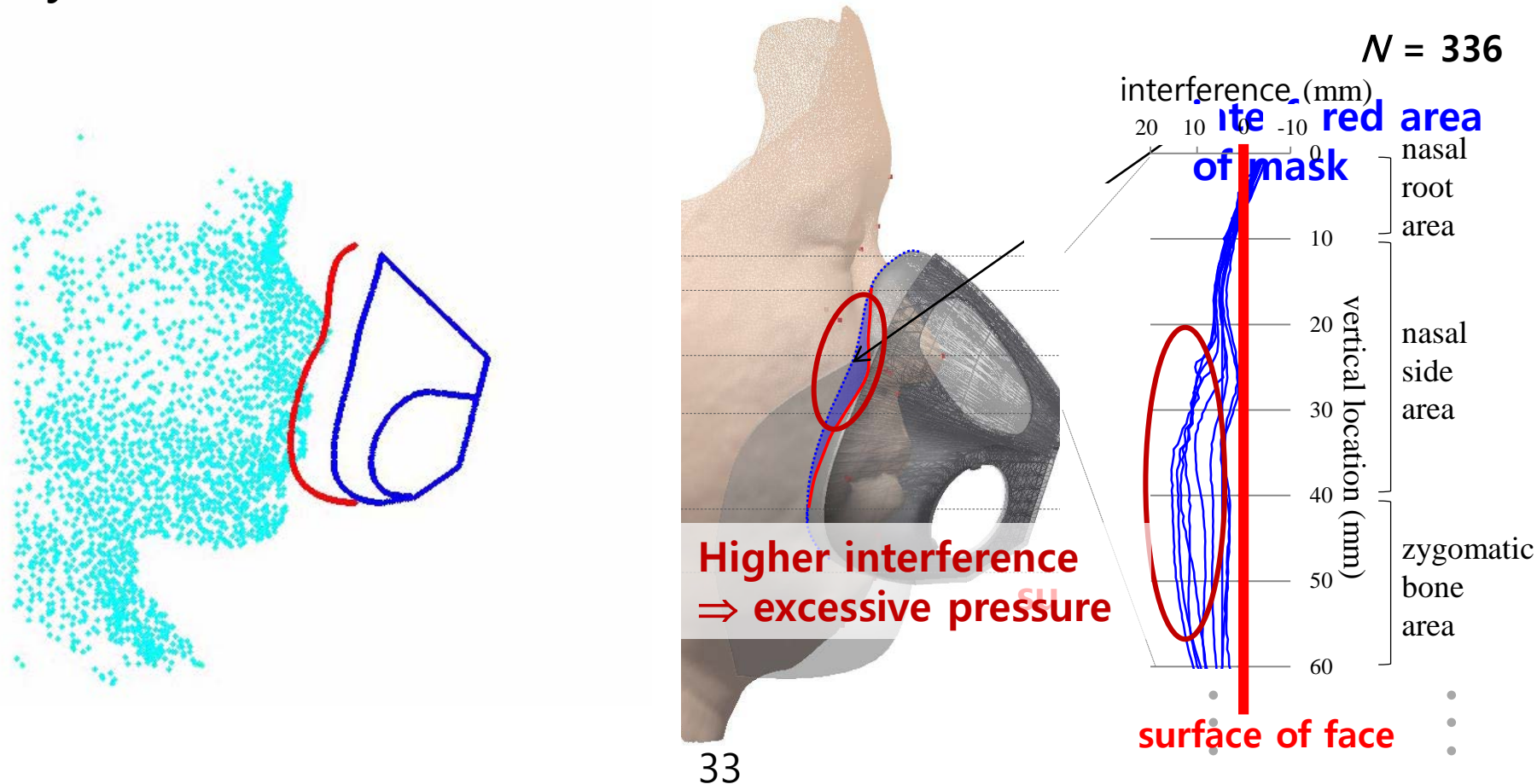


design of 3-size **earphone hook**



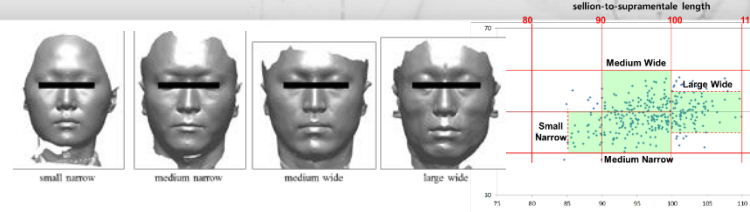
# Design Based on Virtual Fit Analysis: Pilot Oxygen Mask

- Used **various 3D face images** ( $N = 336$ ) and **simplified OM CADs**
- **Virtual alignment** and analysis
- Analyzed **interference** between face and mask



# Iterative Design Improvement Through VF

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

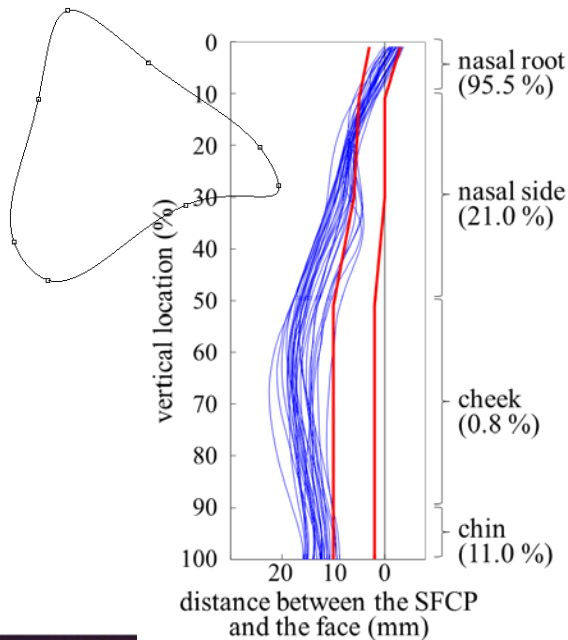


**S2. Evaluation of design appropriateness through VFA**

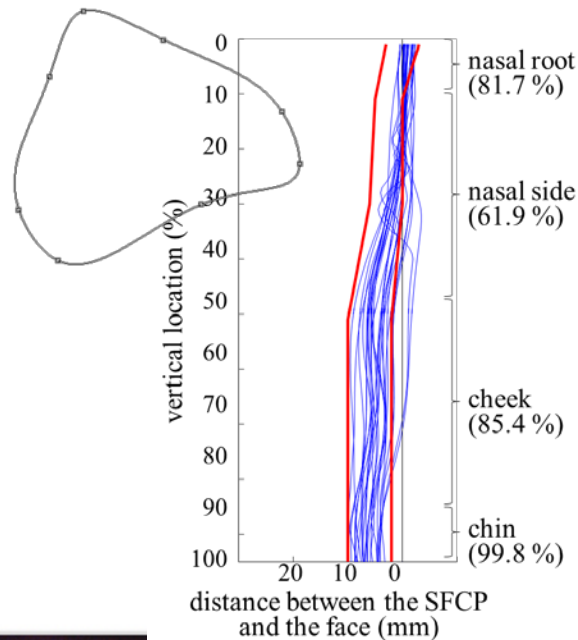
**S3. Adjustment of OM shape**

**Iteration**

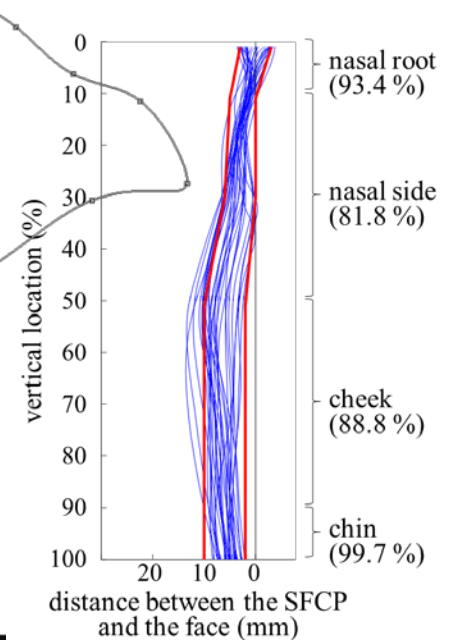
**existing design**  
(mean accommodation: 32%)



**initial design**  
(MA: 82%)



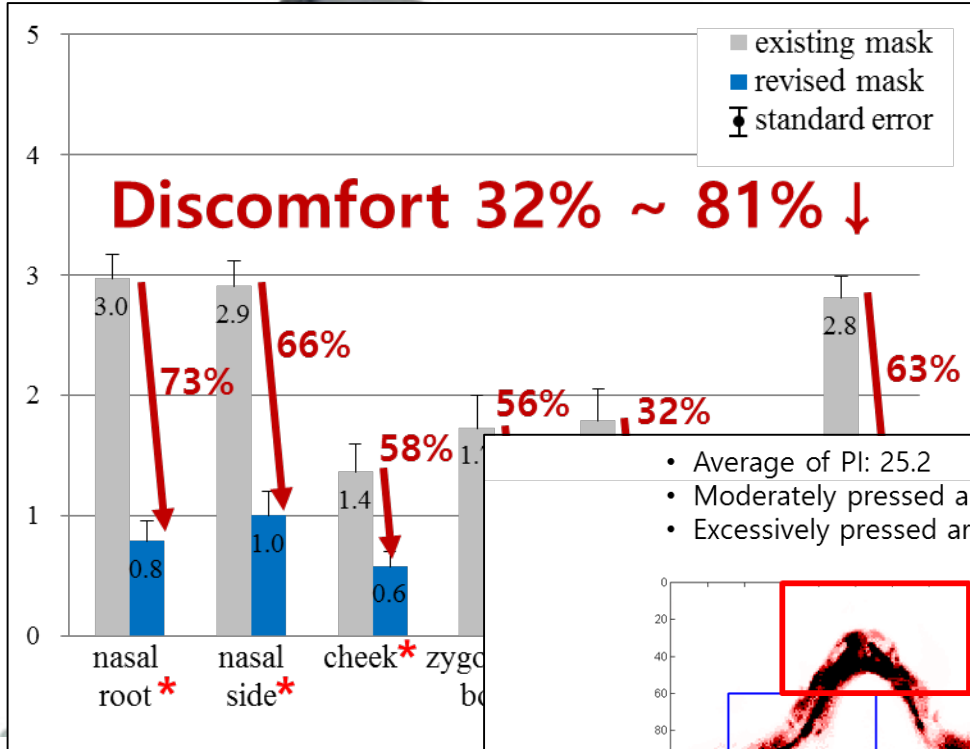
**final design**  
(MA: 91%)



# Comparison of OM Shape

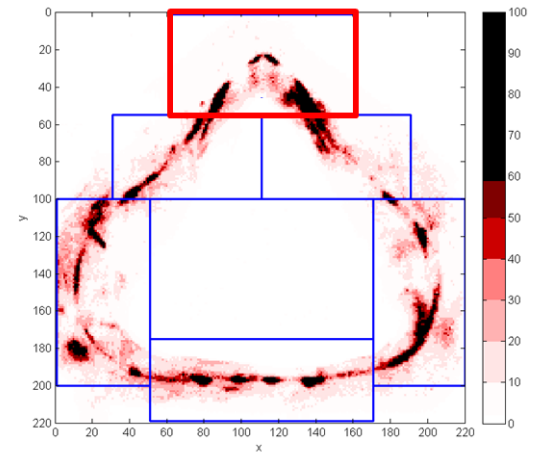
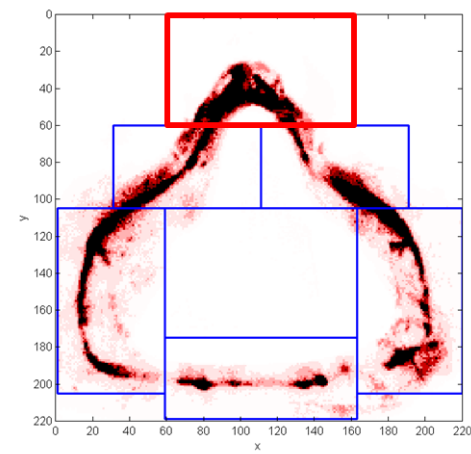
Existing mask

Revised mask



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

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



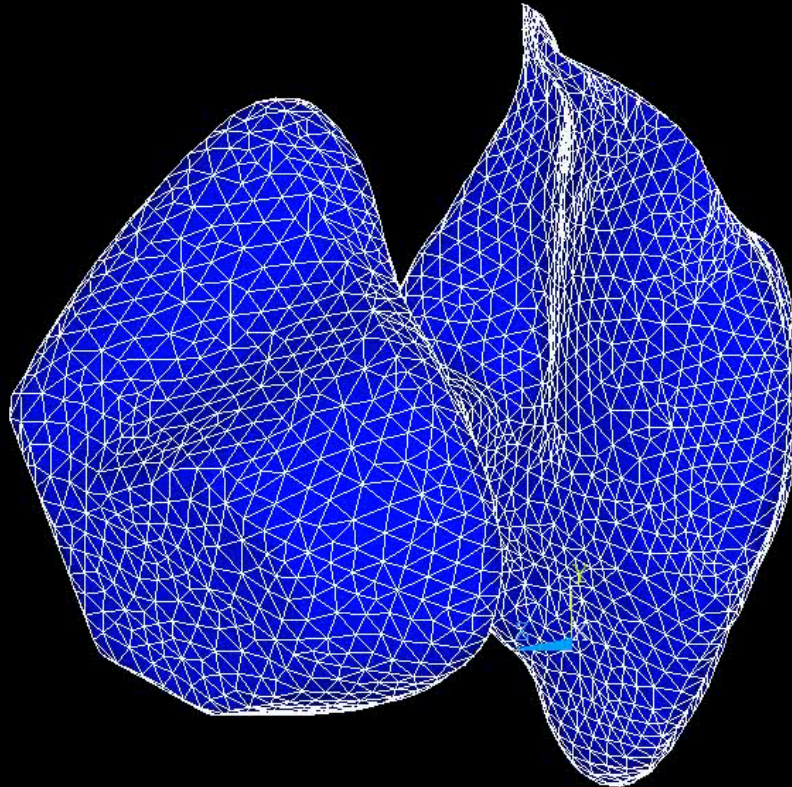
## Contact pressure evaluation using pressure film

# Pressure Estimation Based on Finite Element Analysis

1  
DISPLACEMENT  
STEP=1  
SUB =102  
TIME=1.50722  
DMX =52.7528

ANSYS  
R15.0

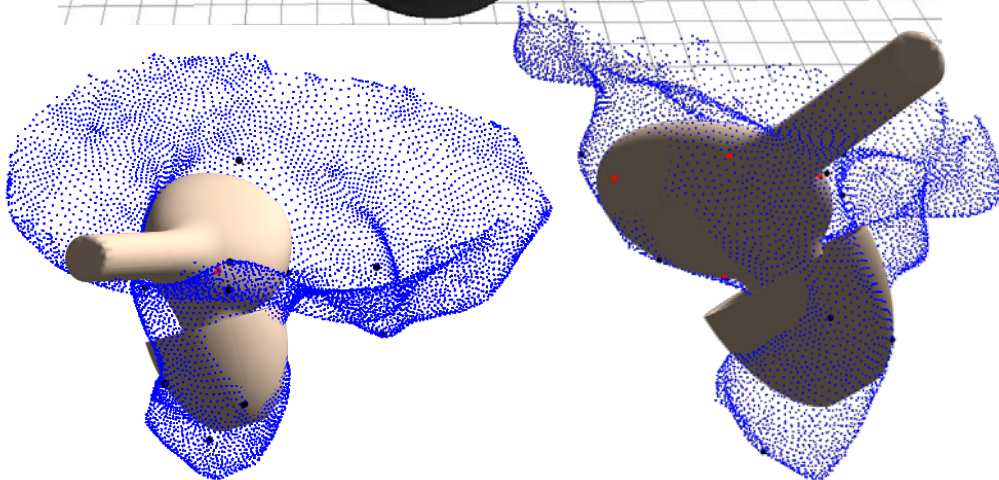
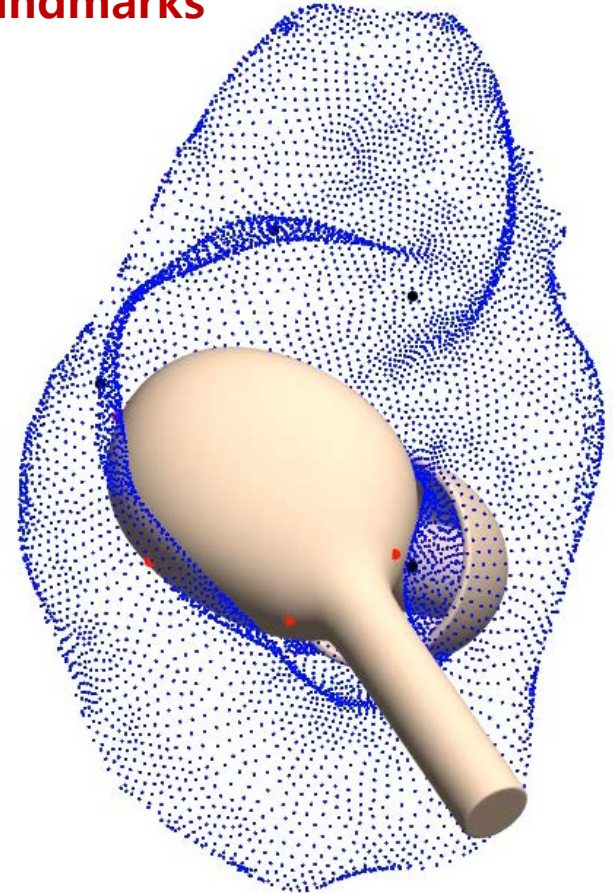
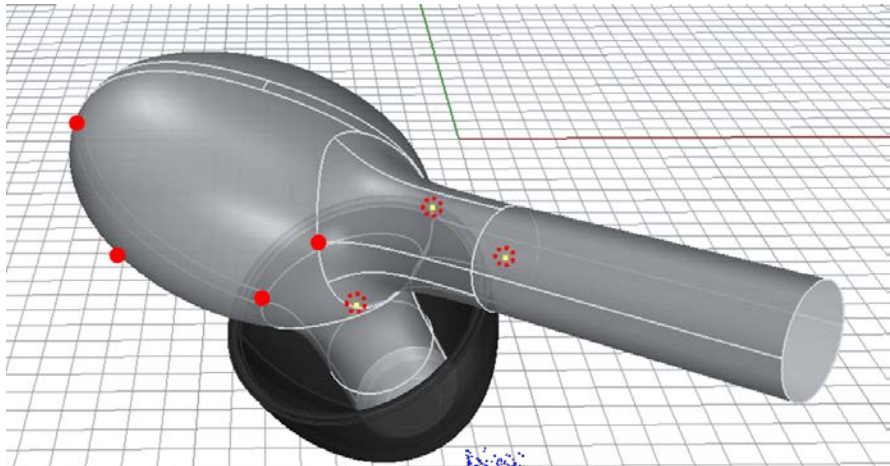
JUN 9 2015  
18:45:30



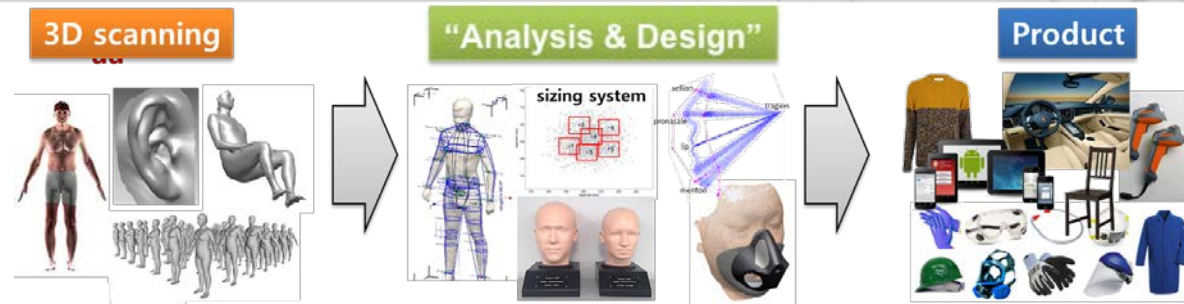
LS-DYNA user input

# Design Based on Virtual Fit Analysis: Earphone

- **Fit simulation** to find **best shape and size** of earphone ( $N = 296$ )
- Based on **distance between ear and earphone landmarks**



# Discussion: Research Issues in Product Design



## • 3D scanning

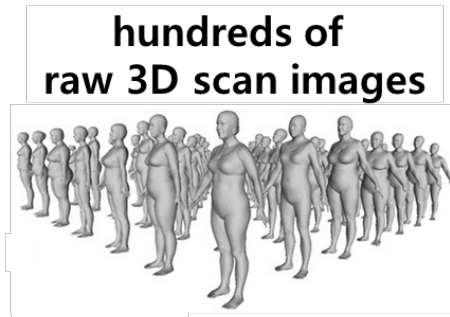
- Scanning in **specialized posture**
- Skin deformation in motion (**4D scanning**) or by wearing/touching to product
- 4D simulation based on **template model**
- **Efficiency for post-processing** (editing, landmarking, measurement, feature extraction)
- Required **more advance software** for product design

## • Analysis & Design

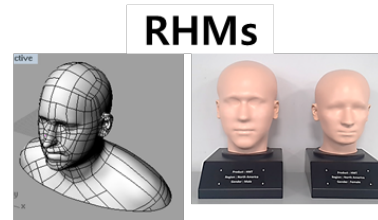
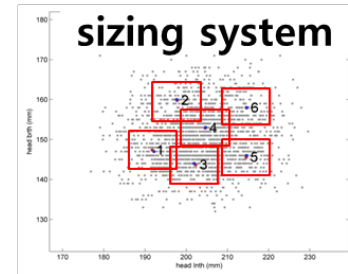
- Analysis of deviation in **complex dimensions** (e.g., curvature, shape, area, volume)
- **Virtual fit simulation**
  - ✓ **Skin deformation**
  - ✓ **Posture change** in product usage
  - ✓ **Pressure/comfort** estimation
  - ✓ **Validation** of simulation methods by experiment
- Design methods
  - ✓ **Optimal** design (by virtual fit or FE simulation)
  - ✓ **Parametric** design
  - ✓ **Rapid prototyping** (3D printing)
- Efficiency of analysis ⇒ **development of computerized programs**

# Discussion: Development of Computerized Systems

- For **easy and convenient analyses** to **product designers**



Vs.



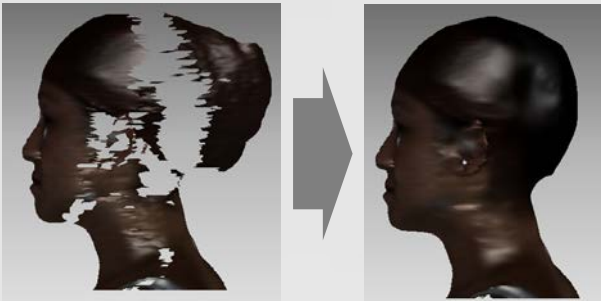
## Computerized programs for sizing system and RHM analyses

The screenshot shows a multi-panel software interface. On the left, there are panels for 'Target Population Characterization Database', 'Anthropometric Variable Selection', 'Key Dimension Selection', 'Solid Formation', and 'RHM Determination'. The central panel displays 'Accommodation Percentage for key dimensions' at 95.4%, a 'Plot of Generated RHM and Grids', and 'Multi-Variable Accommodation Percentages (MAPs)'. The right panel shows '3D Anthropometric Sizing Analysis System' with a 'Sizing System for Headband Design' scatter plot at 72.0% accommodation, 'Representative Results' showing various head views, and a 'Multi-Variables by Each Size' table.

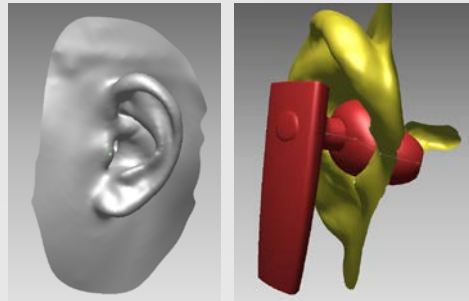
Size	Head Length	Head Width	Head Height	Ear to Ear	Ear to Ear (Depth)
00	145.0	145.0	100.0	100.0	100.0
01	147.5	147.5	102.5	102.5	102.5
02	150.0	150.0	105.0	105.0	105.0
03	152.5	152.5	107.5	107.5	107.5
04	155.0	155.0	110.0	110.0	110.0
05	157.5	157.5	112.5	112.5	112.5
06	160.0	160.0	115.0	115.0	115.0
07	162.5	162.5	117.5	117.5	117.5
08	165.0	165.0	120.0	120.0	120.0
09	167.5	167.5	122.5	122.5	122.5
10	170.0	170.0	125.0	125.0	125.0

- Virtual fit analysis**
- Pressure estimation**
- Comfort estimation**
- Parametric design**

# Thank you



CAESAR Head Data Improvement



Ear Anthropometry



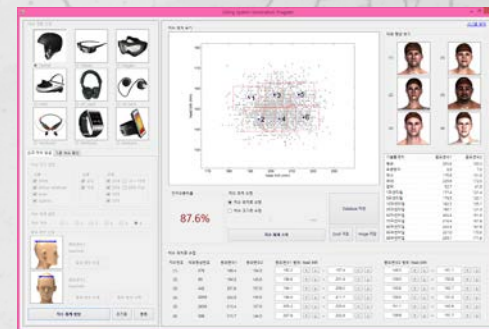
Hip Protector



Representative Models



Virtual Fit Analysis



Sizing Analysis System