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Article

Comparison of Rates of Air Leakage Due to Differences in Face Shape and Mask Size

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Abstract: Effective infection control requires a close fit between the mask and face to minimize gaps. This study investigated whether surgical mask performance varies with face shape and mask size. Three facial models were 3D-printed using head-related transfer function data. Two mask sizes were tested on each model, and 3D measurements were taken at five facial points: the nose, cheeks, and chin to assess mask-to-face gaps. To simulate droplet emission, an aqueous sodium chloride solution was released from a pseudo-oral cavity in the models, and air leakage was measured using a mask-fitting tester. A two-way analysis of variance (ANOVA) was used to examine the effects of face and mask size on leakage. Small face models showed significantly higher leakage than medium and large ones ($p < 0.001$), and S-sized masks leaked more than M-sized masks regardless of face size ($p = 0.038$). Linear regression showed a positive correlation between chin gaps and leakage when using S-sized masks ($p < 0.05$). These results suggest that medium-sized masks offer better overall performance. However, for small faces, fit—especially at the chin, requires particular attention.

Keywords: Air Leakage Rates, Face Shape Gap, Gap

1. Introduction

The COVID-19 pandemic significantly changed public attitudes toward mask-wearing, not only in healthcare settings but also in general society. Before the pandemic, masks were mainly worn in specific situations, such as by individuals with weakened immunity, allergies, such as hay fever or coughs. During the pandemic, however, mask-wearing became a widespread public health measure, often required or strongly encouraged for everyone.

Initially, the World Health Organization (WHO) stated that there was insufficient evidence to recommend mask use for healthy individuals. However, in June 2020, the WHO revised its guidelines to recommend mask use in public settings. In response, many countries introduced mask mandates or strong recommendations. Japan stood out for its high rate of mask usage. As of July 2022, 86% of the population wore masks in daily life. In March 2023, Japan's Ministry of Health, Labor and Welfare updated its guidance, leaving mask-wearing to individual discretion. Following this, in May 2023, COVID-19 was reclassified as a Category 5 infectious disease, and by June, the national mask-wearing rate had dropped to 59% [2]. This rate continued to decline gradually, though with some fluctuations. Changes in mask-wearing frequency during the COVID-19 pandemic, as well as seasonal variations, were influenced by factors such as social anxiety, trait anxiety, and heightened perceptions of vulnerability to infection [3]. Public opinion

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on mask-wearing has been divided, leading to confusion, partly due to a lack of clear, consistent evidence on mask effectiveness.

A systematic review published in the January 30, 2023 issue of *The Cochrane Database of Systematic Reviews* [4] evaluated 78 trials on the effectiveness of physical interventions, including masks, in preventing the spread of acute respiratory infections. However, the review could not draw definitive conclusions, highlighting ongoing uncertainty regarding mask efficacy.

The U.S. Centres for Disease Control and Prevention recommends using the most protective mask, one that fully covers the nose and mouth, fits well, and can be worn comfortably for long periods. The effectiveness of masks depends primarily on two factors: filtration efficiency and facial fit [5-7]. Filtration captures viruses and bacteria by removing them from the air passing through the mask material [8,9]. However, even small gaps between the mask and the face can significantly reduce both the filtration ratio and overall fit factor [12].

A proper facial seal is critical to ensuring mask performance, as gaps allow unfiltered air to enter or escape, undermining the mask's protective function [10]. Mask size and individual facial features play a key role in determining the location and extent of leakage [11].

For example, more than 40% of particles bypass the filtration layer of surgical masks during quantitative fit testing [13]. Air leakage studies on five types of surgical masks found that, despite high filtration capabilities, 10–40% of particles escaped through facial gaps caused by poor fit [8]. These findings suggest that while surgical masks are effective at filtering particles, improper fit can significantly compromise their performance.

Studies also show that mask size and face shape affect fit. Reducing the size of N95 masks from medium to small improved fit test results [14], and large pollen-protection masks showed poor fit performance in young women compared to smaller sizes [15]. These findings suggest that both mask size and facial structure significantly influence fit quality.

In summary, fit performance is a critical factor in the effectiveness of surgical masks. Selecting masks that conform closely to an individual's facial contours is essential to minimize air leakage and maximize protection. However, few experimental studies have systematically examined the relationships among face shape, mask size, and fit performance. Given the wide diversity in human facial features and available mask sizes, it is possible that standard surgical masks used in healthcare settings may not provide optimal protection for all individuals.

Therefore, this study aimed to examine whether differences in face shape and mask size affect the fit of surgical masks. We believe that the findings of this study can help individuals select the appropriate size of surgical masks for their faces and serve as a useful resource for preventing the spread of infectious diseases.

1.1. Definition of terms

Fit performance: This is the ability to enhance fit. This ensured that the mask adhered snugly to the face, allowing air to enter and exit during breathing and be effectively filtered by the mask material.

Air leakage rate: It is the ratio of the particles inside the mask compared to those outside. It is calculated by measuring the number of dust particles both inside and outside the mask, indicating how much unfiltered air leaks through gaps between the mask and the face.

2. Materials and Methods

2.1. Mask

The masks used were Saraya Surgical Mask F (M-size) and Saraya Surgical Mask S (S-size), both of which are medical masks compliant with the U.S. standard ASTM-F2100-19 LEVEL 1 (Saraya, Osaka).

2.2. Creation of face models (Figure 1)

Based on the database from the Research Institute of Electrical Communication, Tohoku University RIEC-HRTF (Research Institute of Electrical Communication of Tohoku University), three types of face models were created using a 3D printer. For the face size settings, the Japanese Head Measurement Database 2001, published by the Artificial Intelligence Research Center was used as a reference. The models were selected based on the following dimensions: (A) maximum width between the left and right zygomatic arches (bizygomatic breadth); (B) maximum distance between the left and right frontal points (width of the mandibular angle) (bigonial breadth); and (C) distance from the subnasal point to the chin (subnasale to gnathion). Models below the 5th percentile were categorized as small faces, those within the 40th–60th percentile range as medium faces, and those above the 95th percentile as large faces. The measurements for each dimension were as follows: small face, A) 130.8 mm, B) 99.2 mm, C) 64.9 mm. Medium face: A) 144.9 mm, B) 109.3 mm, C) 70.6 mm. Large face: A) 154.5 mm, B) 121.1 mm, C) 83.0 mm. Nose height was set as the average value for Japanese individuals.

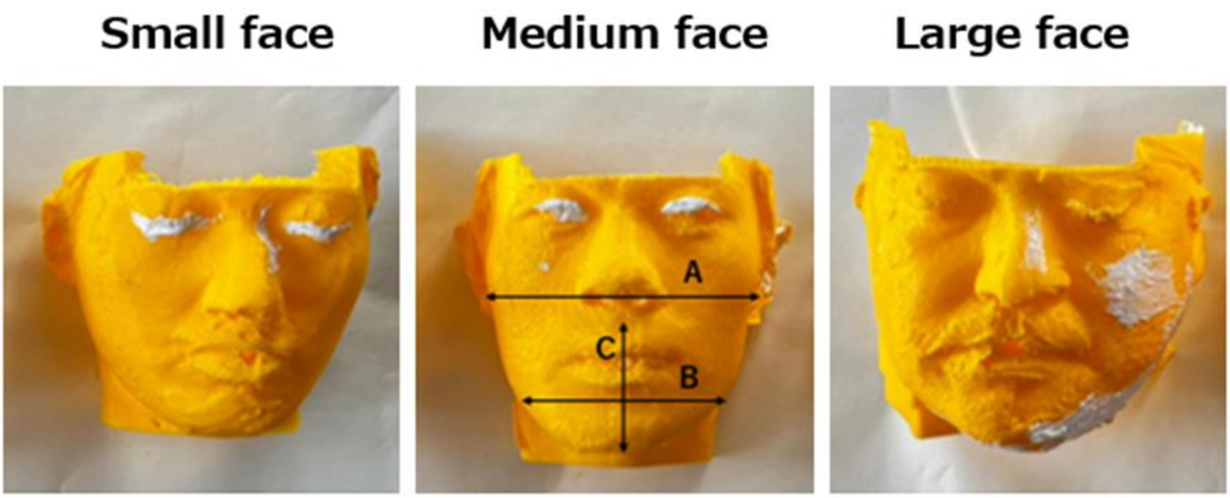

Figure 1. Face models of each shape; Face models selected and created from head measurement data of Japanese men; A: Bizygomatic breadth, B: Bigonial breadth, the width of the mandibular angle, C: Subnasale to gnathion

2.3. Three-dimensional measurement of the face (Figures 2 and 3)

Facial measurements were conducted using a three-dimensional measuring device (CRYSTA-Apex V776; Mitsutoyo, Kawasaki, Japan) to confirm the gaps between the face model and the mask. Measurements were obtained both with and without a mask.

Computer-generated graphics were created using the coordinate data to visualize the mask-to-face gaps, and the distances between the mask and the facial surface at various locations were calculated. The gap size at each location was then quantitatively assessed. Based on findings by Marco et al. [6], gaps are most likely to occur around the cheeks, chin, and the area above the nose. Therefore, five measurement sites were selected: the maximum gap distance on the left and right cheeks, the maximum gap distance at the chin, and the approximate triangular gap areas on both sides of the nose.

Since the gaps at the cheeks and chin were irregular in shape, only the maximum distance between the mask and the face was used as the representative value. In contrast, the gaps on both sides of the nose formed roughly triangular shapes; thus, their areas were estimated using the base and height measured from above the face model.

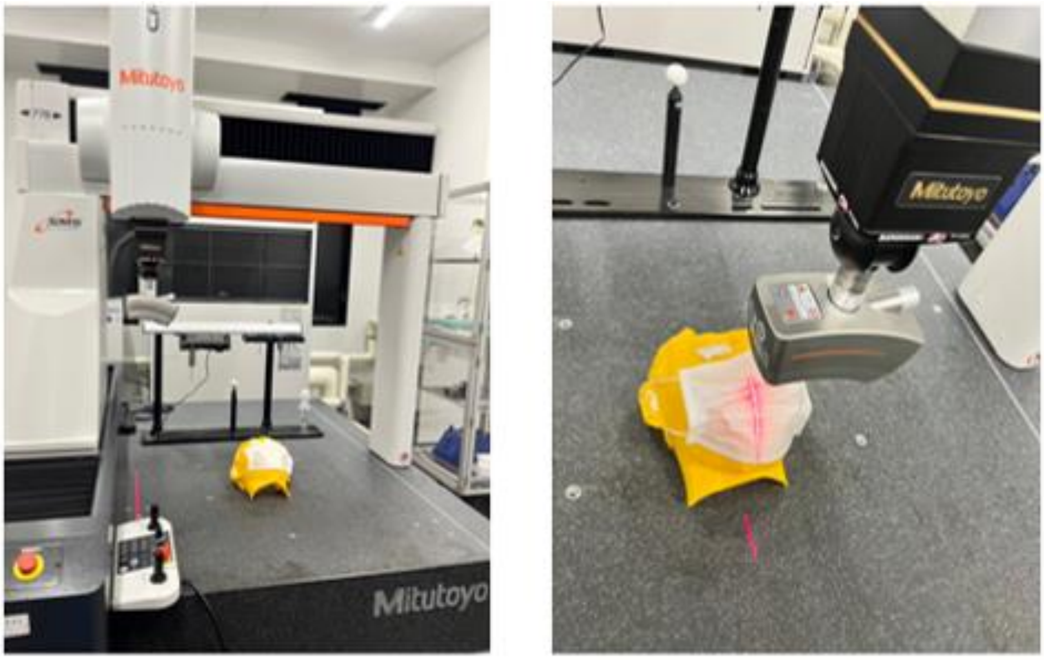

Figure 2. Facial measurement using a 3D scanning device; This figure shows the process of measuring a facial model using a 3D measuring device; The facial model with the mask was measured from various angles to obtain the coordinate data.

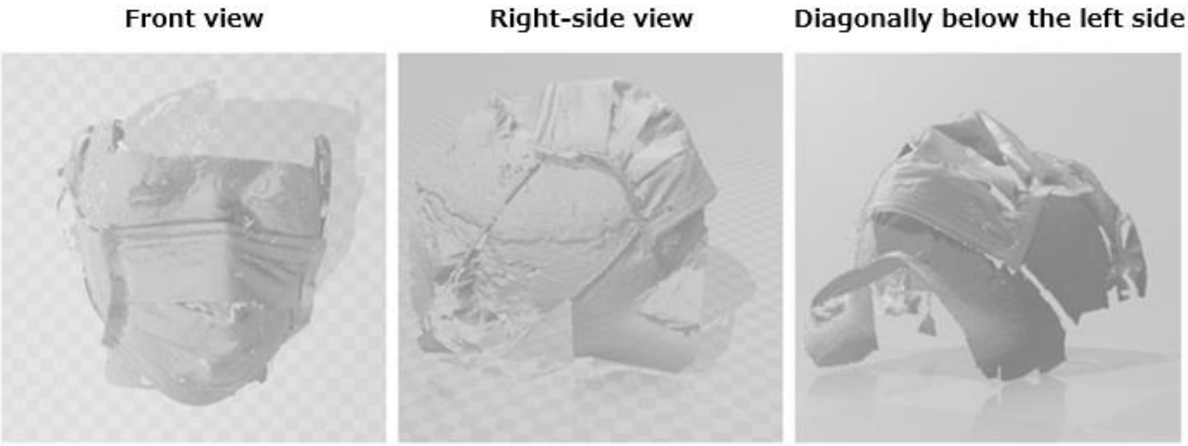

Figure 3. Facial model viewed from various angles (small face); This figure illustrates the observation and measurement of computer graphics created based on the coordinate data measured using a 3D measuring device from various angles.

2.4. Measurement of air leakage rate (Figure 4)

To control particle concentration in the measurement environment, a sodium chloride solution was sprayed using a particle generator during testing. The face model was designed with pseudo-oral and pseudo-nasal cavities, through which particles generated from the sodium chloride solution were released using a nebulizer. To simulate exhalation, the particles were directed toward the front of the face through tubes connected to both the oral and nasal cavities. The air leakage rate was then measured while the face models were fitted with masks. Measurements were conducted using a Rouken-type mask-fitting tester MT-05U (Shibata Scientific, Tokyo, Japan), and the air leakage rate was calculated using Equation (1).

$$LP = Ci / Co \times 100 \quad (1)$$

where,

LP = Leakage Percentage [%], C_o = Outside Count, and C_i = Inward Count.

Respiratory particles are classified by size: droplets are defined as particles ≥5 μm in diameter, aerosols range from 1 to 5 μm, and particles smaller than 1 μm are referred to as droplet nuclei [16]. This study aimed to evaluate the effectiveness of masks in preventing infections transmitted through droplets and aerosols, such as COVID-19. Therefore, the particle size measured during the air leakage test started from 0.5 μm, the smallest detectable size on the mask-fitting tester. To minimize measurement error, all mask fittings were performed by a single experimenter, and each mask was tested 10 times.

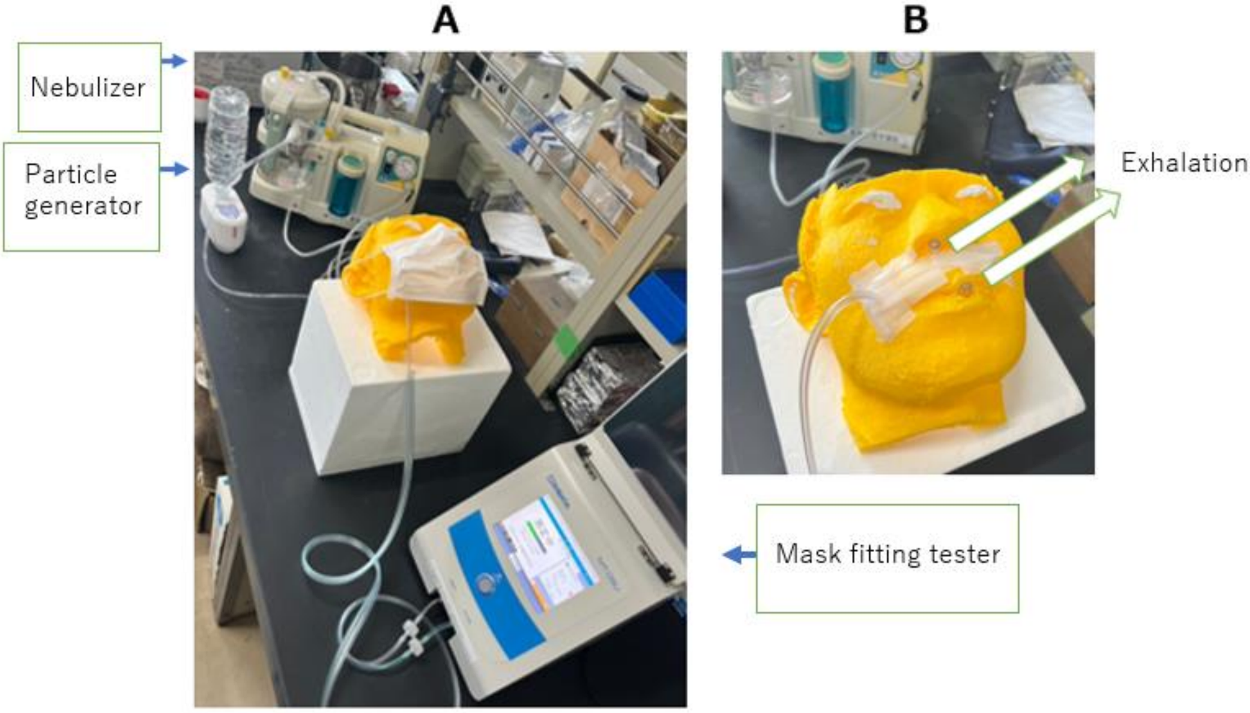

Figure 4. Procedure for measuring air leakage rate; **A** shows the setup for measuring air leakage rate from a mask during simulated exhalation using a facial model in a laboratory setting. The mask-fitting tester MT-05U was used for the measurements. A particle generator maintained a constant particle concentration in the room, and exhaled air was simulated using a nebulizer. **B** is a photograph illustrating the exhalation process, in which simulated exhaled air is released through tubes positioned within the nasal and oral cavities of the facial model.

2.5. Examination of the correlation between facial measurement data and air leakage rate measurement data

The correlations between facial shape, mask size, and air leakage rate were analyzed, along with the relationship between gap size at the mask–face interface and air leakage rate.

2.6. Analysis and statistical processing

Statistical analysis was performed using SPSS Ver. 27 for Windows.

3. Results

The results are presented in the following sub-sections: (1) the size of the gap between the mask and the facial surface; (2) the air leakage rate; and (3) the relationship between the size of the gap between the mask and the facial surface and the air leakage rate.

3.1. Size of the gap between the mask and the facial surface

Table 1 shows the gap sizes between the mask and the facial surface, as visualized using computer graphics. Each value represents a single data point obtained from the scenario in which the mask was worn.

Table 1. Comparison of the size (mm, mm²) of the mask and facial surface gap areas in relation to facial shape and mask size using computer graphics

	Right cheek (㎜)	Left cheek (㎜)	Chin (㎜)	Approximate Triangle on the Right Side of the Nose (㎜ ²)	Approximate Triangle on the Left Side of the Nose (㎜ ²)
Small face _S-size mask	7.9	14.2	8.6	21.2	20.0
Small face _M-size mask	7.9	14.2	8.6	20.3	22.4
Medium face _S-size mask	14.0	13.5	2.0	22.8	20.3
Medium face _M-size mask	14.6	15.0	3.1	21.5	21.1
Large face _S-size mask	10.6	7.5	3.2	22.2	20.2
Large face _M-size mask	14.3	13.9	5.8	20.2	20.5

The maximum gap between the mask and the surface of the face on the right cheek was 14.6 mm for a medium face wearing an M-size mask, while the minimum gap was 7.9 mm for a small face wearing masks of various sizes. The maximum gap on the left cheek was 15.0 mm for a medium face wearing an M-size mask, while the minimum gap was 7.5 mm for a large face wearing an S-size mask. The gap on the chin was largest at 8.6 mm for a small face wearing masks of various sizes, while the smallest gap was 2.0 mm for a medium face wearing an S-size mask. The approximate triangular area on both sides of the nose showed little variation across different face and mask sizes, ranging from 20.0 mm^2 to 22.8 mm^2.

3.2. Air leakage rate

Table 2 presents the results of the air leakage rate measurements. When data with missing measurements were excluded, the number of data points varied. To determine whether facial shape or mask size had a stronger influence on air leakage rate, a two-way ANOVA was performed. The results showed that both face shape and mask size were significantly associated with air leakage. A post hoc Bonferroni test was then conducted to identify specific differences among the three facial shapes. The test revealed that small faces had a significantly higher air leakage rate compared to medium and large faces.

Table 2. Number of experiments and air leakage rate (%) for each mask size by facial shape

		Mask Size					
		S-size			M-size		
		n	Average	SE	n	Average	SE
Facial Shape	Small face	90	34.5	3.6	100	16.1	1.6
	Medium face	38	10.3	1.6	50	17.1	2.3
	Large face	50	15.5	1.9	50	12.6	1.8

SE: Standard Error

Additionally, Table 3 shows that the S-sized mask had a higher air leakage rate than that of the M-sized mask, regardless of facial size. Figure 5 shows an interaction between facial shape and mask size. Table 4 presents the results of a one-way ANOVA analyzing the combined effects of facial shape and mask size. The results revealed significant differences, with the Bonferroni test showing that the air leakage rate for the small face with an S-sized mask was higher than those for the medium and large faces with either mask size (Figure 6).

Table 3. Comparison of air leakage rate (%) by facial shape and mask size

		Estimated Surrounding Mean	Standard Error	95% CI	p-value	Multiple Comparisons
facial shape	small face	24.5	1.4	21.8-	＜0.001***	small face＞medium face
	medium face	13.7	2.0	9.7-		small face＞large face
	laege face	14.1	1.9	10.4-		
mask size	S-size	19.5	1.5	16.6-	0.038*	
	M-size	15.3	1.4	12.6-		

*CI: Confidence Interval; Two-Way Analysis of Variance (ANOVA); *: p<0.05 ***：p<0.001*

Table 4. Comparison of air leakage rate (%) for different combinations of facial shape and mask size

	n	Average	SE	P-value	Multiple Comparisons
Small face _S-size mask(a)	90	34.5	3.6	<0.001***	(a)>(b)***
Small face _M-size mask(b)	100	16.1	1.6		(a)>(c)***
Medium face _S-size mask(c)	38	10.3	1.6		(a)>(d) ***
Medium face _M-size mask(d)	50	17.1	2.3		(a)>(e) ***
Large face _S-size mask(e)	50	15.5	1.9		(a)>(f)***
Large face _M-size mask(f)	50	12.6	1.8		

*SE: Standard Error; One-Way Analysis of Variance (ANOVA); ***：p<0.001*

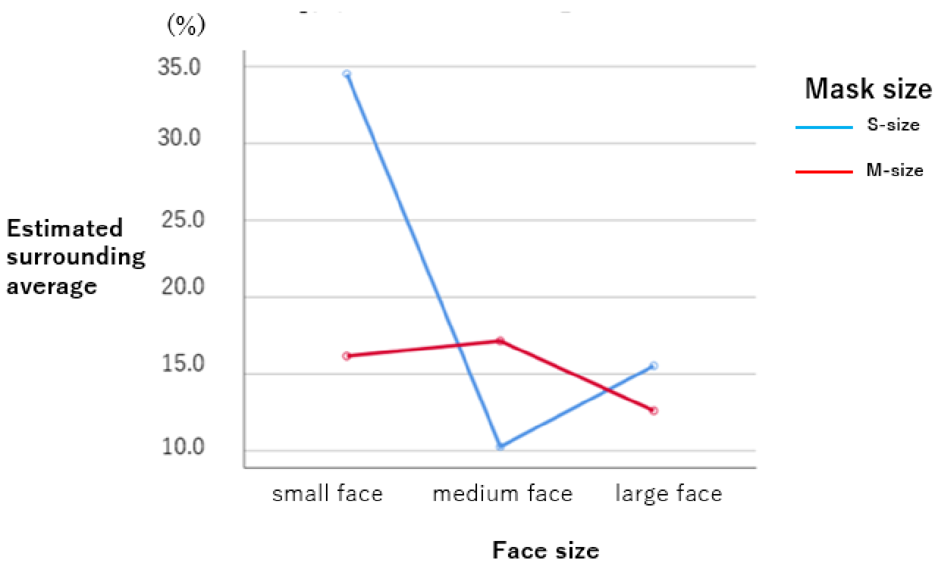

Figure 5. Graph showing air leakage rates in relation to facial shape and mask size (two-way ANOVA); There was an interaction between facial shape and mask size

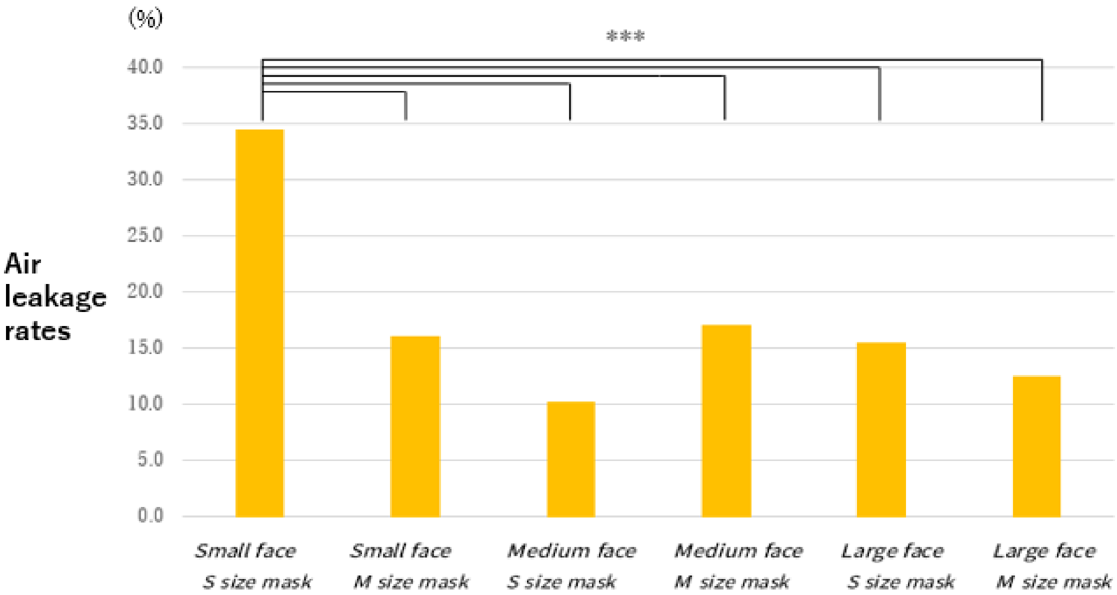

Figure 6. Graph comparing air leakage rates based on face shape and mask size (one-way ANOVA); The air leakage rate for the small face with an S-sized mask was higher than that for the medium and large faces with either mask.

3.3. Relationship between the size of the gap between the mask and the facial surface and the air leakage rate

Linear regression analysis was performed to examine the relationship between the size of the gap between the mask and the facial surface and the air leakage rate using computer graphics. The results showed a positive correlation between the gap at the chin and the air leakage rate when an S-sized mask was worn (Table 5).

Table 5. Relationship between gap size on the facial surface and air leakage rate for S and M-Size masks

	Body part	Partial Regression Coefficient	SE	P-value
S-size	Right cheek	-3.59	1.38	0.234
	Left cheek	1.21	2.97	0.754
	Chin	3.37	0.20	0.039*
	Approximate Triangle on the Right Side of the Nose	-14.62	1.59	0.069
	Approximate Triangle on the Left Side of the Nose	2.33	2.48	0.520
M-size	Right cheek	13.57	2.26	0.105
	Left cheek	1.39	2.82	0.709
	Chin	- 0.04	0.65	0.958
	Approximate Triangle on the Right Side of the Nose	-52.92	5.95	0.071
	Approximate Triangle on the Left Side of the Nose	1.37	2.00	0.619

*SE: Standard Error Linear Regression Analysis; *：$p<0.05$*

4. Discussion

The fit performance of the two types of surgical masks was tested on three different facial models. The results showed that the highest air leakage rate occurred when a smaller-sized face wore an S-sized mask. This contradicts previous findings, which suggested that smaller mask sizes provide a better fit for slender, feminine, or young faces [17]. On the contrary, regardless of the mask size, small faces showed higher air leakage rates than medium and large faces. According to the Japanese head dimension database used in this study, the average mandibular angle width, which affects mask fit, was 110 ± 5 mm, ranging from 99 to 120 mm. The difference between small and large faces reached up to 21 mm. Small faces typically have a more three-dimensional structure and narrower skeletal frame. In contrast, surgical masks start flat and must be shaped by bending the nose wire and pleats. This makes it harder for small, three-dimensional faces to achieve a close fit, resulting in greater air leakage. Comparing mask sizes, S-sized masks had higher leakage rates than M-sized masks, regardless of face size. Previous simulations showed that reducing mask size increases gaps for square or masculine faces but reduces them for slender or feminine faces [17]. Since all facial models here were male, smaller masks likely increased gaps.

Analysis showed that for S-sized masks, larger gaps at the chin correlated significantly with higher air leakage. While the masks had moldable nose wires for a better fit, there was no such feature for the chin. Mist visualization studies found leakage occurs mostly at the upper nose, cheeks, and chin [6]. In this study, nose height was standardized, and the chin gap was notably larger for small faces than medium or large ones, suggesting chin fit strongly influences leakage.

These findings highlight the impact of mask design and facial structure on fit. Proper chin coverage is crucial, and techniques like folding and stapling the lower part of the mask to close chin gaps are recommended, especially for small masks [16].

In this experiment, a facial model capable of exhaling air was created and a mask was worn during use. This allowed the collection of more reliable data in a controlled environment with no facial movements or changes during the experiment. By continuing to apply this research methodology, we plan to investigate the fit performance of design-oriented cloth masks under various conditions.

5. Conclusions

By examining the differences in the fit performance of surgical masks due to variations in face shape and mask size, it was found that small faces and small- sized masks were more likely to result in air leakage. In particular, masks worn on small faces were more prone to leakage than masks of different sizes worn on medium or large faces. Additionally, when wearing small masks, larger gaps at the chin led to significantly higher air leakage rates. These results suggest that medium-sized masks are recommended as the first choice regardless of face size, and that individuals with small faces should select mask sizes more carefully and pay attention to the fit around the chin.

Supplementary Materials: The following supplementary materials are available online at www.scipublications.com/xxx/s1, Figure S1: title, Table S1: title, Video S1: title.

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Conflicts of Interest: The authors declare no conflicts of interest.

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