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Designing a video laryngoscope imaging system with a 7mm blade for neonatal patients

Ming-Ying Hsu[1], *Wen-Tse* Hsiao[2], and *Han-Chao* Chang[2*]

[1]National Synchrotron Radiation Research Center, Experimental Facility Division, 30076 HsinChu, Taiwan
[2]National Applied Research Laboratories, Instrument Technology Research Center, 30076 HsinChu, Taiwan

Abstract. When a newborn infant has been pushed from the birth canal due to ventilation failure while using a resuscitation mask, the doctor must implement infant intubation and other emergency steps to keep the baby alive. However, due to the excessively small mouth area of a newborn or premature infant, the doctors are unable to view the glottis entrance, which can lead to either a failed intubation or longer intubation time, thereby resulting in either a drop in oxygen levels or a rise in intrathoracic pressure. Although the normal video laryngoscope with a 12mm metal blade certainly improves this type of difficult intubation, nevertheless, doctors often complain that the depth of field (DOF) is insufficient and the width of the blade is too wide when performing intubation on neonatal patients. Therefore, this study aims to develop two modules of infant's video laryngoscope, an ultra-thin 7mm metal blade and an optical imaging system, the core technology of which includes an optical design of a 2.5mm lens and verifications of imaging quality. In order to allow physicians to determine the infant's airway position immediately and to avoid the binocular disparity from a physician while giving intubation, this study has simulated the optical properties of monolithic lenses while designing the imaging system, allowing the doctor to have a clearer and undistorted image within the field of view.

1 Introduction

Annually, anaesthetists or emergency physicians perform more than a million tracheal intubations. Neonate and premature infant tracheal intubation is the most challenging task for physicians prior to surgery or emergency treatment; babies and their mouth ranges are so small, that doctors are unable to view the glottal entrance, which can lead to intubation failure or an excessive intubation time, resulting in a delayed treatment or declined oxygen concentration.

The video laryngoscope is an indispensable tool for performing endotracheal intubation. The video laryngoscope is divided into three parts, the monitor, the handle and the blade. A light source is positioned at the front of the blade for illumination to assist the doctor with the intubation. In conventional clinical laryngoscope intubation, the patient is laid head up, the laryngoscope is inserted into the mouth from the left to the right and the tongue is then flipped; according to the patient's mouth size, the corresponding blade size is selected [1], the laryngoscope is inserted manually until it reaches the patient's epiglottis cartilage, and then the patient's head is moved to the intubation posture. According to the anatomy and the export of the hypopharyngeal position, the "Sniffing Position" [2] is considered the optimal intubation posture in which to place the patient (Figure 1). After that, the endotracheal tube is inserted through the mouth, 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 [2] (Figure 2). According to Caplan [3] and Lambert [4], there are still 30% to 40% of cases of surgical anesthesia deaths resulting from difficult intubations. In recent years, even though doctors have been using German or American-made video laryngoscopes, the blade size (12mm) [1, 5] is too big for Asian newborns, the image's depth of field (DOF) is insufficient, as well as other clinical problems. Therefore, for this study, 7mm ultra-thin blades were designed and a set of 2.5mm image acquisition modules were completed to solve the DOF problem, in order to provide a new imaging optical system for improved neonatal intubations.

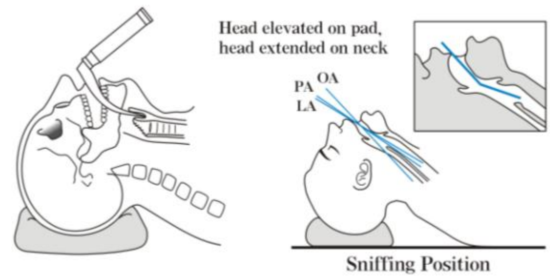

Fig. 1. Best intubation posture "Sniffing Position".
Source: Kim et al [2]

* Corresponding author: roman@narlabs.org.tw

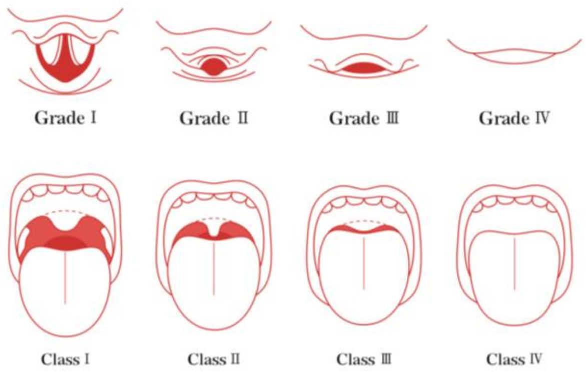

Fig. 2. Mallampati I~IV
Source: Kim et al [2]

2 Materials and Methods

In order to allow the doctor to immediately observe the position of the trachea and thus avoid any misjudgments; the study used 7mm short thin metal blades, as well as a single-lens optical design to correspond to neonatal oral size, which allow doctors to obtain a larger field of view (FOV) to clearly see the blade tip and the baby's glottis position (Figure 3).The largest diameter of the video laryngoscope in this study was 3.0 mm, so the lens shape had to be less than 2.5mm to insert into the machine system. When a physician presents innovative ideas for an optical video laryngoscope system, it is necessary to consider whether it is technically and physically feasible. The aperture must be proportional to the DOF, the aperture diameter also must be proportional to the input light intensity to satisfy the conditions of the optimal imaging quality while the number of lenses is less. In order to obtain high-quality optical imaging, the design of the system size calculation, the initial structure of the calculation, aberration correction and image quality evaluation must all 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.

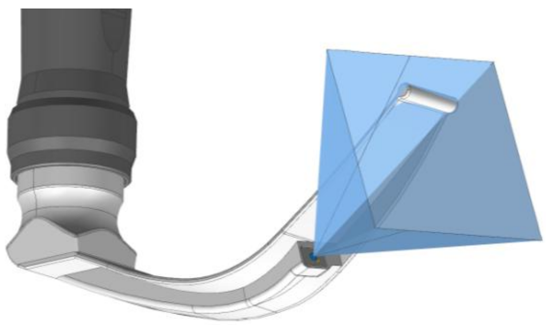

Fig. 3. Optical Design of FOV for video laryngoscope

2.1 Shape Size Calculation & Initial Structure Calculation

First of all, this study had to determine the basic optical properties, to meet the requirements of product technology, which determine the magnification ratio or the focal length, FOV, numerical aperture, working distance from light bar position and shape size. Therefore, this stage is often referred to as the shape dimension calculation. The general concern is calculated according to the theory and a formula of the ideal optical system in this dimension. In the calculation, the mechanical structure and the arrangement of electronic components must be considered to prevent the mechanism from being realized. The initial structure is usually confirmed by following two methods: 1. the first is calculated by the size according to the primary aberration theory. 2. Secondly, mining from the database to select the initial structure, a more practical and easier way to succeed and, as a result, one that has been widely adopted by many optical designers. It requires designers to have a deep understanding of optical theories and thorough experience in the design selection. As the task of choosing the initial structure directly affects the design of follow-up light-machine components, this will consequentially affect the overall image quality of video laryngoscopes.

2.2 Aberration Correction and Image Quality Evaluation

After the initial structure had been selected, this study used an optical calculation program to calculate all aberrations and light path aberration curves. From data analysis, this study was able to find out the aberration factors which affect the imaging quality of the optical system, and find ways to improve the quality and also to conduct aberration correction. Aberration analysis and light paths' balance is a repeated process, until it meets the quality of imaging (Distortion <0.05%). The imaging quality of optical systems is related to the size of aberrations, and the optical design aims at correcting aberrations in optical systems. However, in any optical system, it is impossible to correct all other aberrations to zero, there is always a residual aberration. Of course, for different sizes of residual aberration, the image quality is not the same. Hence, the designer must understand the value of optical aberration and tolerance for a variety of the optical system's residual aberrations, so that the design can correspond with the size of residual aberration of the optical system's imaging quality. The evaluation method of optical system imaging quality [6, 7, 8] includes modulation transfer function (MTF), the chief ray angle (CRA) and tolerance analysis.

This study used the MTF evaluation method. An object is composed of a spectrum of various frequencies, when light irradiates the object, the light source is imaged in the plane. After that, the image energy distribution map of the light source is used, and the optical system's MTF is ascertained using the Fourier transform. An optical imaging system is treated as being a linear system with non-sinusoidal frequencies under the transmission. The object is imaged by the optical system and can be regarded as a sinusoidal distribution of linear transmission at different frequencies. The frequency of the transmission feature remains the same, but the contrast changes, the phase goes and stops at a certain frequency. The reduction in contrast and the change of the bit phase vary with frequency, and the functional relationship between them is called MTF. As the optical transfer function and aberration, it can be used to evaluate the optical system imaging quality. It has an objective and reliable advantages, and is easy to calculate and measure. Not only can it be used for the evaluation of optical design results, but also for controlling the optical system design process, lens inspection, optical design and other aspects. After the optical design has been completed, the optical path diagram is combined with the mechanical design, and the stray light and ghost phenomenon are analysed by the optical machine simulation software. According to the situation of the light machine, the analysis slightly adjusts the optical design, in order to minimize the stray light.

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 conform to Omni Vision's CMOS sensor (OV6930, 400 x 400 pixels, pixel size 3μ m) and an imaging distance of 30mm. Research results show that in the same 30mm as the distance, on axis MTFs were 84% and 65%, which became 78% and 55% respectively when simulated in a 70% field (Figures 4&5).

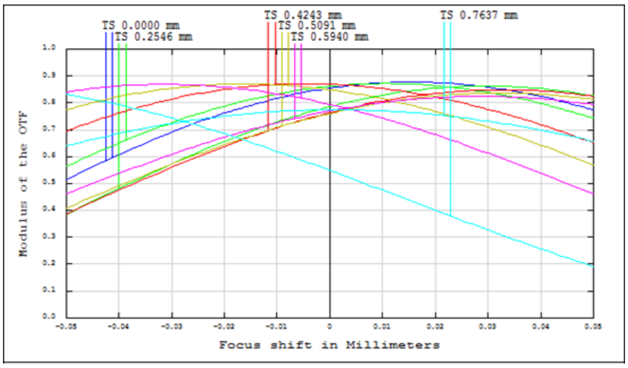

Fig.4. MTF (42 lp/mm)

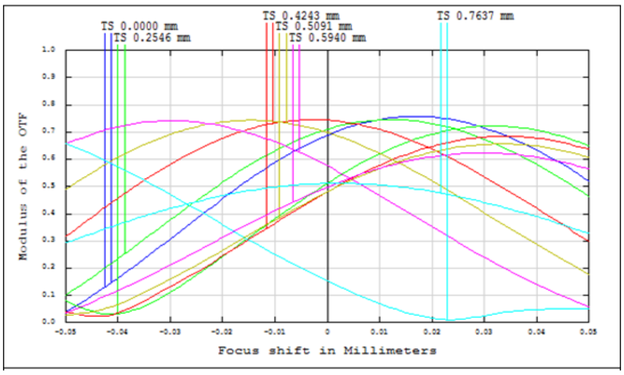

Fig.5. MTF (83 lp/mm)

Therefore, this study adopted a through-focus MTF of 42 lp/mm, and its EFL was 1.47mm, and the F. No was 3.90. In the calculation of through-focus MTF 42 lp/mm (MTF> 25%), the DOF value in the 100-10000nm near field position was within the 25-33mm range, thereby satisfying the DOF requirements for a video laryngoscope. Relative illumination is the percentage by which the image moves away from the middle of the image to the corner, as this affects the overall system resolution. In this study the point of highest transmission was defined as 100% when the field was 0.00 (image height=0.00 mm), and finally the Relative illumination became 58.3% when the field was 1.00 (image height=0.850) (Figure 6).

Finally, after having analysed the tolerance, all the MTF values were larger than 0.2, meaning this optical design is practicable for video laryngoscopes (Figure 7). the figure as close as possible after the point where it is first referenced in the text. If there is a large number of figures and tables it might be necessary to place some before their text citation. If a figure or table is too large to fit into one column, it can be centred across both columns at the top or the bottom of the page.

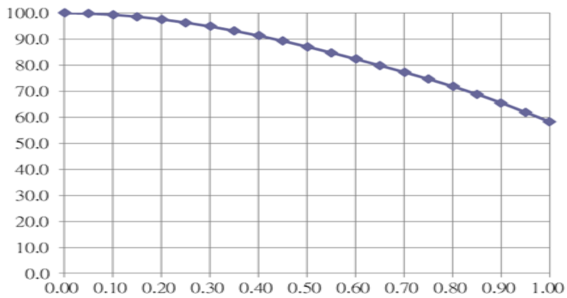

Fig.6. Relative Illumination

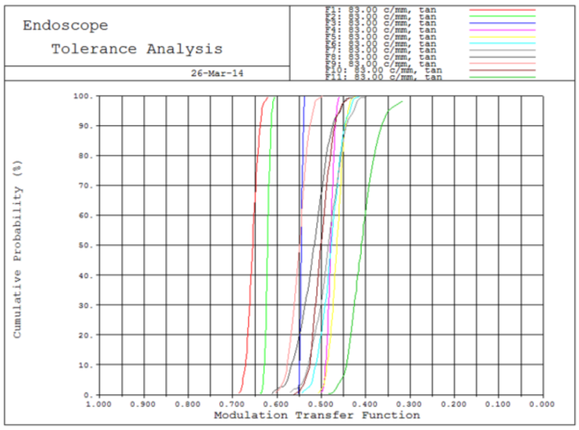

Fig. 7. Tolerance analysis

4 Conclusions

The specifications of the optical components of medical devices often require a balance between the other commercially available components (e.g., CMOS sensor) and clinical requirements (7mm blades), and furthermore, to achieve the basic need for optical quality. In this study, the OV 6930, small and with a low power demand, was selected as the main CMOS sensor for 7mm video laryngoscopes. In order to see the top of blade and neonatal glottis position simultaneously on the screen, this study had to choose an inferior MTF design (42 lp/mm) with a smaller FOV, and was unable to select a better MTF value with FOV design (83 lp/mm). However, these two still exceed the basic 0.2 MTF requirement. After the completion of the imaging system, this study will continue with colour adjustment, 7mm ultra-thin Ti-6Al-4V metal blade production and mechanical testing.

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