Designing A Video Laryngoscope Imaging System with A 7-mm Blade for Neonatal Patients

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**ABSTRACT**

In case of ventilation failure while using a resuscitation mask after a newborn infant is pushed from the birth canal, a doctor must perform intubation in the infant as well as other emergency measures to keep the baby alive. However, because of the considerably small mouth area of a newborn or premature infant, doctors are unable to view the glottis entrance, which can lead to a failed intubation or long intubation time, thereby resulting in either a drop in oxygen levels or a rise in the intrathoracic pressure. Although a normal video laryngoscope with a 12-mm metal blade certainly improves this type of difficult intubation, doctors often complain that the depth of field of this laryngoscope is insufficient and the width of the blade is too wide for performing intubation on neonatal patients. Therefore, in this study, we developed a video laryngoscope imaging system with two modules, an ultrathin 7-mm metal blade, and an optical imaging system. The core technology of this system includes a 2.5-mm optical lens and verification of imaging quality. To allow a physician to immediately determine an infant’s airway position and prevent binocular disparity while performing intubation, the optical properties of monolithic lenses were simulated while designing the imaging system, thereby allowing the physician to obtain a clear and undistorted image within the field of view.

**KEYWORDS**

Infant; video laryngoscope; 7-mm metal blade; optical imaging system
1. Introduction

Annually, anesthetists or emergency physicians perform more than a million tracheal intubations. Performing tracheal intubation in neonates and premature infants prior to a surgery or emergency treatment is the most challenging for physicians; babies and their range of mouth opening are so small that doctors are unable to view the glottal entrance, which can lead to intubation failure or considerably prolonged intubation time, resulting in a delayed treatment or declined oxygen concentration [1].

Video laryngoscope, which is an indispensable tool for performing endotracheal intubation, is divided into three parts: a monitor, handle, and blade (Figure 1). Miller and Macintosh are the two most commonly used designs of clinical blades. Miller usually has a straight rectangular design, whereas Macintosh has a curved slender design. Both the blades are available in sizes of 0 (neonatal) to 4 (large adult). A light source is positioned at the front of the blade for illumination to assist the doctor during intubation. In conventional clinical laryngoscope intubation, the patient is in the supine position, the blade of the laryngoscope is inserted into the mouth from the left to the right, and the tongue is then flipped. On the basis of the size of a patient’s mouth, an appropriate blade size is selected [2]; the laryngoscope is inserted manually until it reaches the patient’s epiglottis cartilage, and the patient’s head is then moved to the intubation posture.

According to the anatomy and hypopharyngeal position, the ‘sniffing position’ [3] is considered an optimal intubation posture for a patient (Figure 2). After placing a patient in this position, the endotracheal tube is inserted through the mouth and then through the glottis into the trachea to form an airway, allowing air or oxygen to pass through the channel to and from the lungs. Depending on whether the soft palate, uvula, throat, and glottis are visible, the difficulty of endotracheal intubation can be divided into Mallampati I–IV grades [3] (Figure 3). However, 30–40% cases of surgical anesthesia deaths still result from difficult intubations [4,5]. In recent years, doctors have also been using German- or American-made video laryngoscopes; however, these laryngoscopes have several clinical limitations, such as their blade size (12 mm) [2,6] is too large for Asian newborns and their image’s depth of field (DOF) is insufficient. Moreover, the Miller design (blade size 1) and its steps of operation are textbook examples that teach doctors regarding the intubation of newborns and children aged under 2 years; thus, most doctors are familiar with Miller-designed products. By contrast, the Macintosh design (blade size 1) is relatively recently introduced in the past decade; thus, it is not so widely used. Passi et al. [7] compared the intubation practices of two blade designs for 50 newborns and
children aged <2 years. They found that optimal laryngeal views may be obtained using either the Miller design by lifting the epiglottis or using the Macintosh design by lifting the tongue base. Therefore, in the present study, 7-mm Macintosh-designed ultrathin blades were used, and a set of 2.5-mm image acquisition modules were developed to solve the DOF problem to provide a new imaging optical system for improved neonatal intubations.

2. Materials and Methods

To enable doctors to immediately observe the position of the trachea and thus avoid any misjudgements, 7-mm ultrathin metal blades and a single-lens optical design corresponding to neonatal oral size were used in this study. This enabled doctors to obtain a larger field of view (FOV) to clearly see the blade tip and the baby’s glottis position (Figure 4). In this study, the largest diameter of a video laryngoscope was 3.0 mm; thus, the lens diameter was less than 2.5 mm for inserting it into the machine system. When a physician presents an innovative idea for an optical video laryngoscope system, it is necessary to consider whether the idea is technically and practically feasible. The aperture must be proportional to the DOF, and the aperture diameter must be proportional to the input light intensity to achieve optimal imaging quality when the number of lenses is less. To obtain high-quality optical imaging, system size calculation, initial structure calculation, aberration correction, and image quality evaluation must be considered. Therefore, the decision-making process of an optical design is as follows: shape size calculation, initial structure calculation, aberration correction, and image quality evaluation.

2.1 Shape Size Calculation and Initial Structure Calculation

In this study, we first determined basic optical properties in order to determine the magnification ratio or focal length, FOV, numerical aperture, working distance from the light bar position, and shape size; this step is often referred to as the shape dimension calculation. The calculation is performed according to the theory and formula of the ideal optical system. In the calculation, the mechanical structure and arrangement of electronic components must be considered whether can be implemented by today’s processing equipment.

The initial structure can be developed using the following two methods: calculating the size according to the primary aberration theory and mining the database to select an initial structure, one that has been widely adopted by many optical designers. Designers are required to have a deep understanding of optical theories and extensive experience of design selection. Because the task of choosing the initial structure directly affects the design of follow-up light-machine components, this consequentially affects the overall image quality of video laryngoscopes.

2.2 Aberration Correction and Image Quality Evaluation

After selecting the initial structure, we used an optical calculation program to calculate all aberrations and light path aberration curves. Data analysis was performed to determine aberration factors that affect the imaging quality of the optical system and identify methods to improve quality and perform aberration correction. Aberration analysis and light path balancing are processes that are repeated until the desired quality of imaging (distortion <0.05%) is achieved. The imaging quality of optical systems depends on the size of aberrations, and the optical design is aimed at correcting aberrations in optical systems. However, in any optical system, a residual aberration always exists, and it is impossible to correct all aberrations to zero. The image quality is not the same for different sizes of residual aberration. Hence, designers must determine the values of optical aberration and tolerance for various optical systems’ residual aberrations, so that the design corresponds to the size of the residual aberration of the desired optical system’s imaging quality. The evaluation method of the optical system imaging quality includes modulation transfer function (MTF), chief ray angle, and tolerance analysis.

This study used the MTF evaluation method. An object is composed of a spectrum of various frequencies. When light irradiates an object, the light source is imaged in the plane. Subsequently, the image energy distribution map of the light source is used, and the optical system’s MTF is ascertained using Fourier transform. An optical imaging system is treated as a linear system with nonsinusoidal frequencies under transmission. The object is imaged by the optical system and can be considered as a sinusoidal distribution of linear transmission at different frequencies.
and 83 lp/mm to conform to the requirements of Omni Vision’s CMOS sensor (OV6930, 400 × 400 pixels, pixel size: 3 μm) and an imaging distance of 30 mm [10]. Giraudon et al. [10] enrolled 132 children weighing between 10 and 20 kg to compare the performance of the direct Macintosh laryngoscope and the McGrath MAC video laryngoscope. They concluded that 30 mm is an optimal distance to observe the position of the trachea.

Moreover, Baker et al. [11] suggested 20 mm as the approximate working distance to operate on the tiny airways of low-birth-weight infants. The optical design and CMOS sensor selection of video laryngoscopes are often the most protected commercial secrets of manufacturers, such as Karl Storz C-MAC and McGrath MAC. Researchers can only speculate on the specifications of optical components based on a product’s imaging photographs or physician’s clinical experience. Therefore, in this study, the same CMOS sensor cannot be used to determine the better optical design or the same optical design cannot be used to verify which CMOS sensor is more suitable as an imaging element for the baby’s airway. We could use only the commercially available CMOS sensor to determine the optical design that yields a higher image quality or uses fewer lenses. Our research results revealed that for the same

3. Results

In this study, Zemax software was used to simulate the through-focus MTF with a spatial frequency of 42 lp/mm and 83 lp/mm to determine the requirements of Omni Vision’s CMOS sensor (OV6930, 400 × 400 pixels, pixel size: 3 μm) and an imaging distance of 30 mm [10]. Giraudon et al. [10] enrolled 132 children weighing between 10 and 20 kg to compare the performance of the direct Macintosh laryngoscope and the McGrath MAC video laryngoscope. They concluded that 30 mm is an optimal distance to observe the position of the trachea. Moreover, Baker et al. [11] suggested 20 mm as the approximate working distance to operate on the tiny airways of low-birth-weight infants. The optical design and CMOS sensor selection of video laryngoscopes are often the most protected commercial secrets of manufacturers, such as Karl Storz C-MAC and McGrath MAC. Researchers can only speculate on the specifications of optical components based on a product’s imaging photographs or physician’s clinical experience. Therefore, in this study, the same CMOS sensor cannot be used to determine the better optical design or the same optical design cannot be used to verify which CMOS sensor is more suitable as an imaging element for the baby’s airway. We could use only the commercially available CMOS sensor to determine the optical design that yields a higher image quality or uses fewer lenses. Our research results revealed that for the same
working distance of 30 mm, the through-focus MTF is 84% in 42 lp/mm and 65% in 83 lp/mm (Figures 5 and 6); while less than 70% contrast, the through-focus MTF is decreasing to 55% in 42 lp/mm but 15% in 83 lp/mm.

Therefore, this study adopted a through-focus MTF of 42 lp/mm, with an effective focal length (EFL) of 1.47 mm and F. number of 3.9. In the calculation of the through-focus MTF of 42 lp/mm (MTF > 25%), the DOF value in the 100–10000-nm near-field position was between 25 and 33 mm, thereby satisfying DOF requirements for a video laryngoscope. Relative illumination is the percentage by which an image moves away from the middle of the image to the corner and affects the overall system resolution. In this study, the point of the highest transmission was defined as 100% when the DOF was 0.00 (image height = 0.00 mm). The relative illumination was 58.3% when the field was 1.00 (image height = 0.850; Figure 7). Finally, after analyzing the tolerance, all the MTF values were found to be larger than 0.2 [12], implying that this optical design is practicable for video laryngoscopes (Figure 8).

4. Conclusions
The specifications of the optical components of medical devices often require a balance between other commercially available components (e.g. CMOS sensor) and clinical requirements (7-mm Macintosh blades). In this study, the compact and low-power OV6930 was selected as the main CMOS sensor for 7-mm video laryngoscopes. To view the top of the blade and a neonate’s glottis position simultaneously on the screen, in this study, we selected an inferior MTF design (42 lp/mm) with a smaller FOV even both designs exceeded the basic 0.2 MTF requirement. After the development of the imaging system, we intend to continue with the adjustment of the image color, production of the 7-mm ultrathin Ti–6Al–4V metal blade, and mechanical testing.

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References
[1] Nadler I, McLanders M, Sanderson P, et al. Time without ventilation during intubation in neonates as a patient-centred measure of performance. Resuscitation. 2016;105:41–44.
[2] Singh R, Kumar N, Jain A. A randomised trial to compare Truview PCD®, C-MAC® and Macintosh laryngoscopes in pediatric airway management. Asian J Anesthesiol. 2017;55:41–44.
[3] Kim H, Chang JE, Min SW, et al. A comparison of direct laryngoscopic views in different head and neck positions in edentulous patients. Am J Emerg Med. 2016;34:1855–1858.
[4] Caplan RA, Posner KL, Ward RJ, et al. Adverse respiratory events in anesthesia: a closed claims analysis. Anesthesiology. 1990;72:828–833.
[5] Lambert RC, Ban C, Rivera AU, et al. Comparison of direct laryngoscopy and video laryngoscopy in intubating a mannequin: should video laryngoscopy be available to manage airway emergencies in the oral and maxillofacial surgery office? J Oral Maxillofac Surg. 2015;73:200–210.
[6] Mellick LB, Edholm T, Corbett SW. Pediatric laryngoscope blade size selection using facial landmarks. Pediatr Emerg Care. 2006;22:226–229.
[7] Passi Y, Sathyamoorthy M, Lerman J, et al. Comparison of the laryngoscopy views with the size 1 Miller and Macintosh laryngoscope blades lifting the epiglottis or the base of the tongue in infants and children <2 yr of age. Br J Anaesth. 2014;113:869–874.
[8] Baker K, Tremblay E, Karp J, et al. Anatomy-driven design of a prototype video laryngoscope for extremely low birth weight infants. J Biomed Opt. 2010;15:066023-1–066023-5.
[9] Yang HS, Jo YG, Kim GU, et al. Measurement of the chief ray angle of mobile phone camera. Opt Rev. 2011;18:403–407.
[10] Liu YY, Xue FS, Li HX, et al. Comparing C-MAC videolaryngoscope with direct laryngoscopy for emergency intubation. Eur J Anaesthesiol. 2017;34:785–786.
[11] Giraudon A, Bordes-Demolis M, Blondeau B, et al. Comparison of the McGrath® MAC video laryngoscope with direct Macintosh laryngoscopy for novice laryngoscopists in children without difficult intubation: A randomised controlled trial. Anaesth Crit Care Pain Med. 2017;36:261–265.
[12] Baker K, Tremblay E, Karp J, et al. Anatomy-driven design of a prototype video laryngoscope for extremely low birth weight infants. J Biomed Opt. 2010;15:066023.
[13] Dube B, Cicala R, Clos A, et al. How good is your lens? Assessing performance with MTF full-field displays. Appl Opt. 2017;56:5661–5667.