Evaluation of the Utility of Homologous Modeling and Principal Component Analysis for Sex Determination of the Mandible

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Abstract: The morphology of the mandible using homologous modeling and principal component analysis, and the accuracy of sex determination based on mandibular morphology were examined. The computed tomography (CT) scans of 84 subjects (44 males, 40 females; mean age, 42.4 ± 15.4 years) were selected for this study. To avoid any effect on the morphology of the mandible, the scans of subjects with fewer than 14 remaining teeth were excluded. Homologous modeling and principal component analysis were performed using mHBM (Digital Human Technology, Tokyo, Japan) and HBM-Rugle software (Medic Engineering, Kyoto, Japan), respectively. The contribution of the first principal component was 20.8% and that of the second principal component was 11.4%. There was a significant difference between male and female in the first principal component (Wilcoxon test, p < 0.05). Subjects with a negative first principal component value were considered more likely to be female, and those with positive values were more likely to be male (accuracy rate, 61.9%). ROC analysis of this method revealed AUC of 0.62, sensitivity of 0.48, and specificity of 0.78. Multivariate analysis was performed using all principal component values, and ROC analysis performed based on these results revealed AUC of 0.85, sensitivity of 0.82, and specificity of 0.85. Analysis using only the first principal component had lower sensitivity and specificity than reported previously, but the results using all principal component values were similar to those in past reports. This method was considered to be useful for sex determination based on mandibular morphology.

Key words: Sex determination, Homologous model, Principal component analysis, Mandible, Japanese

Introduction

Mandibular reconstruction is very important because mandibular defects affect facial appearance and oral function1–3. In order to reconstruct the mandible, it is necessary to understand the morphology of the mandible in detail. Here, we report the technique of homologous modeling and principal component analysis for examining the morphology of the mandible. In contrast to the conventional method for evaluating the mandible in which the distances and angles between anatomical landmarks are measured, in homologous modeling the number of polygons is unified and differences between the polygons are comprehensively evaluated.

In the field of forensic medicine, many studies have been conducted to determine sex from the morphology of mandibles; however, accurate determination of the morphological differences for this purpose is difficult. In addition, substantial inter-observer and intra-observer differences have been reported when attempting to determine morphological differences between the sexes4–9. Sex determination based on mandibular morphology requires detailed knowledge of the morphology of the mandible.

The aim of the study was to examine mandibular morphology in detail using homologous modeling and principal component analysis. The accuracy rate, sensitivity, and specificity of sex determination based on mandibular morphology were obtained. 

Materials and Methods

Patients

The CT scans of 84 subjects (44 males, 40 females; mean age, 42.4 ± 15.4 years) who underwent CT between January 2018 and March 2019 at the Department of Oral Surgery of Osaka Medical College were selected for this study. Excluded from the study were subjects who had jaw deformities due to trauma or congenital or acquired diseases and subjects with fewer than 14 teeth, which can affect the morphology of the mandible. The experimental protocols were approved by the Institutional Ethics Committee of Osaka Medical College, Osaka, Japan. Informed consent was obtained from all subjects.

Methods

Homologous modeling and principal component analysis were performed according to the method described by Suzuki et al.7 (Fig. 1). A 3D image was constructed from the CT scans of each patient. Twenty landmarks were plotted on the surface of each 3D-CT mandibular model and converted into stereolithographic format using HBM-Rugle (Medic Engineering, Kyoto, Japan) image measurement software (Fig. 2). A homologous model of the mandible was then constructed for each sample using Homologous Body Modeling software mHBM (Digital Human...
Technology, Inc., Tokyo, Japan) and principal component analysis was performed using HBM-Rugle (Medic Engineering, Kyoto, Japan).

Principal components related to sex were clarified using Wilcoxon test. We analyzed these results in terms of accuracy rate, sensitivity, and specificity for sex discrimination. Additionally, a regression equation was created using all principal components, and sex discrimination was performed based on these values.

**Statistical analyses**

In principal component analysis, the principal component parameters were set as 19. Multivariable logistic regression analysis was used to distinguish between male and female. Additionally, sensitivity and specificity in distinguishing the male and female groups were estimated by receiver-operating characteristic (ROC) analysis using maximum cut-off values determined by the Youden index (defined as sensitivity + specificity − 1). The areas under the curves were calculated and analyzed by one-tailed t-test. The predictive value for sex estimation was calculated by dividing the number of cases above and below the cut-off values by the total number of cases of males and females. All descriptive data analysis and statistical analysis was performed with JMP® v. 5.1.2 (SAS Institute Inc, Cray, NC).

**Results**

The contribution of the first principal component analysis was found to be 20.8% and the second principal component was 11.4% (Table 1). A significant difference between male and female was observed in the first principal component (Wilcoxon test, \( p < 0.05 \)). Visualization of the

| Principal Component | Eigen Value | Contribution Rate (%) | Cumulative Contribution Rate (%) |
|---------------------|-------------|-----------------------|---------------------------------|
| 1 2627.1            | 20.8        | 20.8                  |
| 2 1446.0            | 11.4        | 32.2                  |
| 3 876.2             | 6.9         | 39.2                  |
| 4 727.2             | 5.8         | 44.9                  |
| 5 630.3             | 5.0         | 49.9                  |
| 6 468.4             | 3.7         | 53.6                  |
| 7 447.7             | 3.5         | 57.2                  |
| 8 381.0             | 3.0         | 60.2                  |
| 9 310.1             | 2.5         | 62.6                  |
| 10 296.8            | 2.3         | 65.0                  |
| 11 268.8            | 2.1         | 67.1                  |
| 12 264.6            | 2.1         | 69.2                  |
result of the first principal component revealed that the mandibular branch was longer and the mandibular angle showed more overhang in males than in females (Fig. 3). In other words, it was considered that the subjects whose first principal component value was positive were more likely to be male, and those with a negative value were more likely to be female, with accuracy of 61.9%. ROC analysis of this method revealed AUC of 0.62, sensitivity of 0.48, and specificity of 0.78.

Multivariate analysis was performed using all principal component values, and ROC analysis performed based on those results revealed AUC of 0.85, sensitivity of 0.82, and specificity of 0.85.

Discussion

Homologous modeling is increasingly being used as a morphological measurement method in which scanned surface shape data are represented using the same number of data points as in topology defined based on the anatomy. Analysis of homologous models using multivariate statistical methods enables extraction of shape variations that are impossible to understand using linear measurements, and presentation of specific virtual shape variations. Kato et al. applied homologous modeling to analyze the morphology of human incisors, and Yamazaki et al. applied this technique to the design of fitted clothing by fabricating a homologous model of the human body. Inoue et al. performed evaluation of mandibular morphology using homologous modeling and principal component analysis. Suzuki et al. reported sex determination using homologous modeling of the mandible. Therefore, we decided to evaluate the accuracy of sex determination performed using homologous modeling and principal component analysis, in comparison with the results of previous reports.

Donnelly et al. studied 96 mandibles from a forensic collection of known sex and a Native American sample where sex was estimated from the pelvic bones. In another study, two independent observers scored the mandibles in four different sessions by visually determination method and reported overall prediction accuracy for sex determination of 63–69%. In the present results, the first principal component positive group was male and the negative group was female, with an accuracy rate of 61.9%, which is similar to the result of Donnelly et al. Kano et al. recently suggested the efficacy of quantitative assessment of postmortem CT morphology of the mandible for sex discrimination, and reported sensitivity and specificity of approximately 80%. Virtual 3-D reconstruction using CT data may be also useful, especially for the analysis of skeletal robusticity involving sex-related differences, independent of the status of the recovered human remains.

The postmortem CT morphometry study of Kano et al. was more accurate than the visually determination method study performed by Donnelly et al. In the present study, sex determination was performed using multiple values of principal component analysis as a more comprehensive method of evaluating mandibular morphology, and the result was similar to that of Kano et al. This result is new discovery. The present results indicate that homologous modeling and principal component analysis are suitable for evaluating the morphology of the mandible and could be of use for determining sex based on mandibular morphology.

In conclusion, analysis using only the first principal component had lower sensitivity and specificity than reported previously, but the results using all principal component values were similar to those in past reports. This method was considered useful for sex determination based on mandibular morphology.

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Conflict of Interests

The authors have declared that no COI exists.

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