RESEARCH ARTICLE

The nasal septum deviation index (NSDI) based on CBCT data

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Objective: To assess whether three-dimensional morphometric parameters could be useful in nasal septal deviation (NSD) diagnosis and, secondarily, whether CBCT could be considered an adequate imaging technique for the proposed task.

Methods: We analysed images of 46 subjects who underwent CBCT for reasons not related to this study. Two experienced operators divided all the images into healthy and NSD subjects. Subsequently, the images were segmented using ITK Snap in order to obtain the three-dimensional model of the nasal airways and compute four morphological parameters: septal deviation angle (SDA), percentage of volume difference between right and left side of the nasal airways, nasal airway total volume and a new synthetic septal deviation index (SDI). Principal component analysis (PCA) was used to unveil relationships between each variable and the global nasal airway variability.

Results: Differences between the groups were found in SDA ($p < 0.001$), in volume percentage difference ($p < 0.05$) and in SDI ($p < 0.001$). PCA showed high correlation between the SDI and the first principal component (0.97, $p < 0.001$).

Conclusions: Among the analysed parameters, SDI seemed to be the most suitable for the quantitative assessment of NSD, and CBCT allowed accurate assessment of airway morphology.

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Introduction

Nasal septal deviation (NSD) consists in a misalignment of nasal septum from the midline, which leads to respiratory disease caused by volume reduction in the nasal cavity. Together with NSD, a hypertrophy of the turbinates, opposed to septal convexity, is often noticed.^{1,2}

Diagnostic investigations currently used for this pathology are anterior rhinoscopy, endoscopy, multislice CT and MR, which allow a good evaluation of the entity and position of NSD.^{3–8} In particular, pre-operative CT scan of the paranasal sinuses is often performed before

septoplasty, in order to evaluate nasal anatomy, to find concomitant sinonasal pathologies and to reduce surgical failure.^{8–10} Despite the fact that pre-operative CT scan of the paranasal sinuses can be recommended in case of obstructive middle turbinate hypertrophy, impossibility to evaluate the middle meatus and the posterior nasal cavity or in patients with chronic sinusitis, the high radiation dose and costs do not allow its usage routinely in patients undergoing septoplasty.¹⁰

In the last decades, CBCT has been emerging, and now, it is widely used in dentistry, thanks to its high image resolution, low radiation dose and low costs.^{11–13} Currently, its clinical use in other medical fields is limited and not widespread because of minor soft-tissue contrast;

however, many studies confirm that CBCT could be a valid support in otolaryngology also.^{14–16}

Given that the evaluation of NSD in CT images is currently mainly based on subjective clinic and radiologic analyses, many studies are trying to find homogeneous and standard evaluation criteria based on the morphometric analysis of the nasal airways.^{1,17–19}

Among them, three-dimensional segmentation is currently used for morphological evaluation of the upper airways, mainly to assess obstructive sleep apnoea, traumas and congenital malformations.^{20–22}

In the present study, we segmented several CBCT images to create three-dimensional models of the nasal airways, which were used to calculate three-dimensional parameters that describe their morphology. The aim of the proposed study was to understand if CBCT could be considered an adequate imaging technique for the proposed task and if such parameters could be useful in NSD quantification before surgery.

Methods and materials

For this study, 46 CBCT images were selected from the archives of SST Dentofacial Clinic (Segrate, MI, Italy) and analysed retrospectively. Subjects who had a history of previous nasal surgery or other abnormality besides NSD were excluded.

Since the images were selected from a dental database, no information about subject otolaryngological diagnosis was available. Therefore, two experienced operators divided the selected images into deviated (NSD group) or non-deviated nasal septum (control group). Both operators were otolaryngologists with more than 3 years' experience in NSD treatments. The classification of the images into NSD or control subjects was randomized and double blinded; it was performed by each operator according to the severity of septum deviation in relation to the median line and to the eventual reduction of the air volume in the nasal cavity.

An excellent level of agreement was found between operators, with an unweighted Cohen κ equal to 0.86. Only in three cases, the operators classified the same subject into different categories; so, these data were excluded from the data set. The final data set was composed of 15 control subjects and 28 NSD subjects.

All CBCT scans were acquired by the same scanner (WhiteFox; ACTEON, Mèrignac, France). The device was operated at 6–10 mA (pulse mode) and 105 kV using an X-ray generator with fixed anode and 0.5-mm nominal focal spot size. The selected volume images are composed of isotropic 0.3-mm voxels.

To evaluate the severity of septal deviation, we assessed the difference between groups in septal deviation angle (SDA), calculated as proposed by Orhan *et al.*²³ The measurements of the angle between the maxillary spine, the crista galli and the apex of the septal deviation were taken using the freeware OsiriX (Pixmeo, Geneva, Switzerland).

Subsequently, we evaluated the percentage difference between the volume of the upper airways in the right and left side of the nose in the same samples. Volume segmentation from the CBCT files was performed using the freeware ITK Snap, which allows the user to accurately segment and calculate volumes of upper airways.^{16,24} For all images, a first automatic segmentation was subsequently refined manually.

At first, in order to obtain an accurate and reproducible segmentation of the nasal portion of the upper airway, a volume of interest (VOI) was delimited for each side of the upper airways. Each VOI was defined as a box bounded anterosuperiorly by the rhinion, the most inferior and anterior point between the nasal bones, inferiorly from the lower limit of the hard palate, posteriorly from the Posterior Nasal Spine Landmark and laterally by the lateral margins of the nasal cavity, as shown in Figure 1.

Once VOIs were selected, we proceeded with the segmentation of the nasal upper airway using the active contour segmentation option. Moreover, to avoid the inclusion of different portions of the maxillary sinuses in different subjects, they were segmented separately and their volume was subtracted from the nasal airway volume. In Figure 2, an example of the outcome of the segmentation process is shown.

The repeatability in the selection and segmentation of the VOI and in deviation angle measurements was verified on a subsample of 10 CBCT. Statistical analyses on measurement repeatability were performed by calculating Student's *t*-test and Dahlberg's formula.²⁵

After the segmentation, the volumes of each side of the upper airway were measured, and then their relative volume percentage difference (VPD) was calculated as:

$$VPD = \frac{|V_r - V_l|}{V_r + V_l} \cdot 100$$

where V_r and V_l , both expressed in cm^3 , represent the volumes of the right and left VOIs defined previously.

Finally, a new index, named septal deviation index (SDI), was introduced. The SDI was designed to summarize information about the angle of septal deviation, volume difference between right and left side of the nose and total volume of the nasal airway and was calculated as:

$$SDI = \frac{(SDA + 1) \cdot (VPD + 1)}{V_T}$$

where SDA is expressed in degrees, VPD is the adimensional volumetric percentage of difference and V_T represents the total volume of nasal airways ($V_T = V_r + V_l$). Both SDA and VPD were increased by a unitary factor to prevent SDI from tending to zero if only one of these factors is null.

The statistical analysis was performed using the MATLAB[®] statistic toolbox (MathWorks[®], Natick, MA). Student's *t*-tests and χ^2 tests were performed to compare different morphometric parameters in healthy and NSD subjects. Statistical significance was set at

Figure 1 Example of a selected volume of interest for the right side of the nasal airways using ITK Snap. The bounding box is highlighted using dashed rectangles in sagittal (top) and frontal (bottom) views.

$p < 0.05$. Furthermore, since the evaluated morphometric variables are related to each other, we used principal component analysis (PCA) to transform all the morphological data into a set of uncorrelated variables called principal components.²⁶ According to Kaiser's rule, we retained the components whose eigenvalues were larger than 1.²⁷ PCA was performed on the correlation matrix of the normalized data set.

Pearson's correlation coefficients retained principal components, and all calculated parameters were also computed. In this way, PCA is used to unveil the relationship between each variable and the global nasal airway variability.²⁸

Results

The analysed groups were composed of 15 control subjects (7 males, 9 females; average age 46 ± 15 years) and 28 NSD subjects (15 males, 13 females; average age

48 ± 15 years). No significant difference was found in age (Student's t) and sex composition (χ^2) between groups ($p > 0.05$).

Repeatability analysis showed no significant differences for both SDA and volume measurements ($p > 0.05$). In particular, random errors explained 0.77% of sample variance for angle measurements and 0.99% for volume measurements.

Values of SDA, VPD and SDI were significantly higher in NSD subjects compared with healthy subjects. Descriptive statistics of these parameters are summarized in Table 1.

In particular, intergroup analysis showed statistically significant differences in SDA ($p < 0.001$), in VPD ($p < 0.05$) and in SDI ($p < 0.001$) between healthy and NSD subjects. No significant difference was found in V_T between groups ($p > 0.05$).

Only the first component (PC1) and the second component (PC2) resulting from the PCA were retained. These

Figure 2 Example of segmentation of the right (B) and left (C) side of the nasal airway and of the left and right maxillary sinuses (A and D, respectively). In the top image, the segmentation outcomes are represented in a posterior coronal CBCT slice. In the bottom image, an example of the three-dimensional volumes segmented in the proposed study is depicted.

two components explained 86.6% of the sample variance. For PC1, higher values of correlation coefficient were found for SDI (0.97, $p < 0.001$) and for standard deviation (0.89, $p < 0.001$); on the other hand, PC2 seemed to be more correlated with V_T (0.94, $p < 0.001$) than the other morphological variables. In Table 2, all the calculated correlation coefficients are detailed.

Discussion

In otorhinolaryngology, NSD is one of the most frequent diagnoses, and it is generally based on the evaluation of patient symptoms and on anterior rhinoscopic outcomes.⁶ This clinical analysis is accompanied by quantitative diagnostic methods used to demonstrate the septal deviation.^{7,8,29} In particular, cross-sectional images allow the correlation of patient symptoms to the

airway anatomy of both the anterior and posterior nasal cavity before surgery.^{10,30}

In this study, we analysed 46 CBCT images belonging to dental patients whose otolaryngological diagnosis is

Table 1 Septal deviation angle (SDA), volume percentage difference (VPD), total volume (V_T) and septal deviation index (SDI) between healthy and nasal septal deviation (NSD) group

Morphological parameters	Groups	Mean	SD	Min	Max
SDA (°)	Control	9.5	2.5	5.9	14.3
	NSD	17.3	5.5	10.0	36.0
VPD (%)	Control	5.5	4.9	0.1	16.4
	NSD	13.6	11.6	0.39	54.7
V_T (cm ³)	Control	18.1	4.7	12.2	30.5
	NSD	16.5	3.1	12.1	23.1
SDI (°/cm ³)	Control	3.8	3.2	0.6	12.0
	NSD	16.5	14.3	1.3	62.9

SD, standard deviation.

Table 2 Eigenvalues and explained variance of the retained principal components and their corresponding Pearson's correlation coefficients for the analysed morphological variables

Principal component	Explained variance (%)	Pearson's correlation coefficient			
		SDA	VPD	V_T	SDI
PC1	57.0	0.75	0.89	0.12	0.96
PC2	29.6	-0.40	0.19	0.94	0.12

The analysed parameters are: septal deviation angle (SDA), septal deviation index (SDI), volume percentage difference (VPD) and total volume (V_T). PC1, first component; PC2, second component.

unknown, to assess whether there was a significant difference in four morphological parameters (SDA, VPD, VT and SNI) between NSD and healthy subjects. This analysis was performed in order to assess whether quantitative and evidence-based morphometric parameters may be useful in NSD diagnosis or septoplasty pre-operative planning and to test the validity of a proposed synthetic index summarizing these parameters.

In the present investigation, two experienced operators divided all the images into control and NSD groups. An excellent level of agreement, with Cohen's $\kappa = 0.86$, was found, suggesting not only concordance between operators, but also adequacy of the CBCT images for the proposed task.

Regarding volumetric and angular measurement, the proposed method appears repeatable, since the measurement error was $<1\%$ of the sample variance for both measures.

At first, we evaluated the SDA, which is frequently used to assess the severity of NSD.^{23,31,32} As expected, the results showed a significant difference between healthy and NSD subjects. Moreover, the high repeatability of SDA measurements demonstrated that CBCT scans could be used to evaluate the severity of NSD.

A significant difference between the groups was also found in the percentage of volume difference between the left and right side of the nasal airways. This value is independent of subject size and consequently of his/her airway dimension. Therefore, it can be a useful three-dimensional index to assess the balance of volume in the two different sides of the airways. In our study, we found higher values of VPD in NSD subjects, suggesting a paradoxical hypertrophy. Our results showed that SDA and VPD could characterize NSD subjects. For this reason, we decided to merge them into a single global parameter, SDI, which is directly proportional to them and indirectly proportional to the total volume of the nasal airways. This index has significantly higher values in NSD than in control subjects and appears to be a useful parameter for septal deviation quantification, since it takes into account various factors contributing to subject respiration. SDI is robust to the variation of only one parameter between SDA and VPD, which may separately contribute to the patient's breathing, and takes into account that septal deviations may create more or less discomfort to the subject depending on the size of his/her nasal airway. In particular, SDI can be a useful parameter because it is not a local descriptor of the nasal

cavity, like SDA, but takes into account the three-dimensional morphology of the nasal cavity. Moreover, this index showed the highest correlation with PC1, which expresses 57.0% of the sample variability.

In multivariate analysis, only PC1 and PC2 were retained. PC1 highly correlates with all the morphological parameters that have significantly higher values in NSD subjects than in healthy subjects. This component is therefore more related to factors that identify NSD, rather than to the size of the airway.

On the contrary, PC2 (29.6% of explained variance) is highly related to the nasal airway size of the subject; so, it is less suited for representing the analysed sample. This is also evidenced by the non-significant difference in terms of V_T in the analysed groups.

From our findings it can be stated that SDA, VPD and SDI are morphological parameters that may help surgeons to better understand the patient's upper airway morphology, estimating the amount of the septal deviation and the air volume in each side of the nose. In particular, they may be a useful tool during the pre-operative assessment of the nasal airway, in order to enable the surgeon to find the optimal surgical intervention that will produce the best outcome.³³

Although results are promising, a further validation of the proposed method is advised. In particular, the validation on a sample of CBCT images of patients with known otolaryngological diagnosis would allow correlating these quantitative parameters with the patient medical history, thus overcoming the limitations caused by the need to group the subjects only in accordance with radiologic examination and without clinical diagnosis.

Conclusions

In the present study, four three-dimensional morphological parameters were analysed to evaluate their usefulness in assessing the deviation of the nasal septum. Retrospectively selected CBCT images, which allowed accurate assessment of the morphology of the airways of the patient, reducing the dose of radiation and therefore its invasiveness, were used.

Among the analysed parameters, the proposed SDI seems to be the most suitable for the quantitative assessment of NSD, since it summarizes different morphometric factors. Further investigation shall expand the study to patients with clinically assessed alterations in respiratory function and nasal airway patency.

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