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Objective characterization of airway dimensions using image processing

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ABSTRACT

Objectives: With the evolution of medical and surgical management for pediatric airway disorders, the development of easily translated techniques of measuring airway dimensions can improve the quantification of outcomes of these interventions. We have developed a technique that improves the ability to characterize endoscopic airway dimensions using common bronchoscopic equipment and an open-source image-processing platform.

Methods: We validated our technique of Endoscopic Airway Measurement (EAM) using optical instruments in simulation tracheas. We then evaluated EAM in a large animal model (*Ovis aries*, n = 5), comparing tracheal dimensions obtained with EAM to measurements obtained via 3-D fluoroscopic reconstruction. The animal then underwent resection of the measured segment, and direct measurement of this segment was performed and compared to radiographic measurements and those obtained using EAM.

Results: The simulation tracheas had a direct measurement of 13.6, 18.5, and 24.2 mm in diameter. The mean difference of diameter in simulation tracheas between direct measurements and measurements obtained using EAM was 0.70 ± 0.57 mm. The excised ovine tracheas had an average diameter of 18.54 ± 0.68 mm. The percent difference in diameter obtained from EAM and from 3-D fluoroscopic reconstruction when compared to measurement of the excised tracheal segment was 4.98 ± 2.43% and 10.74 ± 4.07% respectively. Comparison of these three measurements (EAM, measurement of resected trachea, 3-D fluoroscopic reconstruction) with repeated measures ANOVA demonstrated no statistical significance.

Conclusions: Endoscopic airway measurement (EAM) provides equivalent measurements of the airway with the improved versatility of measuring non-circular and multi-level dimensions. Using optical bronchoscopic instruments and open-source image-processing software, our data supports preclinical and clinical translation of an accessible technique to provide objective quantification of airway diameter.

1. Introduction

Laryngotracheal stenosis is a common complication of critically ill children, affecting 1–2% of patients in the neonatal intensive care unit and up to 11% of pediatric patients requiring mechanical ventilation [1,2]. As an adjunct to clinical metrics, the quantification of airway narrowing plays a vital role in directing surveillance, medical interventions and surgical management. Subjective assessment of airway stenosis has been shown to result in misclassification, even with experienced practitioners [3]. In order to critically assess and manage laryngotracheal stenosis, objective

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characterization is necessary. The most commonly used method of objective measurement is approximation of the inner airway diameter with the known outer diameter of endotracheal tubes as proposed by Myer et al., classifying airway size into four grades in relation to age appropriate norms [4]. The simplicity and reliability of the Cotton-Myer system has made it the gold standard for airway sizing and the associated classification of grading will undoubtedly continue to be useful in the characterization of airway stenosis.

Although endotracheal tube approximation is the preferred technique for airway sizing, it has some limitations. First, sizing with a circular instrument such as an endotracheal tube is most accurate when approximating a circular structure; regions of stenosis are commonly irregular in shape and not adequately measured with circular endotracheal tubes. Additionally, there are clinical scenarios that preclude approximation of the airway with an endotracheal tube including patients with a difficult airway, distal stenosis, or multilevel lesions. The aim of our study is to describe and validate a method for airway measurement integrating commonly available optical instruments used in pediatric airway evaluation and an open-source image-processing platform using both *ex-vivo* and ovine models. Our hypothesis is that our method of endoscopic airway measurement (EAM) is as effective as radiographic techniques for measuring airway dimensions.

2. Materials and methods

2.1. Technique for endoscopic airway measurement (EAM)

An endoscope with an associated optical instrument is selected. Once the optical instrument is secured to the endoscope, a calibration image is captured using a ruler in contact with the end of the optical instrument. Endoscopic images are then captured with attention directed to maintaining the tip of the optical instrument at the level of interest in the center of the airway lumen. Images are adequate if the captured image includes the entire lumen of the airway at the level of the end of the optical instrument.

The calibration image and endoscopic image are then uploaded into Image J (v 1.49, NIH, Bethesda, MD, USA). The calibration image is used to set a distance to pixel ratio using the ruler in the image as reference. This ratio is then applied to the endoscopic image since the distance to pixel ratio will be the same for all images captured with the same camera and same resolution at the same distance from the end of the lens. The optical instrument guarantees this relationship as it provides a fixed distance from the end of the telescope. Once the scale is set, the airway lumen to be measured is outlined with Image J using the freehand drawing tool. The airway dimensions are then calculated using Image J.

2.2. Ex-vivo model

Polyvinyl chloride (PVC) conduits (internal diameter of 13.6 mm, 18.5 mm, and 24.2 mm) were used as *ex-vivo* tracheal models. An optical forceps (spoon-shaped, round) (10350L) was mounted on a 5.5 mm diameter/50 cm length Hopkins® Straight Forward Telescope 0° (10320 AA) (Storz, Tuttlingen, Germany) and used to obtain images with a Storz telepack X (Tuttlingen, Germany) (Fig. 1, c and d). The spoon-shaped optical forceps head served as a calibration instrument and images were obtained using a ruler placed at the end of the forceps (Fig. 1a and b). Measurements taken with EAM were compared to measurements obtained with an electronic digital caliper (accuracy 0.001 inch, repeatability 0.0005 inch) (iGAGING, San Clemente, California).

2.3. Ovine model

The use of juvenile sheep in this study was approved and overseen by the Institutional Animal Care and Use Committee (IACUC Protocol #AR13-00071) to ensure humane treatment and the respect for animal rights. Anesthetic induction of the sheep was performed using either ketamine and diazepam or propofol. Following endotracheal intubation, the animals were maintained under general anesthesia using propofol and/or isoflurane. After initial preparation, the Hopkins rod telescope with optical forceps was inserted into the airway and images of the planned tracheal resection segment were digitally captured using the Storz telepack system. Calibration images were obtained as described in Section 2.1 (Fig. 1e and f). Three-dimension rotational fluoroscopy was performed (Infinix, Toshiba, Japan) and analyzed using Vitrea® Enterprise Suite Imaging Software (Vital, Minnetonka, MN, USA; Fig. 1g and h). The animals then underwent tracheal resection of a 3 cm segment with orthotopic implantation of a tissue-engineered tracheal graft. Images of both the proximal and distal ends of the resected segment were obtained for measurement of the excised tracheal segment in addition to direct measurement with the electronic digital caliper.

2.4. Bronchoscopic image analysis

Two images of the trachea were measured using EAM. The airway circumference at the level of the end of the instrument was traced using Image J as described in Section 2.1 and used to calculate a luminal area and diameter.

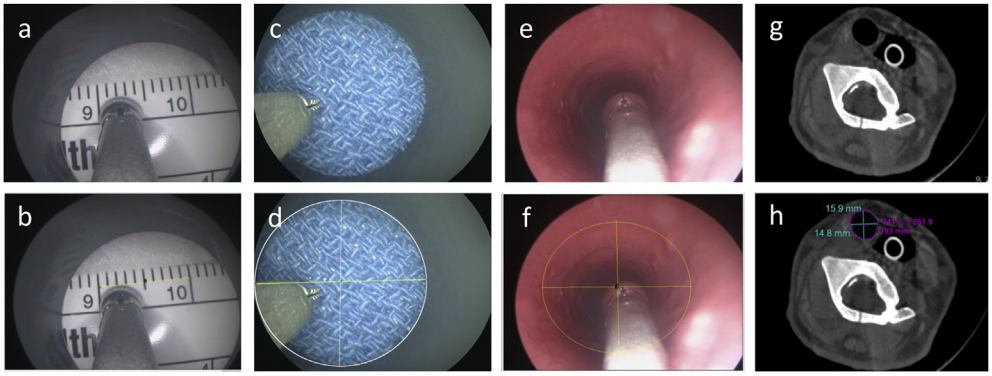

Fig. 1. Bronchoscopic and Fluoroscopic Images in both an ex-vivo (a-d) and in-vivo (ovine) model (e-h). Calibration images with (b) and without (a) measurements are demonstrated. (c) and (d) show the *ex-vivo* images and measurements, while (e) and (f) demonstrate the *in-vivo* ovine model and measurements. 3-D rotational fluoroscopic images are shown in (g) and (h).