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Original Article

Morphometric analysis of the nasal septum in normal Chinese individuals using a three-dimensional model of the nasal septum with facial CT scanning

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Abstract: Objectives: Three-dimensional (3D) models were reconstructed based on computed tomography (CT) scan data and to analyze the morphometric characteristics of the nasal septum in Chinese individuals. Methods: Ninety-six healthy adults aged 20-83 years old without confirmed nasal disorders were enrolled in this study from 2014 to 2015. 3D models of the nasal septum were reconstructed based on their CT scan data, and 7 indices were used for the evaluation of the spacial structure of the nasal septum. Results: Data of the nasal septum revealed larger nasal septum volumes in males than those in females ($P<0.01$). The ratio of the cartilage volume to the total septal volume significantly decreased with age ($P=0.010$), whereas the ratio of the vomer volume to the total volume significantly increased with age ($P=0.018$). There were no significant correlations of the nasal septum with age ($P=0.666$) and gender ($P=0.55$). Conclusions: The reconstructed 3D model of the nasal septum demonstrates that the septal volume was larger in males than in females, and the ratio of vomer volume and cartilage volume to total septal volume changed with age, which may provide a reference for clinical treatment.

Keywords: Nasal septum, reconstructed three-dimensional model, morphometric measurements, computed tomography

Introduction

Nasal septum, located in the middle of the nose pyramid, seperates the nasal cavity and offers support to the nose structure [1-3], which is vital in nasal respiration, secretion, and immunity [3, 4]. Its deformity is severly detrimental to the function and appearance of the nose [5]. The cartilage of the nasal septum is a common autogenous grafting material used in the rhinoplasty [6-9], which entails a thorough understanding of the morphometric features of the nasal septum to ameliorate clinical diagnosis and surgery assessment.

Previously, morphometric analysis of the nasal septum was conducted mostly based on human cadavers and two-dimensional computed tomography (CT) image [2, 3, 7]. Brett et al. examined the anatomical variation of the components of the nasal septum using 57 cadaver specimens and found a greater variation in the cartilaginous area in males than that in females and an irrelevance between the extent of septal deviation and the amount of available graft material. It is considered insightful in rhinoplasty but circumscribed when being extrapolated to living tissue. In addition, difficulties in the collection of qualified specimens are obvious [2]. CT is frequently used in clinical practice to acquire morphometric views of the nasal septum in axial, coronal, and sagittal planes, and even 3D images. Facial CT, including cross-sectional and coronal scans, is mainly used for the examination of oral and maxillofacial diseases, including the infratemporal fossa, sinuses, pterygopalatine fossa, parotid, submandibular glands, and the temporomandibular joint. However, evaluation of these indices is generally performed on the median plane of the nasal septum, without consideration of the information from multiple 3D planes [9, 11]. To date, few studies have concentrated on the measurements of the nasal septum from a 3D perspective [12].

Accordingly, the study reconstructed a 3D nasal septum model by analyzing the morphometric features from CT scan images. The volume indices were used to examine the relationship between components of the nasal septum and its deviation. The 3D reconstruction provides contributory clues that are not available from two-dimensional plane images for preoperative assessments and diagnoses of nasal septal diseases.

Methods

The clinical data of patients who underwent facial CT scanning at Shanghai Ninth People's Hospital of China from Jan 2014 to Dec 2015 were reviewed retrospectively. The included patients were those with normal nasal septum. Patients with nasal histories of craniofacial trauma, nasal septal surgery, congenital malformations, twisted nasal septum, sinusitis, nasal septal deviation, nasal septal perforation, pregnancy, or nasal-related symptoms, or less than 20 years old were excluded. Finally, 96 patients were included in the study, and their data were collected. The study was approved by the clinical and laboratory ethics committee of Shanghai Ninth People's Hospital, with the approval number of 2016-82-T39.

Reconstruction of a 3D model of the nasal septum

Computed tomographic images were acquired after clearing patients' secretion in the nasal cavity. With the patients in a supine position, cranial and nasal CT scans were performed at room temperature with a 16-slice spiral CT LightSpeed Ultra (GE Healthcare, Waukesha, WI) under the following scanning parameters, 120 mA, 120 kV, a thread pitch of 1.375 mm, and velocity of 27.5 mm/s. Parameters of 3D reconstruction were as follows, a layer thickness of 0.625 mm, reconstruction increment of 0.625 mm, window width of 2000 Hounsfield units, and window level of 1000 Hounsfield units.

The midsagittal image was defined as a vertical plane cutting through the maxillary spine and the crista galli, which allows clear observation of the whole nasal septum. In this image, selected dots that contoured the irregular boundary of the nasal septum were connected (**Figure 1A**), and then the closed-loop was applied on all the sagittal images as the boundary of the septum (**Figure 1B**).

A 3D model of the nasal septum was reconstructed based on the multiple layers of sagittal images (**Figure 1C**). Based on intensity thresholds, the nasal septum was divided into 3 parts, namely, the septal cartilage, the perpendicular plate of the ethmoid (PPE), and the vomer (**Figure 1D**). Proplan CMF (Materialise, Belgium) was adopted for analysis of the above data.

Evaluation of nasal septum deviation

Four volume indices were measured to evaluate the space metrics of the nasal septum, including the volume of the total nasal septum, the volume of PPE, the volume of septal cartilage, and the volume of vomer. Volumes of these subspaces were normalized to the total nasal volume, namely, the ratio of the cartilage volume to the total septal volume, the ratio of the PPE volume to the total septal volume, and the ratio of the vomer volume to the total septal volume. The volumes and components of the nasal septum were obtained by the software Proplan CMF.

Nasal septum deviation rate was used as a parameter to evaluate the nasal septum deviation. The nasal septum to a surface was fitted using the least square method to minimize the effects of variation on the thickness of the cartilage and the overlying mucosa (**Figure 2A**). The high-resolution fitting surface contained information that reflects the irregularity of the nasal septum (**Figure 2B**). A control plane was established to represent a "non-deviated" nasal septum to reduce the effect of variation in the size of the nasal septum in individuals. Consequently, the nasal septum deviation rate was defined as:

$$\eta = \frac{A_{fit} - A_{mid}}{A_{mid}}$$

where A_{fit} is the area of the fitting surface and A_{mid} is the area of the "non-deviated" surface. Data were processed using Matlab.

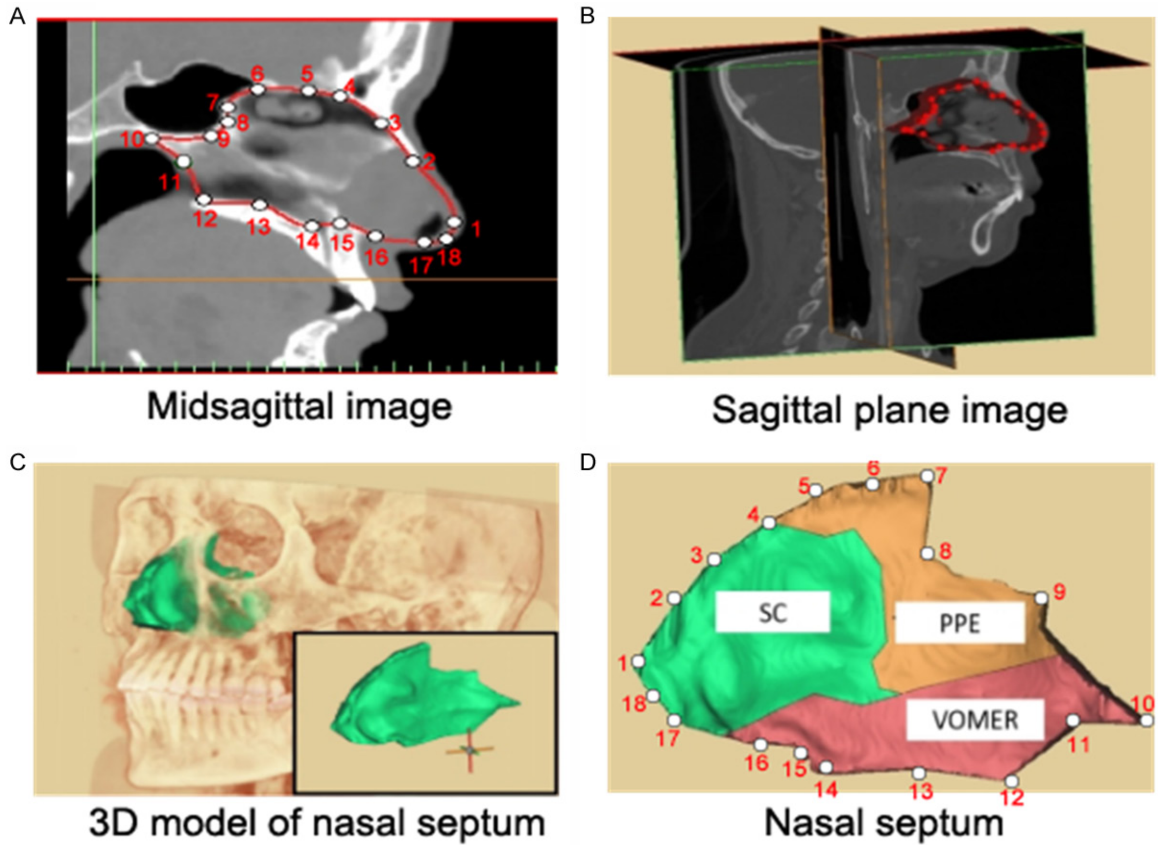

Figure 1. Reconstruction of the 3D model of the nasal septum. A. Vertical plane cutting through the maxillary spine and the crista galli. Boundary that separates the nasal septum from the adjacent tissues of nasal septum in the midsagittal image is defined by connecting dots at selected landmark locations. B. The boundary is applied to all the sagittal plane images. C. The 3D model of nasal septum is reconstructed by merging sagittal plane images (as shown in green). D. The reconstructed 3D model of nasal septum is then divided into 3 parts (color coded and labeled): the green part for SC (septal cartilage), the orange part for PPE (perpendicular plate of the ethmoid), and the red part for vomer.

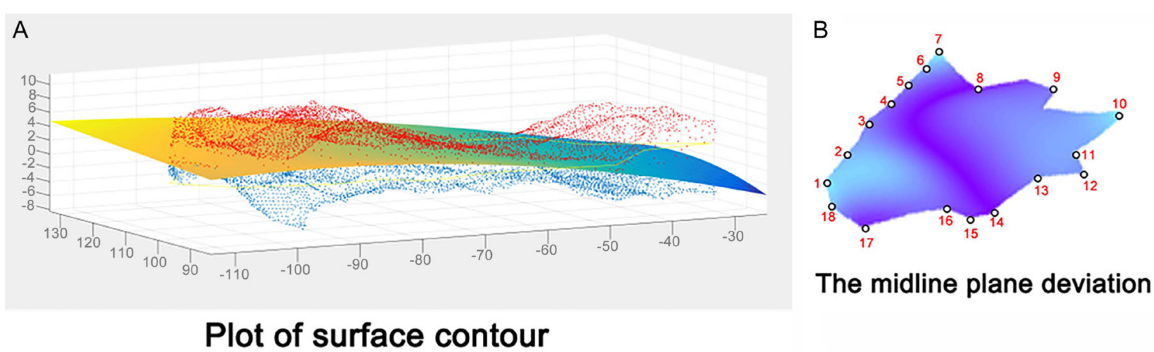

Figure 2. Plot of surface contour from raw CT data with left in red and right in blue. Midline plane is the midpoint between left and right measurement, fitted and plotted with the least square method and smoothed. The midline plane deviation is color coded with blue for right shift and red for left shift. Top down view of the surface contour reflects the irregularity of the nasal septum. Depth of the contour is reflected in darkness of the color.

Statistical analyses

Statistical analyses were performed using SPSS (version 16.0). The independent-sample t-test was used for the analysis of measurement data. Pearson correlation analysis was used to analyze the correlations between the size of the nasal septum and age and between

Table 1. The volume of the nasal septum and its components (mm^3)

	Mean ± SD	95% CI
Total septum	11774±3067	11306-12241
Septal cartilage	4699±1041	4488-4910
PPE	4043±1138	3812-4273
Vomer	2974±992	2773-3174

Table 2. The ratio of each component to the total nasal septum (mm^3)

	Mean ± SD	95% CI
Septal cartilage	0.4035±0.0736	0.3886-0.4185
PPE	0.3425±0.0658	0.3293-0.3559
Vomer	0.2491±0.0498	0.2390-0.2592

nasal septum deviation and age. All nasal septal and coordinate landmark data were collected using Osirix DICOM imaging software. $P<0.05$ was considered statistically significant.

Results

The enrolled samples consisted of 42 males and 54 females, aged 20-83 years old, with an average age of 46.28±15.40 years old.

Size of the nasal septum

The average volume of the total septum was (11774±2306) mm^3. The average volumes of PPE, vomer, and septal cartilage were (4043±1138) mm^3, (2973±992) mm^3, (4699±1041) mm^3, respectively (**Table 1**). Therefore, the ratio of average cartilage volume to the total nasal septum volume was 0.404±0.074, the ratio of average PPE volume to the total nasal septum volume was 0.343±0.066, and the ratio of average vomer volume to the total nasal septum volume was 0.249±0.050 (**Table 2**).

Nasal septum deviation

The average deviation rate of the nasal septum (η) was 0.0120±0.008.

Size of the nasal septum in individuals of different gender

The analysis results showed that the volume and components of the total nasal septum were significantly different between females and males (total septum, $P<0.01$; PPE, $P<0.01$; cartilage, $P<0.01$; vomer, $P<0.01$) (**Table 3**), while there was no significant difference in the ratio of each component of the nasal septum between females and males (PPE, $P=0.756$; cartilage, $P=0.677$; vomer, $P=0.256$) (**Table 4**).

Nasal septum deviation in individuals of different gender

Nasal septum deviation in males and females was (11638±2124) mm^3 (95% CI: 11300-12221) and (11636±2121) mm^3 (95% CI: 11302-12213), respectively. There was no significant difference in nasal septum deviation between males and females ($P=0.550$).

Correlation between the size of nasal septum and age

The volume of the total septum was not significantly correlated with age ($P=0.104$) (**Figure 3A**). The ratio of cartilage volume to the total septum significantly decreased with age ($P=0.010$) (**Figure 3B**), and the ratio of vomer volume to the total septum significantly increased with age ($P=0.018$) (**Figure 3C**). No significant correlation was found between the ratio of PPE volume to the total nasal septum and age ($P=0.331$) (**Figure 3D**).

Correlation between nasal septum deviation and age

The data indicated that nasal septum deviation had no age-dependent correlation ($P=0.666$) (**Figure 4**).

Discussion

Nasal septum is essential for nasal function, and its deviation may cause airway obstruction. In addition to symptoms evaluation and endoscopic exam, CT images are also routinely used to assist pre-operative planning [2, 10], but the conventional CT scanning is circumscribed by the lack of stereoscopic images. A reconstructed 3D model of the nasal septum provides holistic views by displaying all three components of the nasal septum [11-13], thereby providing more details of the nasal septum morphology, such as major deviation parts and impaired area.

To evaluate the function of nasal septum, the nasal septum deviation rate was adopted as a

Table 3. Comparison of the volume of each component of the nasal septum between males and females (mm^3)

	Total septum	*Septal cartilage*	*PPE*	*Vomer*
Males	*13040.32±1321.63*	*5180.45±1220.93*	*4438.65±1224.54*	*3367.23±1220.53*
Females	*10746.14±1224.63*	*4308.32±13120.64*	*3722.41±1322.45*	*2655.54±1324.62*
t	*3.469*	*5.341*	*4.125*	*2.256*
P	*0.001*	*0.002*	*0.003*	*0.001*

Table 4. Comparison of the ratio of each component to the total septum between males and females

	Septal cartilage	PPE	Vomer
Males	0.4000±0.0526	0.3402±0.0596	0.2555±0.0716
Females	0.4064±0.0636	0.3444±0.0686	0.2439±0.0776
t	2.645	3.645	5.168
P	0.677	0.756	0.256

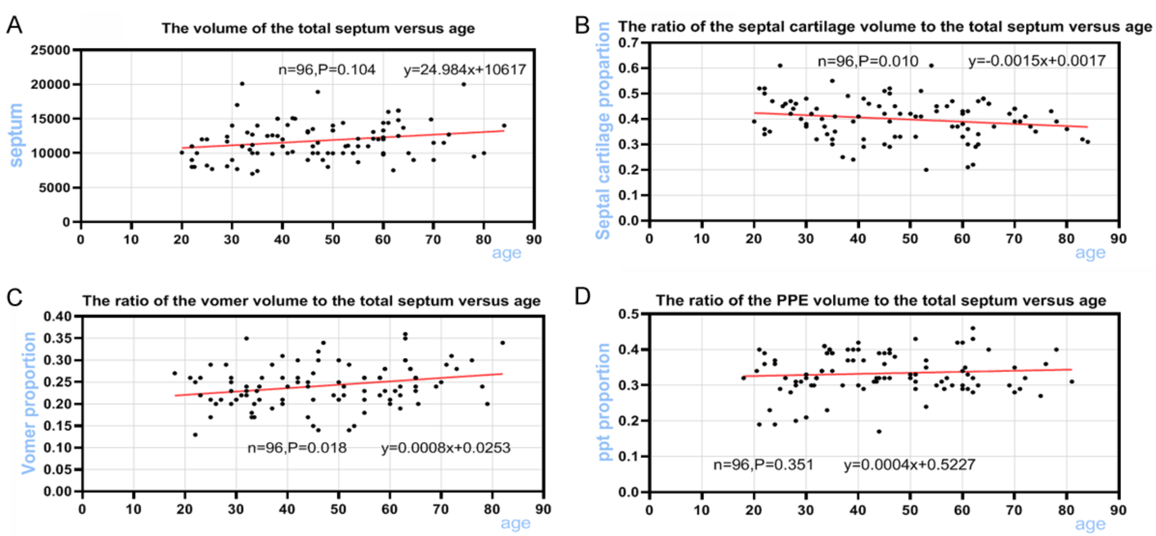

Figure 3. Correlation between the size of nasal septum and age. A. The volume of the total septum versus age (*P*=0.104). B. The ratio of the septal cartilage volume to the total septum versus age (*P*=0.010). C. The ratio of the vomer volume to the total septum versus age (*P*=0.002). D. The ratio of the PPE volume to the total septum versus age (*P*=0.331).

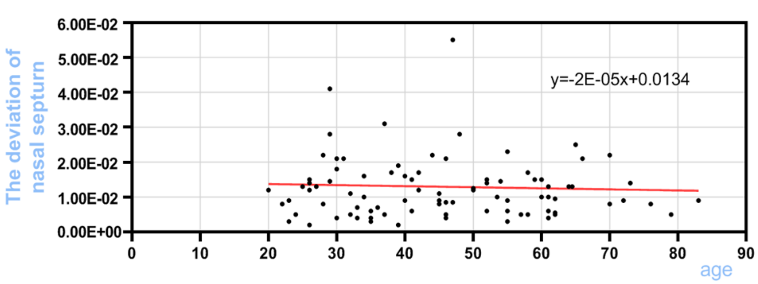

Figure 4. The deviation of nasal septum is plotted as function of age. Red line is the linear regression of the scatter plot. Slope is virtually flat (*P*=0.666), suggesting that there is no age dependent change.

parameter, which mitigates the impact of variation on the thickness of the cartilage and the overlying mucosa. Herein, there were no differences in nasal septum deviation among individuals of different genders or at a different age, which indicates stableness of nasal septum deviation given the irrelevance between the disease development and age.

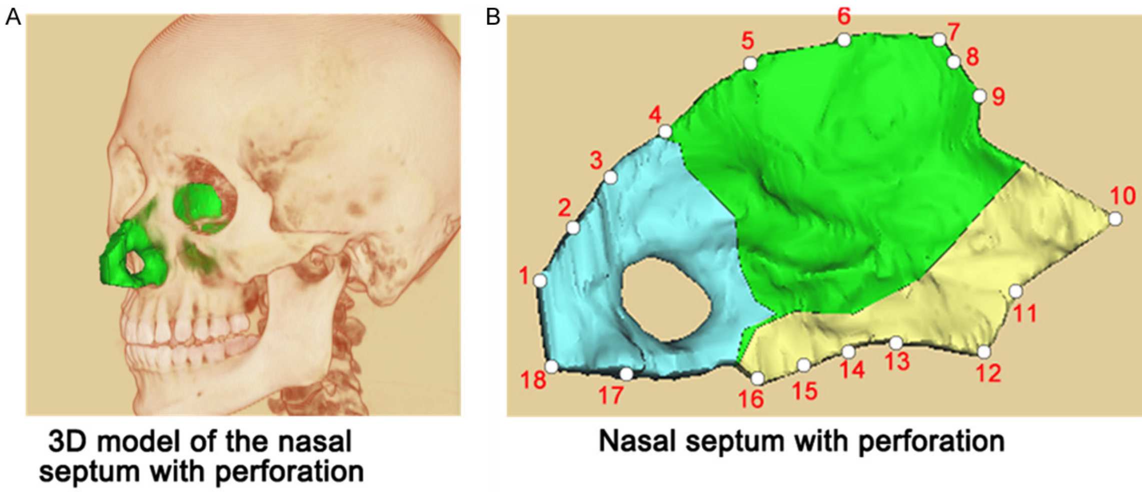

Figure 5. A reconstructed 3D model of the nasal septum with perforation. A. A reconstructed 3D model of the nasal septum; B. A realistic overview of the anatomy.

Repair of nasal septum perforation is one of the most challenging parts of nasal septum surgery, and a successful repair entails a precise diagnosis which mainly includes the size and location of the perforation. Such information is obtained from pre-operation radiological and endoscopic examinations, the results of which, however, are rather unsatisfactory [14-16].

For the purpose of developing better surgical plans, a reconstructed 3D model of the nasal septum was required to obtain a realistic overview of the anatomy (**Figure 5**).

The nasal septum is commonly used as the donor site for autogenous cartilage graft in rhinoplasty procedures, including dorsal augmentation, spreader grafts, septal extension grafts, and tip grafts [9]. However, the number of available septal cartilage in the human body is limited, which underlines the significance of the preoperative evaluation of the amount and shape of the harvestable cartilage to avert damage to the nasal framework, especially the keystone area. A reconstructed 3D model of the nasal septum can provide views from all plane angles and contribute to the measurement of the size of the harvestable cartilage during preoperative planning.

In this study, the volume of the nasal septum, including the total nasal septum and its components, was significantly larger in the males than in the females (**Table 3**), while the ratio of each component to the total nasal septum had no significant difference between them. This conclusion is consistent with that of previous study [2]. The nasal septal area measurement result in this study was similar to the autopsy results reported by Korean scholar Kim [10], but with significant difference with the autopsy results of Xu et al. [11]. Together, these results suggest that the total area of nasal septal cartilage was larger in all other studies, which also included imaging studies conducted by several Korean scholars [12]. The variance in the size of nasal septal cartilage is evident among different ethnic groups and within the same ethnic group, which entails more studies with a larger sample size for evaluation.

The ratio of the cartilage volume to the total nasal septum significantly decreased with age, while the ratio of vomer volume to the total nasal septum significantly increased with age in this study. Nonetheless, previous research reported that the ratio of the PPE area to the total nasal septum increased with age, and the ratio of cartilage area to the total nasal septum decreased with age [2]. Such discrepancies might be ascribed to the changes in the thickness of PPE and vomer with aging. Further research is warranted to develop the parameter for thickness and to clarify the correlation between the thickness of the nasal septum and age.

Aslıer et al. [17] explored the relationship between craniofacial structures and the nasal septum from a three-dimensional perspective. The measurement of the nasal septum was performed by computer software on photographs taken from the frontal view, and the cranial structure did not affect the nasal structure. Studies [18-21] revealed the impact of the nasal septum on the morphogenesis of the surrounding facial skeleton during individual development, as well as the pattern of adult facial morphology.

As mentioned above, this method is available in the comparison between normal individuals and those with nasal obstruction to test its clinical practicability. The limitations of the present study include the lack of categorical measurements involving multi-ethnic populations and the failure to exclude geographical factors, which will be expanded in future studies for more supportive results.

In conclusion, the cartilaginous proportion of the total septum decreases with age, while the nasal septum deviation remains unchanged. Clinically, more precise information of the nasal septum can be obtained through a reconstructed 3D model of the nasal septum to develop a better preoperative plan.

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Disclosure of conflict of interest

None.

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References

[1] Godley FA. Nasal septal anatomy and its importance in septal reconstruction. Ear Nose Throat J 1997; 76: 498-501, 504-506.

[2] Kim J, Cho JH, Kim SW, Kim BG, Lee DC and Kim SW. Anatomical variation of the nasal septum: correlation among septal components. Clin Anat 2010; 23: 945-949.

[3] Miles BA, Petrisor D, Kao H, Finn RA and Throckmorton GS. Anatomical variation of the nasal septum: analysis of 57 cadaver specimens. Otolaryngol Head Neck Surg 2007; 136: 362-368.

[4] Constantian MB and Clardy RB. The relative importance of septal and nasal valvular surgery in correcting airway obstruction in primary and secondary rhinoplasty. Plast Reconstr Surg 1996; 98: 38-54; discussion 55-8.

[5] Holt GR. Biomechanics of nasal septal trauma. Otolaryngol Clin North Am 1999; 32: 615-619.

[6] Lovice DB, Mingrone MD and Toriumi DM. Grafts amd implants in rhinoplasty and nasal reconstruction. Otolaryngol Clin North Am 1999; 32: 113-141.

[7] de Pochat VD, Alonso N, Figueredo A, Ribeiro EB, Mendes RR and Meneses JV. The role of septal cartilage in rhinoplasty: cadaveric analysis and assessment of graft selection. Aesthet Surg J 2011; 31: 891-896.

[8] Gunter JP and Rohrich RJ. Augmentation rhinoplasty: dorsal onlay grafting using shaped autogenous septal cartilage. Plast Reconstr Surg 1990; 86: 39-45.

[9] Kim JS, Khan NA, Song HM and Jang YJ. Intraoperative measurements of harvestable septal cartilage in rhinoplasty. Ann Plast Surg 2010; 65: 519-523.

[10] Wang H, Fan F, Wang S and You J. Intraoperative measurements of harvestable septal cartilage in rhinoplasty. Ann Plast Surg 2011; 67: 201.

[11] Xu HT, Yan S, Wu SF, Zhu B, Sun Y and Xu F. Anatomical study of nasal septal cartilage in Chinese. Chin J Cosmetic Plastic Surg 2009; 20: 267-270.

[12] Kim JH, Jung DJ, Kim HS, Kim CH and Kim TY. Analysis of the development of the nasal septum and measurement of the harvestable septal cartilage in koreans using three-dimensional facial bone computed tomography scanning. Arch Plast Surg 2014; 41: 163-170.

[13] Holton NE, Yokley TR and Figueroa A. Nasal septal and craniofacial form in European- and African-derived populations. J Anat 2012; 221: 263-274.

[14] Shahbazi A, Feigl G, Sculean A, Grimm A, Palkovics D, Molnár B and Windisch P. Vascular survey of the maxillary vestibule and gingiva-clinical impact on incision and flap design in periodontal and implant surgeries. Clin Oral Investig 2021; 25: 539-546.

[15] Mocella S, Muia F, Giacomini PG, Bertossi D, Residori E and Sgroi S. Innovative technique for large septal perforation repair and radiological evaluation. Acta Otorhinolaryngol Ital 2013; 33: 202-214.

[16] Frank DA, Kern EB and Kispert DB. Measurement of large or irregular-shaped septal perfo-

rations by computed tomography. Radiol Technol 1988; 59: 409-412.

[17] Aslıer NGY, Zeybek G, Karabay N, Keskinoğlu P, Kiray A, Sütay S and Ecevit MC. The relationships between craniofacial structure and frontal sinus morphology: evaluation with conventional anthropometry and CT-based volumetry. Ear Nose Throat J 2020; 99: 637-647.

[18] Hartman C, Holton N, Miller S, Yokley T, Marshall S, Srinivasan S and Southard T. Nasal septal deviation and facial skeletal asymmetries. Anat Rec (Hoboken) 2016; 299: 295-306.

[19] Teixeira J, Certal V, Chang ET and Camacho M. Nasal septal deviations: a systematic review of classification systems. Plast Surg Int 2016; 2016: 7089123.

[20] Üstün Bezgin S, Çakabay T, Bayramoğlu SE, Sayın N and Koçyiğit M. Evaluation of choroidal thickness measurements in patients with marked nasal septal deviation. Braz J Otorhinolaryngol 2020; 86: 242-246.

[21] Tian Q, Chu T, Sun H and Pang M. Outcomes of endonasal septoplasty and extracorporeal septal reconstruction in anterocaudal septal deviation. Ear Nose Throat J 2021; 100 suppl: 645S-651S.