ORIGINAL ARTICLE

# Reformatted Computed Tomography to Assess the Internal Nasal Valve and Association With Physical Examination

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**Objectives:** To assess the cross-sectional area and angle of the internal nasal valve more accurately by reformatting computed tomography (CT) scans of the nasal airway according to a more appropriate orientation than scans traditionally sectioned in the coronal plane and then to compare the results with clinical data on the nasal valve obtained from physical examination.

**Methods:** We performed a retrospective review of the medical records of 24 rhinoplasty patients treated at a private practice facial plastic surgery office affiliated with a tertiary care university hospital. The patients had fine-cut (0.75-mm section) CT scans ordered for nasal airway obstruction or nasal valve compromise at the same institution. These patients were evaluated from January 1, 2000, through December 31, 2010. The previously acquired CT scans were reformatted to obtain sections through the internal nasal valve at a more appropriate orientation. The internal nasal valve cross-sectional area and valve angle were measured through a standardized section (1 cut immediately anterior to the head of the inferior turbinate) from the reformatted scans. The cross-sectional area was also measured through the same point on the traditionally oriented CT scan, and the values were compared. The results from each patient's scan were compared with data from the patient's medical record and analyzed against the patient's preoperative modified Cottle examination findings.

**Results:** The CT scans oriented in the reformatted plane through the internal nasal valve provided a narrower valve angle than the traditionally oriented CT scans and more closely approximated the hypothesized true value of the internal nasal valve of 10° to 15° ($P < .001$). In a comparison of the same-side internal nasal valve angle and cross-sectional nasal valve area between the 2 different CT scan orientations, a statistically significant difference in the internal nasal valve angles between the 2 scan orientations was discovered, but this finding did not reach significance when distinguishing the nasal valve cross-sectional area. Finally, no correlation was found with regard to the preoperative modified Cottle maneuver scores for the internal nasal valve angle and cross-sectional valve area values in either scan orientation.

**Conclusions:** Precise preoperative evaluation of the internal nasal valve is critical to the workup for reconstruction or repair of problems that involve this area. Although tools such as acoustic rhinometry exist to evaluate the cross-sectional area of the nasal valve, many rhinoplasty surgeons do not have access to this expensive equipment. A CT scan with reformatting in the proper plane of the internal nasal valve can provide the surgeon with improved anatomical information to assess that region. With this in mind, however, the surgeon should always perform a thorough preoperative physical examination and treat the patient and his or her symptoms, not the imaging studies, when considering a candidate for a surgical intervention.

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ALTHOUGH FUNCTIONAL AND anatomical analysis of the nasal cavity has been extensively studied, a standard objective measure of nasal obstruction has not yet been established. Specifically, the internal nasal valve, the site of maximum resistance along the entire respiratory tract from the nasal vestibule to the alveoli, has been the target of much research. Small changes in nasal valve size result in large changes in airflow resistance, which in turn affects nasal function.[1,2] As a result, the internal nasal valve is an extremely important area for surgeons to accurately assess before reconstruction or repair of the nose. Existing tools, including rhinomanometry and acoustic rhinometry, can be used to assess nasal resistance and the internal nasal valve area; however, each of these tools has its limitations. For one, many rhinoplasty surgeons do not have this expensive equipment readily available to them. In addition, studies[3-5] that involve these tools are equivocal in their correlation with a patient's preoperative and postoperative assessments of nasal patency and function. Numerous studies[5,6] have found that high preoperative intranasal resistance or increased postoperative internal nasal valve area correlated with higher levels of patient satisfaction. However, the results from these data are far from uniform, and the internal nasal valve cross-sectional area has not correlated well with subjective reports of nasal patency.

Despite mixed data from objective outcome studies on improvement of nasal function, a great deal of level 4 (case series) evidence remains that supports the current techniques used in functional rhinoplasty operations. However, numerous authors[1,7] have called for further studies on objective outcome measures to correlate known positive clinical outcomes with standardized, objective methods.

To fill this void, computed tomography (CT) has been proposed as an objective tool to measure internal nasal valve anatomy preoperatively and postoperatively.[8,9] However, the traditional coronal imaging plane does not provide an adequate assessment of the internal nasal valve. In studies by Cakmak et al[10] and Poetker et al,[11] the authors suggest that the nasal valve angle may be better estimated when CT scans are reformatted to a plane perpendicular to the estimated acoustic axis.[10,11] These studies demonstrate that CT may be a valuable tool in objectively assessing outcomes of functional nasal operations; however, neither study correlated the objective data to clinical findings.

Our study assesses the cross-sectional area and angle of the internal nasal valve more accurately by reformatting CT scans of the nasal airway according to a more appropriate orientation than scans traditionally sectioned in the coronal plane. We then compare these results with clinical data on the nasal valve obtained from physical examination.

## METHODS

### STUDY DESIGN

Our study retrospectively reviewed the medical records from the last 10 years (January 1, 2000, through December 31, 2010) of patients who had CT scans ordered for nasal airway obstruction or nasal valve compromise and then underwent subsequent functional and/or cosmetic rhinoplasty surgery. We used reformatted CT scans of the nasal airway to more accurately assess the internal nasal valve area. A plane perpendicular to a line along the patients' bony nasal dorsum was used to delineate the new orientation in which the CT scan should be reformatted, and the internal nasal valve cross-sectional area was measured at a standardized section (1 cut immediately posterior to the head of the inferior turbinate). The area of the internal nasal valve was measured in the traditional coronal plane and the angled reformatted plane. More important, these measures were also correlated with the preoperative physical examination findings, including modified Cottle maneuver scores, to establish which study correlated better with in-office examination findings.

A total of 46 patients were identified who had available CT scans at our same institution and subsequently underwent surgical correction. For each patient, data were collected regarding physical examination findings, previous surgical history, nasal airway obstruction symptoms, and, when available, modified Cottle maneuver scores.

The modified Cottle maneuver was performed in the standard fashion.[12] A curette or the wooden end of a cotton-tipped applicator was used to first lift the upper lateral cartilages and then the lower lateral cartilages bilaterally. Patients had scores of 1 to 10, with a higher number representing improved ability to inspire. Measurements are taken at 3 points: at rest, with the lower lateral cartilage supported, and while supporting the upper lateral cartilage. Tests were performed before decongestion. Of the 46 patients, modified Cottle maneuver results were available for 24 patients. It was the medical records of these 24 patients that were used for all of the data correlation.

### RADIOGRAPHIC ANALYSIS

Masked to the clinical data reviewed, the staff neuroradiologist was able to assess the internal nasal valve angle and cross-sectional valve area through CT scan analysis (Somatom Sensation 64, Sensation 40, or Somatom Definition AS+ scanner; Siemens). Axial plane images were acquired with a collimation of 0.6 mm, 120 kV, and 80 to 140 mA; a rotation time of 1 second; and a field of view of 14 cm. The raw data were obtained from the top of the frontal sinuses to the bottom of the maxillary incisors and reconstructed for the sinonasal cavities in the axial plane using a section thickness of 0.75 mm in bone algorithm.

The 0.75-mm-thick axial sections were reformatted using the 3-dimensional software on the iSite Philips PACS system (iSite View Forum Applications; Philips Medical Systems). The images were reformatted in the standard coronal plane perpendicular to the hard palate and in the coronal oblique plane perpendicular to the bony nasal dorsum, which approximates the acoustic axis, estimated on the sagittal view.

Measurements of the internal nasal valve were obtained on the image cut immediately anterior to the inferior nasal turbinate. Measurements included the nasal valve angle and the cross-sectional area of the nasal valve (**Figure 1** and **Figure 2**). The nasal valve angle was measured along the medial and lateral margins of the airway lumen averaging the contour irregularities, with the apex extending to the anterior-superior margin of the soft tissue. The area was obtained along the margins of the airway lumen. All of the images were reconstructed and measurements were performed by a masked attending neuroradiologist (M.H.).

### STATISTICAL ANALYSIS

Statistical analysis was performed by a separate statistician uninvolved with clinical record or radiologic analysis. Mean and standard deviation were calculated in a standard manner with 95% CIs. Analysis of variance (ANOVA) was used to compare left and right coronal and reformatted planes with respect to the measures of the internal nasal valve angle and valve area. The internal nasal valve angle and cross-sectional area measures were used as the dependent variables in separate analyses, and each model included plane as a classification factor. The error variance was allowed to vary across planes to remove the assumption of variance homogeneity. A Tukey multiple comparison correction was used so that the comparisons for each dependent variable had a familywise type I error probability of .05. ANOVA was also used to assess whether the true mean angle measure from each plane differed from a theoretical true value of 15. Pearson correlation coefficients were used to assess the association of the angle and valve area measures from each plane with each of the in-office measurements. All reported $P$ values emanated from 2-sided tests with statistical significance defined as $P < .05$, and computations were performed using SAS statistical software (SAS Institute Inc).

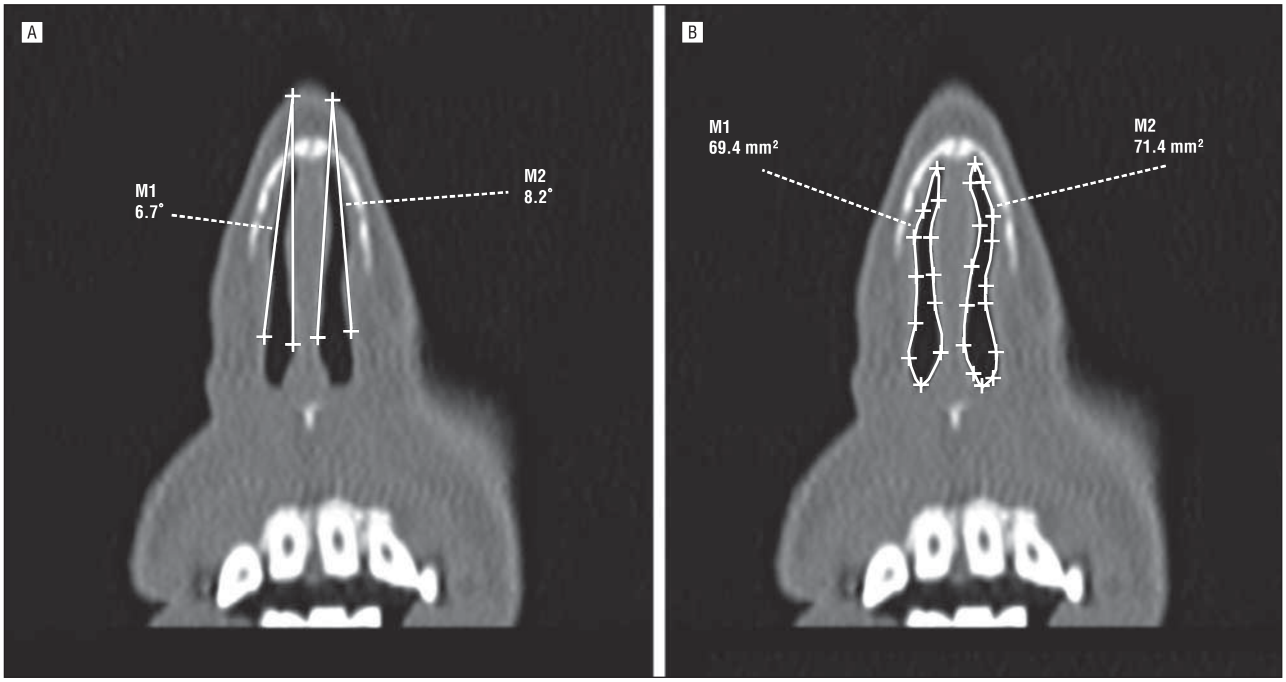


**Figure 1.** Computed tomograms of the internal nasal valve region. A, Measurement of the internal nasal valve angle according to the standard coronal plane orientation. B, Measurement of the cross-sectional area of the internal nasal valve region in the same patient, with the scan oriented in the standard coronal plane orientation. M1 indicates right nasal cavity; M2, left nasal cavity.

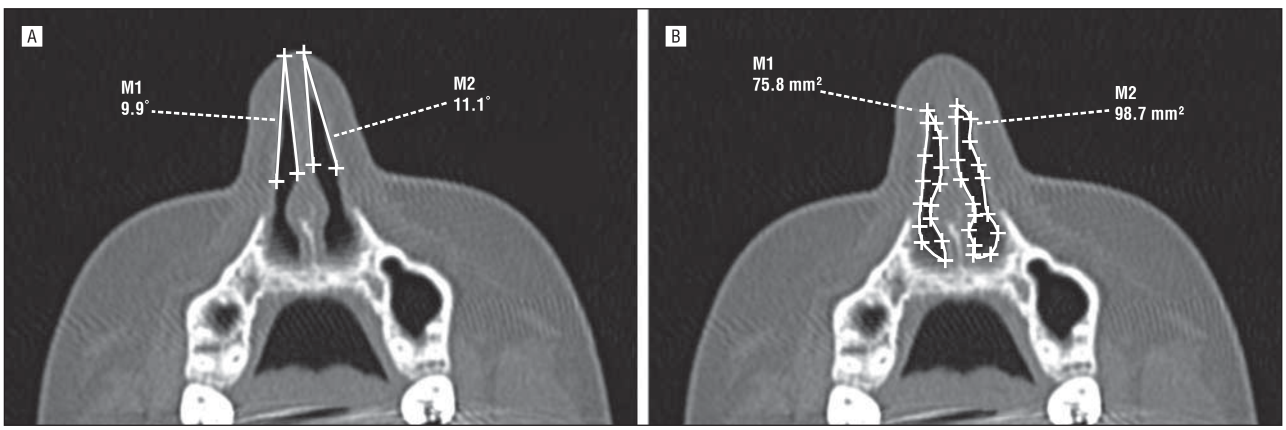


**Figure 2.** Reformatted computed tomograms of the internal nasal valve region. A, Measurement of the internal nasal valve angle in the same patient but now oriented according to the reformatted plane. B, Measurement of the cross-sectional area of the internal nasal valve region in the same patient now oriented in the reformatted plane. Abbreviations are defined in the legend to Figure 1.

## RESULTS

Mean values were calculated for nasal valve angle and area on both the standard and modified reformatted coronal views as described. Left- and right-side internal nasal valve angles were calculated independently. **Table 1** lists the mean value, data range, and standard deviation of the radiographically derived measurements. ANOVA revealed that the mean angles from each of the planes were significantly lower than the hypothesized true value of the internal nasal valve angle, which was 15° ($P < .001$). A comparison of the same-side internal nasal valve angle and cross-sectional nasal valve area between the 2 different CT scan orientations revealed a statistically significant difference in the internal nasal valve angles between the 2 scan orientations ($P < .001$ for the left plane and $P = .008$ for the right plane) but did not reach significance when distinguishing nasal valve area ($P = .23$ for the left plane and $P = .30$ for the right plane).

Last, the Pearson correlation was calculated with regard to the physical examination and modified Cottle maneuver scores for the internal nasal valve angle and cross-sectional area values independently. No correlation score reached significance when evaluating both CT scan orientations for the internal nasal valve angle or cross-sectional valve area, when the correlation cutoff was set at −0.05 or +0.05 (**Table 2** and **Table 3**).

## COMMENT

In our data, reformatted CT scan images were able to demonstrate a different subset of internal nasal valve angle val-

**Table 1. Radiographically Derived Measurements of the True Mean of the Left and Right Coronal Planes and Reformatted Measures of the Internal Nasal Valve Angle and Cross-sectional Valve Area**

| | Mean (SD) [95% CI] | |
|---|---|---|
| Type | Angle, ° | Valve Area, mm² |
| Left coronal plane | 7.69 (2.52) [6.95-8.44] | 93.71 (27.98) [85.48-101.94] |
| Right coronal plane | 7.69 (2.22) [7.04-8.34] | 97.98 (31.26) [88.78-107.17] |
| Left reformatted plane | 10.28 (2.94) [9.41-11.14] | 82.84 (26.08) [75.16-90.51] |
| Right reformatted plane | 9.71 (3.54) [8.66-10.75] | 85.50 (35.97) [74.92-96.09] |

**Table 2. Pearson Correlation and Corresponding *P* Values for the Association of the Valve Angle Measurements From Each Plane With Each of the In-Office Measurements**

| | Left Coronal Plane | | Right Coronal Plane | | Left Reformatted Plane | | Right Reformatted Plane | |
|---|---|---|---|---|---|---|---|---|
| Measure | *r* | *P* Value | *r* | *P* Value | *r* | *P* Value | *r* | *P* Value |
| Left baseline | 0.09 | .68 | 0.09 | .70 | −0.02 | .93 | −0.13 | .54 |
| Left ENV | 0.04 | .87 | 0.31 | .15 | 0.24 | .27 | 0.01 | .95 |
| Left INV | 0.04 | .86 | 0.08 | .71 | 0.03 | .90 | −0.28 | .19 |
| Right baseline | −0.13 | .56 | 0.02 | .92 | 0.05 | .84 | 0.28 | .19 |
| Right ENV | 0.10 | .64 | 0.29 | .17 | 0.13 | .57 | 0.23 | .29 |
| Right INV | 0.06 | .80 | 0.19 | .37 | 0.02 | .92 | 0.18 | .40 |
| Total | −0.12 | .59 | −0.06 | .80 | −0.13 | .56 | 0.03 | .89 |

Abbreviations: ENV, external nasal valve; INV, internal nasal valve.

**Table 3. Pearson Correlation and Corresponding *P* Values for the Association of the Valve Cross-sectional Area Measurements From Each Plane With Each of the In-Office Measurements**

| | Left Coronal Plane | | Right Coronal Plane | | Left Reformatted Plane | | Right Reformatted Plane | |
|---|---|---|---|---|---|---|---|---|
| Measure | *r* | *P* Value | *r* | *P* Value | *r* | *P* Value | *r* | *P* Value |
| Left baseline | 0.25 | .26 | −0.12 | .58 | 0.45 | .03 | 0.24 | .27 |
| Left ENV | 0.14 | .53 | −0.04 | .85 | 0.45 | .03 | −0.07 | .75 |
| Left INV | 0.07 | .76 | −0.27 | .21 | 0.45 | .03 | −0.24 | .27 |
| Right baseline | −0.19 | .38 | 0.12 | .58 | −0.05 | .83 | 0.00 | >.99 |
| Right ENV | −0.14 | .52 | 0.22 | .31 | 0.06 | .80 | 0.06 | .79 |
| Right INV | −0.19 | .38 | 0.03 | .89 | −0.03 | .90 | −0.10 | .65 |
| Total | −0.14 | .54 | −0.21 | .34 | 0.24 | .28 | 0.08 | .72 |

Abbreviations: ENV, external nasal valve; INV, internal nasal valve.

ues when compared with traditional coronal CT scan. With mean values of 10.28° and 9.71° for the left and right sides, respectively, these calculated angles seem to correlate more with the classically described values for the internal nasal valve angles of 10° to 15°.[13] In comparison, the CT scans with the standard coronal formatting showed internal nasal valve angles smaller than traditionally quoted values. These data appear to reproduce the findings of previous studies[10,11] in which CT scans reformatted along a similar plane also demonstrated this concept.

Unique to our study was the measurement of nasal valve cross-sectional areas in the reformatted plane. Mean values for nasal valve area in the reformatted plane were 82.84 and 85.50 mm² for left and right, respectively, whereas in the standard CTs, mean nasal areas were 93.71 and 97.98 mm². These values, when compared, did not meet criteria for statistical significance. Interestingly, although the reformatted CT scans revealed larger nasal valve angles, nasal valve areas trended toward being smaller when compared with traditionally oriented sinus CT scans. Currently, there is not a well-described radiologic estimate of the normal internal nasal valve area with which we can compare our measurements in both types of CT scans. This limitation could be because much of the original work on the internal nasal valve angle was based on cadaveric studies. If the atrophied tissues of those cadaver specimens were analyzed with CT scans, they would not correlate with the results of an in vivo CT scan of healthy tissues in a living patient.

The modified Cottle maneuver is often used by the senior author (M.C.) when preoperatively evaluating patients with nasal airway obstruction symptoms. Scores from in-office examination were compared with the measurements of the nasal valve area and internal nasal valve angles in both CT scan formats. The Pearson correlation was calculated along with its corresponding *P* value for each modified Cottle maneuver value, including baseline, external nasal valve, and internal nasal valve. A cutoff for biological data has been established at $r = \pm 0.5$ to show a significant correlation. Our analysis of the data failed to elucidate any correlation between modified Cottle maneuver scores and measurements of internal nasal valve angles or cross-sectional areas. A small set of values in our data approached significance on one side but failed to show the same correlation in the contralateral nasal cavity. This finding led us to conclude that modified Cottle maneuver scores do not seem to correlate with the radiologic data found, not only for our reformatted images but also for the traditional CT images. The reason that these findings did not correlate might have to do with the concept of static air flow vs dynamic airway collapse. When evaluating a patient with the modified Cottle maneuver, the patient is asked to inspire nasally, often leading to a dynamic collapse of their nasal airway or internal nasal valve. On the other hand, the CT scans represent a static moment in time that is captured while the patient is asked to hold his or her breath or breathe quietly.

The modified Cottle maneuver has been previously shown to be a valuable preoperative tool to access the site of nasal obstruction. When the Cottle maneuver was performed in a standard fashion, the authors were able to improve nasal patency by catering surgical intervention to modified Cottle maneuver findings.[12] In contrast, recent studies[11,14] have demonstrated the capacity of radiographic imaging to delineate nasal anatomy, although most reports have not been able to correlate these findings to clinical symptoms, physical examination findings, or postoperative improvements in nasal patency. Various other modalities have been studied, such as acoustic rhinometry. Acoustic rhinometry has its own pitfalls, including access to equipment, increased evaluation times, and limitations in determining the exact cause of nasal valve collapse. The ease and availability of performing the modified Cottle maneuver and its reliability make it an ideal screening examination for these patients.

Our findings beg the question of whether physical examination findings should be emphasized over radiologic assessments. The modified Cottle maneuver often delineates the need for surgical repair while identifying the root of nasal valve stenosis, but we propose that it also acts as a screening tool. Because CT alone has not been proven to correlate with patient symptoms or modified Cottle maneuver score, we advocate not obtaining sinus CT imaging when there are no external nasal deformities or an abnormal modified Cottle maneuver score. The combination of patient symptoms and physical examination findings may be a more appropriate assessment of the nasal valve because of its dynamic evaluation of the nasal airway rather than the static images of the CT scan. Computed tomographic imaging can assist the surgeon with some aspects of the rhinoplasty decision-making process, but physical examination findings can be more useful for preoperative surgical planning.

Further prospective studies and refinements of our model will be necessary to make formal conclusions on the importance of our reformatted CT images in evaluating the nasal valves. A control group would be ideal to compare the internal nasal valve angles and cross-sectional valve areas of patients without nasal symptoms with our data. In addition, correlations between their modified Cottle maneuver scores and CT findings would further elucidate the validity of our data.

Precise preoperative evaluation of the internal nasal valve is critical to the workup for reconstruction or repair of problems that involve this area. Although tools such as acoustic rhinometry exist to evaluate the cross-sectional area of the nasal valve, many rhinoplasty surgeons do not have this expensive equipment available to them. A CT scan with reformatting in the proper plane of the internal nasal valve can provide the surgeon with improved anatomical information to assess that region. With this in mind, however, the surgeon should always perform a thorough preoperative physical examination and treat the patient and his or her symptoms, not the imaging studies, when considering a candidate for a surgical intervention.

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