Cone Beam Computed Tomography: An Innovative Tool for Airway Assessment

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Improvements in airway imaging technology provide the potential for an improved understanding of airway pathology and upper airway mechanics. We present here a preliminary report on the applicability of cone beam computed tomography technology in conjunction with multidimensional digital analysis for the purposes of clinical airway management. The use of this technology for airway imaging in anesthesiology has not been reported. Traditional skeletal and soft tissue images as well as distance and volume measurements were obtained without difficulty. Three-dimensional image reconstructions as well as "virtual laryngoscopy" were achieved with resulting excellent image quality, suggesting a broad range of possibilities for upper airway examination and analysis. A modified Muller test with volumetric rendering of the airway passages under baseline and negative pressure conditions was also performed, made possible as a result of the system's short (9 s) scanning times. We believe that cone beam computed tomography technology offers an additional dimension to airway evaluation that has considerable potential.

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Advances in magnetic resonance imaging (MRI) and computed tomography (CT) technology have opened new dimensions for understanding upper airway anatomy and physiology. Practical application of these technologies, however, is limited because of cost, accessibility, and complexity. Cone beam CT technology (CBCT) has emerged as a potential alternative to MRI and CT scanning for obtaining complete, fast, and detailed upper airway images at relatively modest cost. This technology applies cone beam x-rays to the head and neck, providing 2-dimensional (D) and 3-D images. The radiograph source is a low-energy fixed anode tube similar to those used in dental panoramic machines. Also used is a cone-shaped radiograph beam with a special image intensifier, as well as a charge-coupled device sensor or an amorphous silicon flat panel for image capturing. When used in conjunction with a DICOM viewer, there are many potential advantages, such as lower costs, scan times under 10 s, and the ability to conduct scans with the patient in the sitting position (Table 1).

We describe the use of a CBCT system (CB Mercu-Ray Dentomaxillofacial Conebeam radiograph CT System, Hitachi Medical Systems, Tokyo, Japan), along with the DICOM viewers CBWorks (Cybermed Inc., Seoul, Korea) and OsiriX Medical Imaging Software (freeware, http://www.osirix-viewer.com) to produce images of the airway.

To describe the potential of CBCT methods to help prepare for airway management, the following clinical examples are presented.

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SKELETAL CEPHALOMETRIC ANALYSIS

CBCT can be used to obtain skeletal measurements using a selection of views (e.g., coronal, transversal) of the cephalic and cervical structures:

Cervical Spine

CBCT is potentially useful for assessing neck stability, allowing rotational imaging to obtain detailed measurements of the distance between the posterior wall of the atlas and the anterior wall of the odontoid process under different conditions (Fig. 1).

Esthetic Facial Proportion

CBCT is potentially useful for assessing the relative positions of the mandible and maxilla, an important issue since a posteriorly placed mandible predisposes to airway obstruction[1] and difficultly with intubation (Fig. 2, top).

Table 1. Potential Advantages of Cone Beam Computed Tomography (CT) Imaging Technology

Comfortable sit-down environment for the patient, especially helpful for those individuals with anxiety when positioned supine inside a magnetic resonance imaging (MRI) or CT scanner
Provides high definition, 0.1-mm thick image slices
Short scanning times, less than 10 s
Less radiation exposure compared to ordinary CT scans
Less cost compared to ordinary CT scans
Digital image manipulation provided, allowing 2 and 3 dimensional processing features with volumetric reconstruction and measurement quantification
Virtual elimination of the need for additional imaging

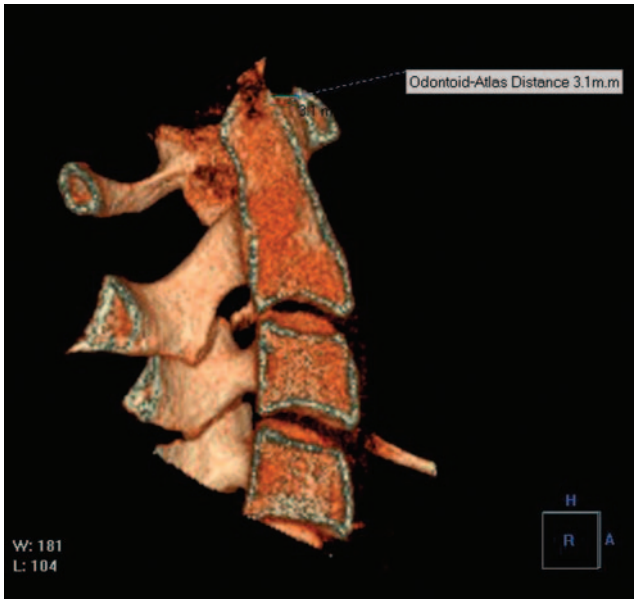

Figure 1. Digitally isolated cervical spine in a healthy 45-yr-old male patient.

Mandibular Body Length

One cephalometric variable found to be linked to increased likelihood of airway obstruction is the "mandibular body length"[2] (Fig. 2, bottom).

SOFT TISSUE STRUCTURES

Tongue

The tongue's size and volume is potentially important in predicting difficulty with intubation. The Mallampati score is one means to evaluate the relation of the tongue to the oral cavity. As our contribution to this concept, we theorize that volume of the tongue in relation to the volume of oral cavity may be a helpful predictor of difficulty with ventilation or with intubation (Fig. 3, top).

Soft Palate

The soft palate extension into the retroglossal area can be measured accurately with CBCT. It has been described as a marker of risk for obstruction of the airway[3] (Fig. 3, bottom).

Airway Shape

The normal airway has been described as oval shaped with a larger lateral distance compared with the anterior posterior distance. Abnormal upper airway geometry is associated with an increased risk of airway obstruction.[4–6] With the CBCT, one is able to perform the necessary measurements with relative ease (Fig. 4, in Web appendix, available at www.anesthesia-analgesia.org).

Airway Caliber

With the CBCT, we were able to objectively measure the caliber of the airway at different levels. The quantification of the airway caliber may be useful in determining the severity of any anatomical obstruction, especially those that occur outside the scope of simple visual evaluation (Fig. 5, in Web appendix, available at www.anesthesia-analgesia.org).

3-D RECONSTRUCTION, VOLUMETRIC ANALYSIS, AND VIRTUAL REALITY

We used CBworks, a 3-D imaging package, to obtain 3-D models of the airway. We hypothesize that such models may be valuable to obtain clinical information such as the multidimensional anatomy of the airway passages, quantification of the severity of malformations, tumors and stenoses, and plasticity of the airway (see below).

Dynamic Volumetric Analysis and Modified Muller Test

Decreased airway volume has been linked to an increased risk of airway collapse and obstruction. MRI studies have shown the decreased airway volumes in obese patients that improve with weight loss. "Normal" values for any given patient have not yet been determined.

The Muller test measures the plasticity of the airway and its tendency to collapse. In this test, negative pressure is presented to the airway by asking the individual being tested to inhale against an obstruction and evaluating the response using nasopharyngoscopy. We took advantage of the small scan times with CBCT to perform a "modified" Muller test in a 45-yr-old man in the sitting position, where volumetric airway changes were obtained under different amounts of negative inhalation pressure (−20 mm Hg, −40 mm Hg, and −60 mm Hg), a process not otherwise practical with the longer scan times for CT and MRI. In this instance, CBCT provides far more information than nasopharyngoscopy, since changes are detectable not only at an internal level, but also in surrounding tissues. (Not only are changes in the hole of the doughnut observed, but also changes in the doughnut itself!) We found a decrease in airway volume with different amounts of negative pressure. We believe this constitutes an exciting finding worthy of future study (Figs. 6a–c in Web appendix, available at www.anesthesia-analgesia.org).

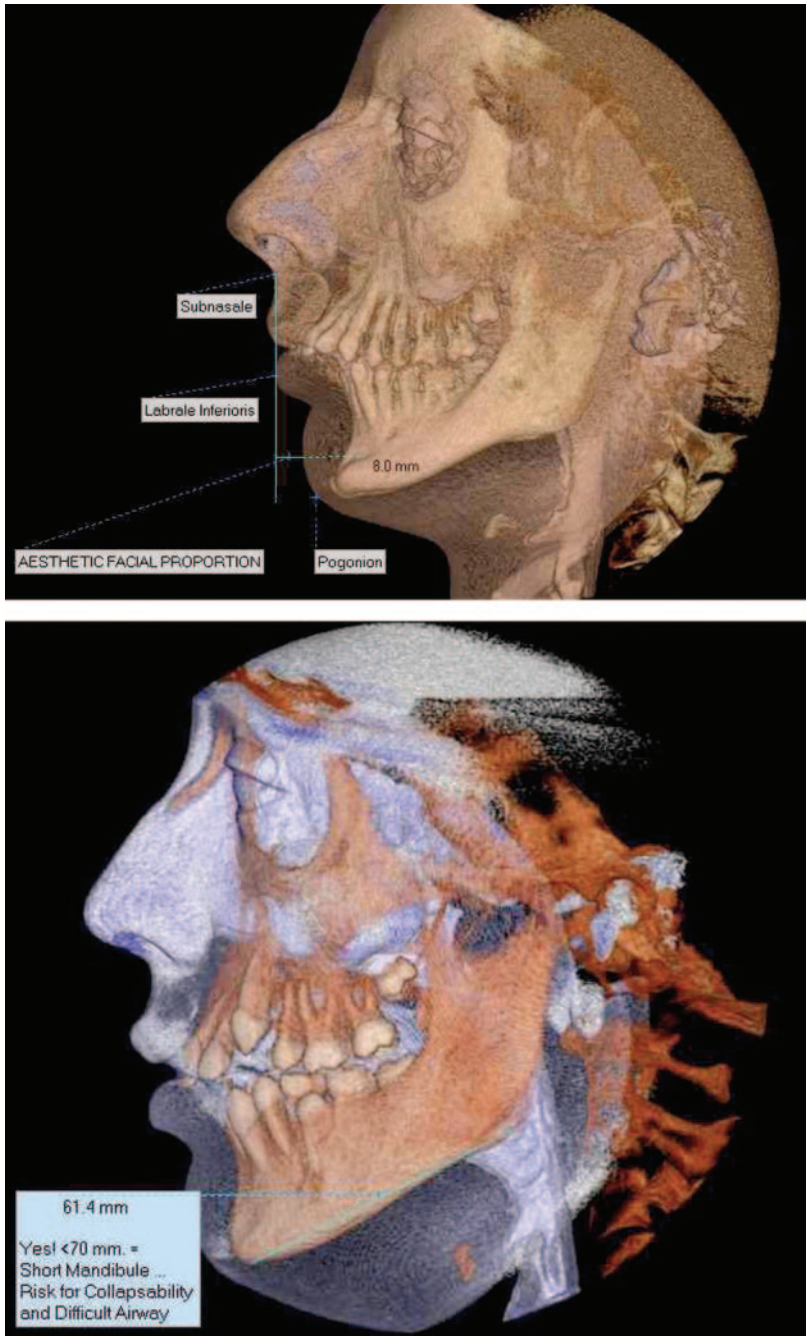

Figure 2. 3-D Anatomical models demonstrating micrognathia and the measurement of mandibular length. Top: A 16-yr-old man with retrognathia. Bottom: A 15-yr-old woman with a history of obstructive sleep apnea.

Virtual Laryngoscopy

The CBCT system we used complies with DICOM technology standards, making it possible to process obtained images in different platforms. We used OsiriX,[7] an image processing software dedicated to DICOM images, to generate "flying through" reconstructions. We found the resulting video clips to be of high quality, similar to fiberoptic imaging, but without the invasiveness. We consider virtual laryngoscopy to be a promising future technique to support clinical anesthesia practice (Figs. 7a–d in Web appendix, available at www.anesthesia-analgesia.org).

DISCUSSION

Management of the airway continues to challenge anesthesiologists. In patients known or suspected to be difficult to intubate, traditional clinical tools such as history and examination may have limited value when preparing for subsequent attempts at intubation. Although the utility of CBCT in this setting remains to be formally tested, we believe that it may eventually prove to be helpful. In particular, studies of CBCT may ultimately identify airway variables that are more predictive of airway difficulties than are our current variables. In addition, established methods for assessing and managing difficult airways might also be evaluated in the light of CBCT methods.

In the last two decades, MRI and CT scanning have emerged as valuable tools for understanding the biomechanics of the airway. However, the use of these technologies has been limited mostly to research

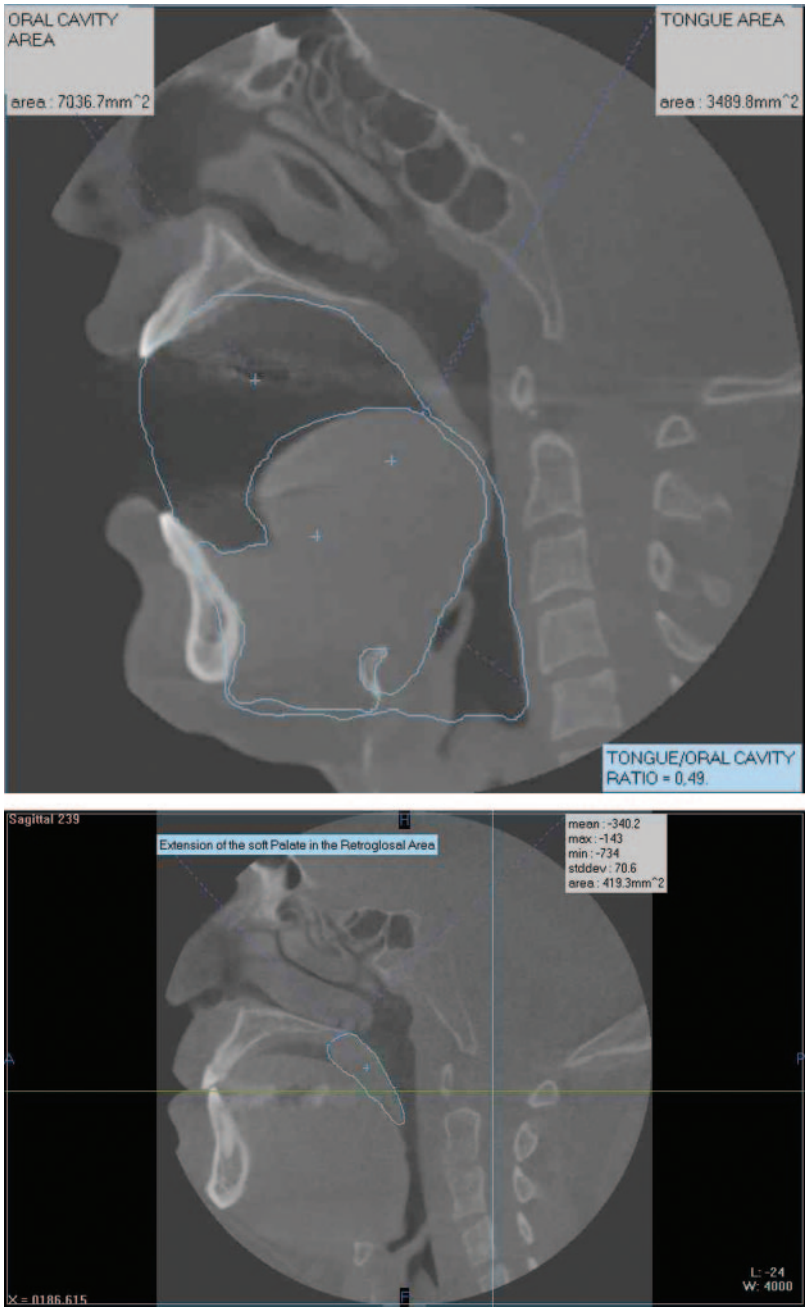

Figure 3. Top: Tongue to oral cavity area ratio measurement in a 31-yr-old healthy male patient. Bottom: Soft palate two-dimensional area measurement in a 52-yr-old man with a history of obstructive sleep apnea.

applications because of their high cost and limited availability, making them impractical for everyday use. Still, some clinical case reports have emerged. For example, Ames et al.[8] describe a 7-yr-old patient with Goldenhar syndrome in whom CT imaging techniques were used to identify the cause of a previous failed tracheal intubation and to produce a movie of the upper airway similar to the view obtained through a fiberscope. Such virtual imaging techniques have the potential to provide a means of noninvasive airway assessment that can be particularly valuable in pediatric patients or patients with extreme anxiety.

We suggest that CBCT may offer even more potential than CT and MRI techniques to provide advanced airway imaging. We found that CBCT can also be used to obtain any measurement previously established in the literature to be predictive of difficult intubation. We were also able to obtain images of every aspect of the airway, including "hidden" anatomy, and to analyze them from any desired axis. Also, volumetric reconstruction methods provide an anatomically accurate internal view of the airway that could be helpful in patients with known supraglottic or infraglottic airway obstruction.

Clinicians have classically performed the Muller test in order to assess the airway in patients with high risk of airway collapsibility (obesity, obstructive sleep apnea). We reformulated this test using CBCT methods and expect that this will eventually advance the management of some difficult airway patients.

The "fly through" reconstructions obtained provide video images comparable to fiberoptic bronchoscopy,

opening a new field in the evaluation of the airway passages.

In our opinion, CBCT has the potential to eventually emerge as a comprehensive and practical system to evaluate the airway, and should become an excellent research and teaching tool for understanding the normal and abnormal airway. Regardless, practical issues such as the cost of the method (which should generally be less than a CT scan), and its suitability for uncooperative adults or unsedated children remains to be assessed more fully.

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