Title: Analysis of differences in nasal shapes and degree of changes with pairing analysis

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Acknowledgments
Special thanks are given to Da Hyeun Lee, an audiovisual engineer at Samsung Medical Information & Media Services, for designing Figure 1 for this study.

Running title: Pairing analysis for aging nose
Authorship responsibility and contributions to authorship

YK: Conceptualization, data collection, analysis and interpretation, writing the article, critical revision of the article
JHP, MP, EL: data collection, analysis and interpretation
SDH, YGJ: analysis and interpretation, writing the article, critical revision of the article
GR, HYK: Conceptualization, data collection, analysis and interpretation, writing the article, critical revision of the article, final approval of the article

Conflict of interest statement

This work was supported by the Technology Innovation Program (20016285) funded by the Ministry of Trade, Industry, & Energy (MOTIE, Korea).

Word count: abstract (286), main text (2215)

Highlights

1. This study aimed to analyze the differences in aging nasal morphometry and the degree of changes within an individual over at least ten-year period by pairing previous and recent three-dimensional reconstructed computed tomography images.
2. Our findings indicate that the aging nose exhibits a relatively longer nasal length with inferior angulation of the nasal tip, with an increase in the nasofrontal angle, profile nasal length, and nasal bridge height, along with a decrease in the nasofacial angle. Most of the degree of nasal morphologic changes demonstrated no differences by specific age period, yet some of values might vary by age period.
3. This study was the first to evaluate aging changes in nasal morphometry within the same person, controlling personal musculoskeletal variations.
4. Based on the above results, more accurate counseling considering the age-specific changes in nasal angles and shapes should be performed before rhinoplasty.
ABSTRACT

Objectives. This study aimed to analyze the differences in aging nasal morphometry and the degree of changes within an individual over at least ten-year period by pairing previous and recent three-dimensional reconstructed computed tomography (CT) images.

Methods. A total of 48 adult Korean patients who underwent at least two CT scans of the nasal region with an interval of at least ten years were selected. Patients were categorized into age (20-39 years, 40-49 years, and 50 years or older) and sex-based six subgroups at the time of initial imaging. Eight nasal parameters were measured on the initial and recent images, and the paired comparison between the two images was performed based on the data. The differences in the degree of change by age were also analyzed.

Results. With an average of 12-year image interval, men demonstrated an increase in the nasofrontal angle (3.2±5.4, p=0.041), profile nasal length (1.7±1.7, p=0.002), and nasal bridge height (1.2±1.6, p=0.002), while showing a decrease in the nasofacial angle (-2.3±2.9, p=0.010). Women demonstrated an increase in the nasofrontal angle (2.5±5.2, p=0.010), profile nasal length (1.4±1.9, p<0.001), and nasal bridge height (1.3±1.6, p<0.001), along with a decrease in the nasofacial angle (-2.0±2.1, p<0.001), glabella angle (-9.1±9.8, p<0.001), and pyriform angle (-8.5±10.1, p<0.001). Except for the nasal bridge height (p=0.036) and pyriform angle (p=0.022), most of the degree of changes in parameters did not show significant differences among age periods.

Conclusion. Our findings indicate that the aging nose exhibits a relatively longer nasal length with inferior angulation of the nasal tip, with an increase in the nasofrontal angle, profile nasal length, and nasal bridge height, along with a decrease in the nasofacial angle. Most of the degree of nasal morphologic changes demonstrated no differences by specific age period.

Keywords. Aging nose; Pairing analysis; Three-dimensional reconstruction; Degree of change
INTRODUCTION

An interesting issue in aesthetics is changes in the face associated with aging. Among various facial changes, those of the nose are probably the most significant and contribute to the desire for rhinoplasty. According to patients surveyed from 2005 to 2014 [1], rhinoplasty accounts for around 10% of all cosmetic procedures per year for patients 55 and older. In addition, according to previous studies, older adults were satisfied with not only structural-functional improvement [2,3] but also with both aesthetic and psychological aspects [4] after rhinoplasty.

Changes in nasal appearance are an area of interest in various academic fields, and numerous data related to diagnostic and clinical procedures have been studied. Based on the established knowledge of substantial variations in facial anthropometric measurements with sex and age [5], earlier research has presented quantitative findings regarding age-related alterations in the nasal structure and dimensions across diverse ethnic populations, including North Americans [6], Europeans [7], French Canadians [8], Chinese [9], and Japanese [10]. There were various methods used to measure nasal and facial structure, with the most commonly used tools including direct anthropometric measurement [11], three-dimensional (3D) laser scanner [12], 3D photogrammetry [13], and computed tomography (CT) [14,15]. From these numerous previous researches, notable changes with aging have been identified not only in soft tissue areas like the nasal tip, nasolabial region, dorsum, and nasal length but also in bony parameters including the glabella angle, orbital angle, pyriform aperture, and maxillary angle[16,17].

However, in all previous studies to date, there has been no examination of changes in the nasal area over time within the same individuals. Even with the same race and age, individuals have their own unique musculoskeletal variations. In this manner, comparing
aging-related changes in the same individual would eliminate errors arising from factors like race, gender, and musculoskeletal characteristics, resulting in a more reliable measurement value.

Therefore, this study aimed to analyze the aging changes in nasal morphometry within an individual over at least ten years by pairing previous and recent 3D reconstructed CT images, and to assess whether the degree of change varied across different age periods.

**MATERIALS AND METHODS**

We retrospectively reviewed patients who underwent at least two CT scans of the nasal region with an interval of at least 10 years between scans at Samsung Medical Center (Seoul, Republic of Korea) between January 2006 and December 2021. A total of 48 adult Korean patients were enrolled in this study.

The exclusion criteria were as follows. First, patients with probable nose change due to chronic rhinosinusitis surgery, septoplasty, rhinoplasty, turbinoplasty, tumor surgery, tumors that did not undergo surgery, or reduction history by trauma were excluded. Second, various conditions that might induce bone changes, such as acromegaly, Paget's disease, osteogenesis imperfecta, and Cushing’s syndrome, were also excluded. Third, patients with a body mass index (BMI) that changed more than 5 kg/m2 with time were excluded due to the possible change in facial fat volume.

The study was reviewed and approved by the Institutional Review Board at Samsung Medical Center (IRB number: 2022-12-123-001).

**Device and software**

The CT imaging was conducted using Toshiba Aquilion systems (Toshiba Medical Systems, Japan).
The axial images had a width range between 2.0mm and 0.6mm, as advancements in CT technology allowed for thinner cuts over time. Using picture archiving communication system (PACS) functions in INFINITT PACS® (INFINITT Healthcare, Seoul, Republic of Korea), coronal and sagittal images were reconstructed along with axial cuts, and the whole images were precisely controlled by scan orientation along the x, y, and z axes. For three-planar reconstruction, axial DICOM (Digital Imaging and Communications in Medicine) image files extracted from the CT scan were applied to the image-analysis software AMIRA 5.4 (Mercury Computer Systems/3D Viz group, San Diego, CA, USA).

**Measurement of three-dimensional nasal morphometry**

By adjusting the resolution using the AMIRA program, the location of the sella inside the cortical bone was checked. The scans were standardized by obtaining a midsagittal view and drawing a reference line from the sella through the nasion to serve as the reference for the z-axis. All parameters were marked with dashed and solid lines in different colors, and their definitions were listed (Fig. 1). Based on that, the nasofrontal angle, nasofacial angle, nasolabial angle, profile nasal length, nasal bridge height, nasal tip protrusion, glabella angle, and pyriform angle were measured.

**Statistical analysis**

Statistical analysis was performed by SAS version 9.4 (SAS Institute, Cary, NC), and a p-value <0.05 was considered statistically significant. The Kruskal-Wallis test was used to compare the difference in BMI among the age and sex-based six subgroups at the time of initial imaging, and the paired t-test or Wilcoxon signed-rank test according to normality assumption was used to determine the significance of the change between initial and latest
CT scans of the same individual. One-way ANOVA (analysis of variance) was used to identify any differences among the age groups, and multivariable linear regression analysis was adjusted for potential confounders, gender, BMI, and age intervals in the age group comparisons.

**RESULTS**

With all 48 patients having available initial and latest CT, a total of 96 CT scans with 3D reconstruction for nasal morphometry were analyzed.

**Demographics**

Dividing the study population by age at the time of the initial CT scan, 17 patients (5 men, 12 women) were in the young (20-39 years) age group, 20 (4 men, 16 women) were in the middle (40-49 years) age group, and 11 (6 men, 5 women) were in the old (50 years or older) age group. Since this study required a follow-up period of at least 10 years, the old age group based on the initial imaging was categorized as 50 years or older. When the age was re-examined based on the time of the recent imaging, all patients in this group were found to be above 60 years old.

By comparing the mean BMI among the six subgroups based on age and sex at the time of the initial imaging, no significant differences were observed in either the initial (P=0.149) or the latest (P=0.310) scan (Table 1).

**Paired comparison between the initial and latest images**

After measuring eight nasal morphometric parameters on the initial and recent images of all enrolled patients, the paired comparison between the two images of the same patient was
performed. The results are summarized in Table 2, and the parameters of each subgroup are presented as box plots to better illustrate trends (Fig. 2).

With an average of 12-year image interval, men demonstrated an increase in the nasofrontal angle (3.2±5.4, p=0.041), profile nasal length (1.7±1.7, p=0.002), and nasal bridge height (1.2±1.6, p=0.002), while showing a decrease in the nasofacial angle (-2.3±2.9, p=0.010). For women, the nasofrontal angle (2.5±5.2, p=0.010), profile nasal length (1.4±1.9, p<0.001), and nasal bridge height (1.3±1.6, p<0.001) showed statistically significant increase, along with a decrease in the nasofacial angle (-2.0±2.1, p<0.001), glabella angle (-9.1±9.8, p<0.001), and pyriform angle (-8.5±10.1, p<0.001).

Comparison of the degree of nasal morphologic changes by specific age period

To evaluate whether the aging rate of the measurement area is different by age periods, the degree of parameter changes was compared using univariate and multivariate analyses adjusted by sex, BMI, and age interval in three age-based subgroups. The results are summarized in Table 3, and the parameters of changes between the initial and latest images are shown as violin plots to better illustrate trends (Fig. 3).

As shown in Table 3, the nasofrontal angle, nasofacial angle, nasolabial angle, profile nasal length, nasal tip protrusion, and glabella angle showed no statistically significant degree of change among the three subgroups on either univariate or multivariate analysis. But for the nasal bridge height, the mean difference was 0.7 ± 0.9 mm in the young, 1.4 ± 1.4 mm in the middle, and 2.2 ± 2.3 mm in the old age group, which showed a statistically significant progressive increase of the degree of change among the three groups on both univariate (P=0.049) and multivariate (P=0.036) analyses. For the pyriform angle, the mean difference was -14.5 ± 14.3 degrees in the young, -3.0 ± 7.4 degrees in the middle, and -8.6 ± 11.0 degrees in the old age group, with significant differences noted among the three groups on
both univariable ($P=0.011$) and multivariable ($P=0.022$) analyses.

**DISCUSSION**

Aging-related alterations in nasal anatomy are significant; even minor deviations in nasal structure can lead to noticeable and unwanted changes, potentially prompting a desire for procedures like rhinoplasty [18].

In our study, the paired matching between the initial and latest images showed an increase in the nasofrontal angle, profile nasal length, and nasal bridge height, along with a decrease in the nasofacial angle with aging in both sexes. As a result of these changes, aged noses exhibit a relatively longer nasal length with inferior angulation of the nasal tip. Aging could lead to possible ossification of the cartilages and loosening of suspensory ligaments, potentially causing migration in the direction of gravity [19], and this hypothesis aligns with the findings of our study. The only parameter that did not show a difference was nasal tip protrusion, which might suggest that the distance between the subnasale and pronasale does not change despite tip drooping.

Previous studies using different tools to measure nasal parameters reported similar results from our research. Kwon et al. [13] measured 41 age-related facial soft tissue changes in Korean females using 3D photogrammetry, reporting a greater nasofrontal angle and smaller nasofacial angle in an older female group than in the younger group. Another study by Lee et al. [20] measured 15 age-related facial metrics in a large Korean population using the photogrammetric method and found that the nasal tip protrusion slightly decreased with aging in both sexes, while the profile nasal length slightly increased with aging only in males. However, all these previous studies with external measurements did not evaluate bony changes as they could not assess inner structures, which limited the clinical significance of
understanding the actual nasal aging process according to age.

Our study measured bony structures after obtaining reference line using 3D reconstruction methods, and results showed that the angle of the glabella and pyriform were decreased in women with aging. We also found the same decreasing trend in men, but it did not show significant statistical differences, probably due to the small number of patients. These changes could be interpreted by Lambros's theory, which refers to the changes in the aging facial skeleton by the shifting of the maxilla and the orbital rim, creating the clockwise rotation of the bones [21]. Previous studies with various ethnicities also reported similar results, with the facial bone rotating in both men and women and making the glabella angle regress and produce soft tissue positional changes with aging [16,17].

We also aimed to assess whether there were variations in the degree of nasal morphological changes based on specific age periods. Comparing the three subgroups by initial age, most parameters demonstrated no statistical differences in the degree of changes, although nasal bridge height showed an increasing degree of change with aging. The pyriform angle also showed a difference among the three subgroups, where the youngest group showed the highest degree of change but also included some outliers with large standard deviations, indicating the need for caution in interpretation.

For performing rhinoplasty, many considerations are needed before and after surgery. Even though they may be well corrected during surgery and show aesthetically satisfactory results, changes in the external nose could appear over time. When materials such as silicone and expanded polytetrafluoroethylene are inserted during surgery, the overall shape of the nose may deform over time due to the incongruity between inserted materials that do not change with aging. Based on the above results, more accurate counseling considering the age-specific changes in nasal angles and shapes could be performed before rhinoplasty.

To the best of our knowledge, this study was the first to evaluate aging changes in nasal
morphometry within the same person. Despite all previous studies discussing anatomic changes associated with aging, none has analyzed such changes within the same person, resulting in limitations in controlling musculoskeletal variations. Paired matching evaluation could reduce bias by obviating possible variations, and could be applied within a small number of participants.

There were several limitations in our study. First, errors can be introduced in CT due to biological patient functions such as breathing, emotion, and facial expression, especially errors in nasal angle and shape. Especially for the nasolabial angle, the measured value might vary depending on the degree of protrusion of the lips during image acquisition. Second, although major factors such as surgery, trauma, and BMI changes were excluded from this study, differences in factors influencing aging, such as tobacco use, alcohol consumption, exposure to sunlight, and eating habits, should be considered as confounding factors. To minimize these variations and errors, a well-designed, controlled, prospective study with a larger study population is needed.

In conclusion, our study results indicate that the aging nose exhibits a relatively longer nasal length with inferior angulation of the nasal tip, with increase in the nasofrontal angle, profile nasal length, and nasal bridge height, along with a decrease in the nasofacial angle. Aging not only affects soft tissue and cartilage changes but also influences the mid-face bony structures. Most of the degree of nasal morphologic changes demonstrated no differences by specific age period, yet some of values might vary by age period.
REFERENCES


FIGURE LEGENDS

**Fig. 1.** Using reconstructed 3D images, all parameters were marked with dashed and solid lines in different colors, and their definitions were listed. Based on that, the nasofrontal angle, nasofacial angle, nasolabial angle, profile nasal length, nasal bridge height, nasal tip protrusion, glabella angle, and pyriform angle were measured.

**Fig. 2.** Parameter comparisons between the initial and latest CT scans of the same individuals. With an average of 12-year image interval, men demonstrated an increase in the nasofrontal angle, profile nasal length, and nasal bridge height, while showing a decrease in the nasofacial angle. Women demonstrated an increase in the nasofrontal angle, profile nasal length, and nasal bridge height, along with a decrease in the nasofacial angle, glabella angle, and pyriform angle.

**Fig. 3.** The degree of nasal area changes between the initial and latest groups are shown as violin plots by the age-based three subgroups. Except for the nasal bridge height and pyriform angle, most of the degree of changes in parameters did not show significant differences among age periods.
Table 1. Demographics of enrolled patients (N = 48)

<table>
<thead>
<tr>
<th>Initial age group*</th>
<th>Young (20-39 years)</th>
<th>Middle (40-49 years)</th>
<th>Old (50+ years)</th>
<th>Total</th>
<th>P value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sex</td>
<td>M</td>
<td>F</td>
<td>M</td>
<td>F</td>
<td>M</td>
</tr>
<tr>
<td>Initial CT Image</td>
<td>No.</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Age†</td>
<td>34.4±3.7</td>
<td>33.9±5.6</td>
<td>46.3±2.7</td>
<td>45.9±4.3</td>
<td>56.2±5.6</td>
</tr>
<tr>
<td>BMI†</td>
<td>25.4±2.2</td>
<td>23.4±4.1</td>
<td>22.5±1.0</td>
<td>21.8±2.1</td>
<td>23.8±1.9</td>
</tr>
<tr>
<td>Latest CT Image</td>
<td>No.</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Age</td>
<td>46.4±4.4</td>
<td>45.8±6.4</td>
<td>58.0±3.5</td>
<td>44.6±4.7</td>
<td>67.6±5.9</td>
</tr>
<tr>
<td>BMI</td>
<td>26.0±2.7</td>
<td>23.9±5.0</td>
<td>22.8±0.9</td>
<td>22.8±2.3</td>
<td>24.0±2.6</td>
</tr>
</tbody>
</table>

* Patients were categorized into age-based subgroups at the time of initial imaging.
† Age and BMI values are presented as mean ± SD
Table 2. Age-related nasal morphometry with paired matching between initial and latest images (N = 48)

<table>
<thead>
<tr>
<th>Measurement*</th>
<th>Unit</th>
<th>Initial image</th>
<th>Latest image</th>
<th>Age-related change (Latest - Initial)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>M</td>
<td>F</td>
<td>M</td>
</tr>
<tr>
<td>Time interval</td>
<td>Yr</td>
<td>46.3±10.4</td>
<td>43.6±9.8</td>
<td>58.0±10.4</td>
</tr>
<tr>
<td>BMI</td>
<td>Kg/m²</td>
<td>24.0±2.1</td>
<td>22.6±2.9</td>
<td>24.3±2.6</td>
</tr>
<tr>
<td>Nasofrontal angle</td>
<td>deg</td>
<td>134.1±7.9</td>
<td>140.4±7.4</td>
<td>137.2±8.7</td>
</tr>
<tr>
<td>Nasofacial angle</td>
<td>deg</td>
<td>30.9±3.9</td>
<td>30.2±3.4</td>
<td>28.7±3.7</td>
</tr>
<tr>
<td>Nasolabial angle</td>
<td>deg</td>
<td>96.5±13.2</td>
<td>93.2±8.5</td>
<td>90.5±16.1</td>
</tr>
<tr>
<td>Profile nasal length</td>
<td>mm</td>
<td>48.6±2.9</td>
<td>42.6±3.7</td>
<td>50.3±3.3</td>
</tr>
<tr>
<td>Nasal bridge height</td>
<td>mm</td>
<td>51.3±3.6</td>
<td>46.5±3.1</td>
<td>52.5±2.6</td>
</tr>
<tr>
<td>Tip protrusion</td>
<td>mm</td>
<td>18.5±2.9</td>
<td>17.1±1.5</td>
<td>18.1±2.7</td>
</tr>
<tr>
<td>Glabella angle</td>
<td>deg</td>
<td>68.9±14.0</td>
<td>67.7±5.2</td>
<td>61.1±13.2</td>
</tr>
<tr>
<td>Pyriform angle</td>
<td>deg</td>
<td>74.9±11.2</td>
<td>73.0±9.6</td>
<td>67.0±11.7</td>
</tr>
</tbody>
</table>

* All measurement values are presented as mean ± SD
<table>
<thead>
<tr>
<th>Measurement of change (Latest - Initial)</th>
<th>Unit</th>
<th>Young (20-39 years) ( n = 17 )</th>
<th>Middle (40-49 years) ( n = 20 )</th>
<th>Old (50+ years) ( n = 11 )</th>
<th>P value</th>
<th>Univariable*</th>
<th>Multivariable †</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nasofrontal angle</td>
<td>deg</td>
<td>1.7±5.9</td>
<td>3.0±4.1</td>
<td>3.7±6.3</td>
<td>0.600</td>
<td>0.755</td>
<td></td>
</tr>
<tr>
<td>Nasofacial angle</td>
<td>deg</td>
<td>-1.3±2.3</td>
<td>-2.1±2.3</td>
<td>-3.1±2.6</td>
<td>0.159</td>
<td>0.278</td>
<td></td>
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<tr>
<td>Nasolabial angle</td>
<td>deg</td>
<td>-0.8±3.4</td>
<td>-5.1±7.4</td>
<td>-4.6±13.2</td>
<td>0.247</td>
<td>0.200</td>
<td></td>
</tr>
<tr>
<td>Profile nasal length</td>
<td>mm</td>
<td>1.1±1.5</td>
<td>1.5±1.4</td>
<td>2.2±2.8</td>
<td>0.265</td>
<td>0.343</td>
<td></td>
</tr>
<tr>
<td>Nasal bridge height</td>
<td>mm</td>
<td>0.7±0.9</td>
<td>1.4±1.4</td>
<td>2.2±2.3</td>
<td><strong>0.049</strong></td>
<td><strong>0.036</strong></td>
<td></td>
</tr>
<tr>
<td>Tip protrusion</td>
<td>mm</td>
<td>-0.1±0.7</td>
<td>-0.3±1.0</td>
<td>-0.5±1.0</td>
<td>0.553</td>
<td>0.698</td>
<td></td>
</tr>
<tr>
<td>Glabella angle</td>
<td>deg</td>
<td>-13.3±15.5</td>
<td>-4.4±7.9</td>
<td>-9.5±10.4</td>
<td>0.080</td>
<td>0.119</td>
<td></td>
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<tr>
<td>Pyriform angle</td>
<td>deg</td>
<td>-14.5±14.3</td>
<td>-3.0±7.4</td>
<td>-8.6±11.0</td>
<td><strong>0.011</strong></td>
<td><strong>0.022</strong></td>
<td></td>
</tr>
</tbody>
</table>

* Univariable analysis by one-way analysis of variance (ANOVA)
† Multivariable analysis by linear regression adjusted for sex, body mass index (BMI), and age group
**Figure 1**

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nasofrontal angle</td>
<td>Angle of glabella-nasion-pronasse(Pn)</td>
</tr>
<tr>
<td>Nasofacial angle</td>
<td>Angle of pogonion(Pg)-nasion-pronasse</td>
</tr>
<tr>
<td>Nasolabial angle</td>
<td>Angle of labiale superius(Ls)-subnasale(Sn)-pronasse</td>
</tr>
<tr>
<td>Profile nasal length</td>
<td>Length of nasion to subnasale</td>
</tr>
<tr>
<td>Nasal bridge height</td>
<td>Length of nasion to pronasse</td>
</tr>
<tr>
<td>Nasal tip protrusion</td>
<td>Distance between nasal tip to subnasale</td>
</tr>
<tr>
<td>Glabella angle</td>
<td>Angle between the reference line and a line drawn from the maximal prominence the glabella to the nasion</td>
</tr>
<tr>
<td>Pyriform angle</td>
<td>Angle of reference line and a line drawn from the nasal bone to the lateral inferior pyriform aperture</td>
</tr>
</tbody>
</table>
Figure 2

- Nasofrontal angle
- Nasofacial angle
- Nasolabial angle
- Profile nasal length
- Nasal bridge height
- Glabella angle
- Pyriform angle

- Initial group
- Latest group
- Statistically increased
- Statistically decreased
Figure 3

- Nasofrontal angle
- Nasofacial angle
- Nasolabial angle
- Profile nasal length
- Nasal bridge height
- Tip Protrusion
- Glabella angle
- Pyriform angle