Assessment of Internal Nasal Valve Using Anatomically-Accurate 3D Airway Models

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Objectives

The optimal method for analysis of the internal nasal valve (INV) on computed tomography (CT) imaging has not been established. The objective of this study was to use anatomically-accurate 3D airway models developed from high-resolution CT scans of adults with healthy nasal airways to identify the most accurate plane for assessing the cross-sectional area and angle of the INV on coronal CT. The INV area obtained from this novel method was compared to 1) the traditional coronal view, perpendicular to the hard palate, and 2) a previously-described reformatted plane perpendicular to the nasal bone.

Introduction

The INV is responsible for almost half of the airway resistance [1] and thus minor changes in valve area result in large changes in airflow resistance, which is clinically relevant in the approach to the patient with symptomatic nasal obstruction. [2,3] In certain clinical or research situations, objective assessment of nasal airflow and internal nasal valve (INV) dimensions may be desirable. Acoustic rhinometry (AR) and rhinomanometry are existing tools that can be used for measurement of nasal patency, but both have limitations, including the need for specialized equipment, extra cost, and lack of routine clinical availability. [2]

Computed tomography (CT) has been established as an objective tool for the assessment of INV dimensions [4,5] and is readily available as a diagnostic modality. Current methods for determining INV anatomy via CT have limitations, however, as evidenced by the fact that the correlation between CT and AR results is imperfect. [2] Clinically, the correlation between radiographic analysis of the INV and subjective symptoms of nasal patency are incompletely explored. [2]

The optimal method for analysis of the INV on reformatted CT imaging has yet to be established. The objective of the current study was thus to use anatomically-accurate 3D airway models (shown in Figure 1), developed from high-resolution CT scans of healthy adult subjects, to search for a more accurate plane for identification of the minimal cross-sectional area and angle of the INV on coronal CT.

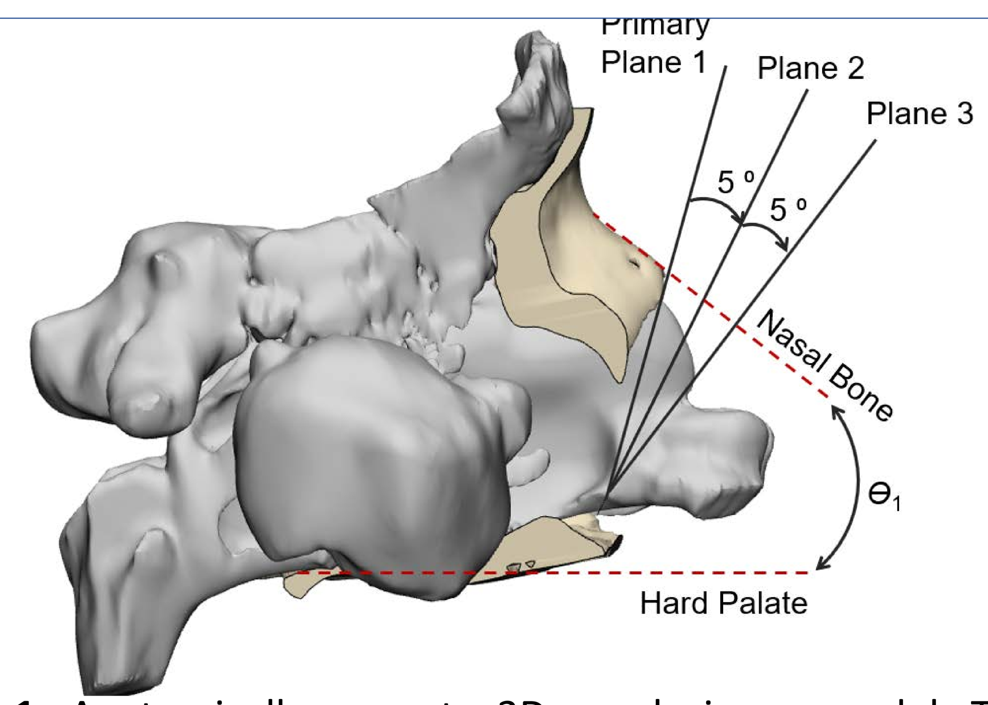

Figure 1. Anatomically-accurate 3D nasal airway model. The angle between the nasal bone and hard palate, Θ_1, and the cutting planes (primary Plane 1, Plane 2, and Plane 3) are illustrated.

Methods and Materials

Anonymized CT scans of the sinonasal region were obtained for adult subjects with healthy nasal airways and reviewed to confirm inclusion of the entire nasal cavity and nasopharynx down to the inferior aspect of the C1 vertebra. Patients with significant radiographic evidence of sinonasal disease were excluded (e.g., sinonasal neoplasm, prior facial trauma or surgery, septal perforation, presence of foreign body, and chronic rhinosinusitis with Lund McKay score >3) [6,7]. The study was reviewed by the Institutional Review Board (IRB) panel A at VCU and FDA Research Involving Human Subjects Committee (RIHSC), and the protocol for collection and conversion of CT images to 3D printed models was approved as an expedited study by VCU and the FDA RIHSC. Twenty adult subjects with healthy nasal airways were included (50% male/50% female, 50% age ≥ 50 years).

The INV is delineated by the plane including the head of the inferior turbinate (IT), upper lateral cartilage (ULC), and nasal septum, and is by definition the narrowest point within the nasal airway. A primary cutting plane was defined in the coronal axis that passed through the edge of the nasal bone, ULC, and anterior aspect of the IT. Cross-sectional area of the INV was measured using the two previously-described reference planes, perpendicular to either the hard palate (A_{INV-C} resulting from plane c in Figure 2) or bony nasal dorsum (A_{INV-B} resulting from plane B in Figure 2). The primary coronal cutting plane was then rotated in 5-degree increments, making sure the anatomic criteria for the INV were still met. The cutting plane resulting in the minimum INV cross-sectional area was identified (Optimum Plane in Figure 2) and its angle with the nasal dorsum was measured.

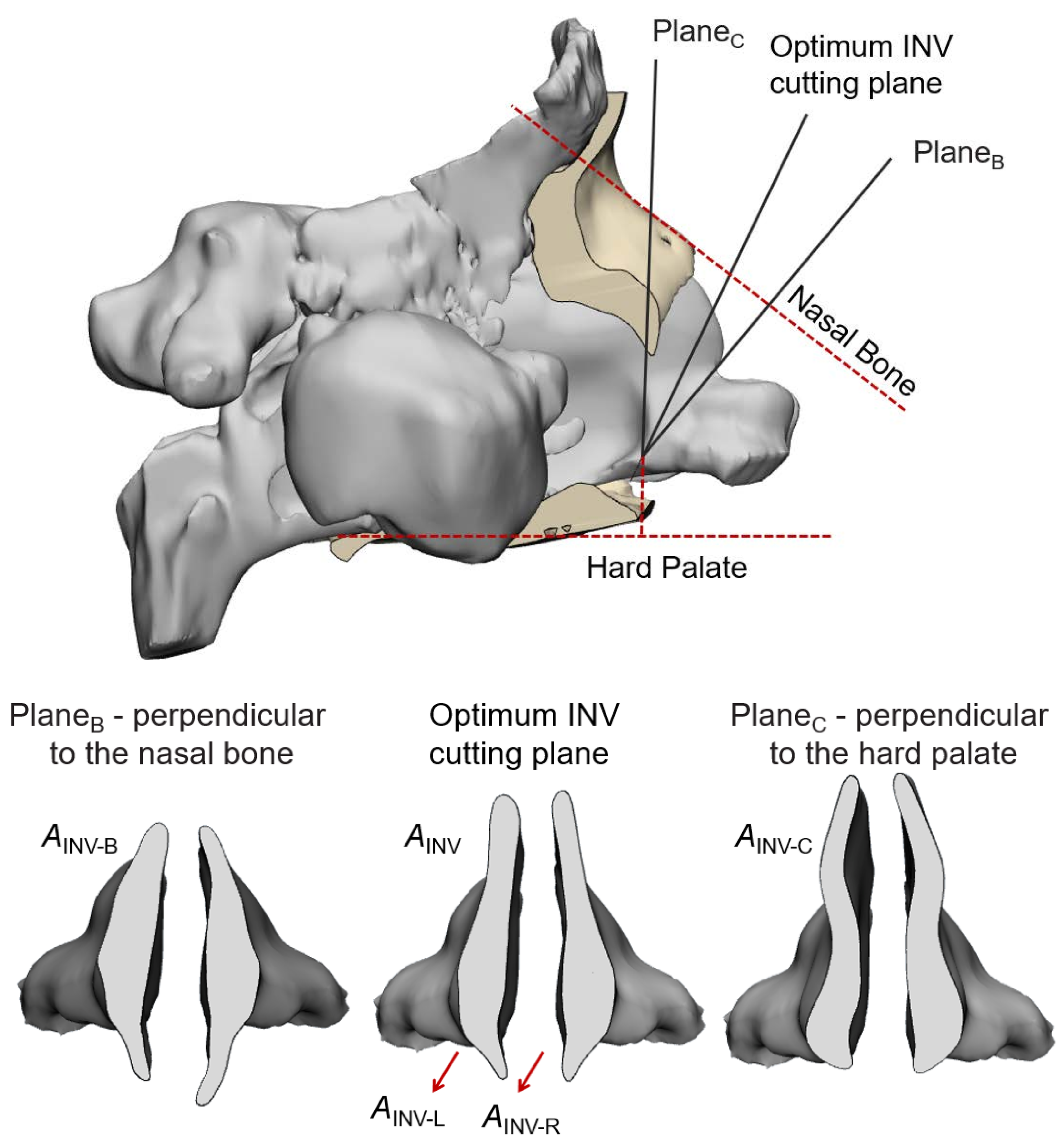

Figure 2. Anatomically-accurate 3D nasal airway model depicting: (top) the optimum cutting plane, the cutting plane perpendicular to the hard palate in the traditional coronal view, $Plane_C$, and the reformatted plane perpendicular to the nasal bone, $Plane_B$. (bottom) the cross-sectional areas of the nasal valve defined using the optimum cutting plane, $Plane_B$ and $Plane_C$.

Results and Discussion

A novel method for determining the optimal plane of INV analysis on reformatted CT through the use of anatomically-accurate 3D airway models was defined. The consistent ratio of anterior volume to total airway volume (0.05±0.02) and ratio of anterior surface area to total airway surface area (0.06±0.01), identified across the 20 models, illustrates consistency in technique for location of the INV. The angle between the cutting plane and the nasal dorsum resulting in the minimum cross-sectional area was 75.00±10.26° in 20 subjects.

The INV is responsible for almost half of airway resistance [1] and thus minor changes in valve area result in large changes in airflow resistance, which is clinically relevant in the approach to the patients with symptomatic nasal obstruction [2,3]. Although the physical exam is essential in diagnosis of INV pathology, objective methods for evaluation may have utility in certain circumstances, and existing methods for doing so have definite limitations. Although the INV is typically assessed on CT reformatted in the traditional coronal plane or perpendicular to the nasal bone, the current study suggests this may overestimate the true INV area (see Figure 3), and a more accurate plane lies approximately 75 degrees from the nasal dorsum.

A two-tailed t-test was performed comparing the values obtained for the INV cross-sectional area. In the current data set there were no differences between the cross-sectional area of the INV measured using either of these previously-reported planes (A_{INV-C} and A_{INV-B}, p=0.52). The average INV area determined from the optimal cutting plane, however, was significantly lower than that obtained via the two previously described methods (p=0.01). These data suggest that traditional methods for evaluating the INV on reformatted CT may actually overestimate the true valve area; this may have implications in terms of accuracy in clinical diagnosis and management of INV disorders.

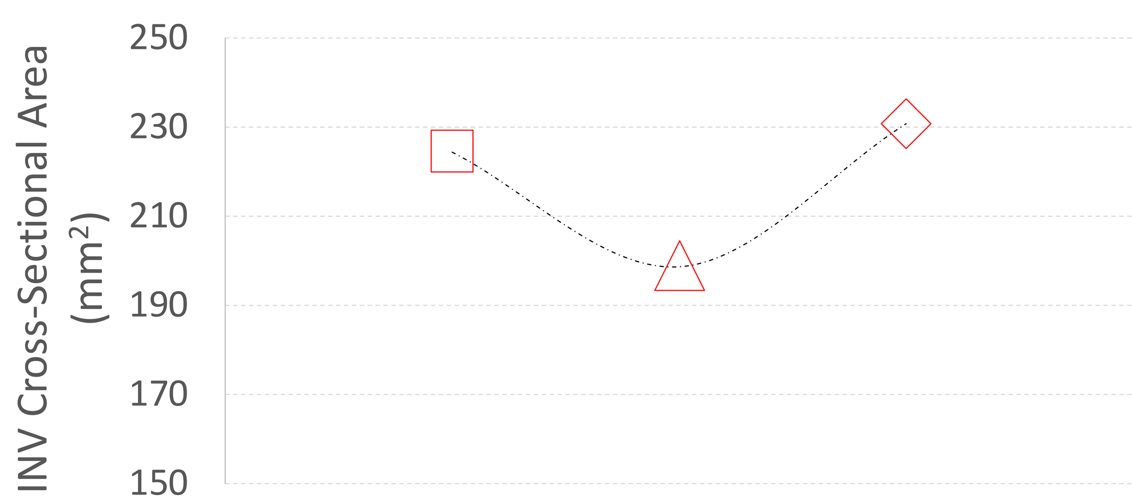

Figure 3. Comparative cross-sectional areas of the valve plotted using standard coronal plane, the optimum coronal plane (defined in this study), and the plane perpendicular to the nasal bone (from left to right).

Conclusions

Traditional methods of evaluating the INV on coronal CT resulted in over-estimation of cross-sectional valve area in the majority of adult subjects. Employing a novel method, we used 3D anatomical airway models to establish an optimal coronal plane for INV analysis with the angle of 75.00±10.26° from the nasal dorsum.

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